# Outlines of Virtual Surgical Planning in Management of Zygomaticomaxillary Complex Fractures

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**Abstract**

**Background:** Virtual Surgical Planning is a computer-based application to analyse the anatomy or deformity, perform the surgery and simulate the outcome so as to weigh the planned procedure in terms of safety and predictability and to fabricate the necessary tool and patient-specific armamentarium to safely execute the procedure. Volumetric imaging, like CBCT, MDCT, and MRI, provides the basis data for printing a 3D model. Based on the treatment plan, 3D imaging techniques may be fused and further processed for model preparation. However, in maxillofacial surgeries, most of the cases are provided with the data obtained by CT. Rapid prototyping (RP) creates a three-dimensional model with a layer-by-layer process of adding based on 3D computer-aided design (CAD) data. This technology is also referred to as "layer production," "solid free form production," or "3D printing". Maxillofacial PSIs can now be designed using preoperative imaging data as input to CAD software. The designed implant is then made using a CAM technique, such as 3D printing. The application of CAD/CAM technique also can simulate the surgery procedures accurately, which contributes to shorten the actual operative time.

**Keywords:** Virtual Surgical Planning, Zygomaticomaxillary Complex Fractures

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**Introduction:**

Virtual Surgical Planning is a computer-based application to analyse the anatomy or deformity, perform the surgery and simulate the outcome so as to weigh the planned procedure in terms of safety and predictability and to fabricate the necessary tool and patient-specific armamentarium to safely execute the procedure.

A typical virtual surgical planning software would include the following components **(1):**

1. Data acquisition

2. Medical image analysis

3. 3D anthropometric analysis

4. Surgical simulation

5. Implant/template design via CAD software

6. Implant/template fabrication

7. On-line communication tool 8. Management system

**Types of 3D-Printed Models**

The 3D-printed models in the oral and maxillofacial surgery speciality can be classified into four types (2).

1. Training models

2. Planning models

3. Simulation models

4. Patient-specific surgical guides

**Training Models**

A purpose of training model is to enhance the quality of teaching. The training model should accurately reproduce the anatomy, should have similar haptic feedback as that of natural bone and should be economical (2).

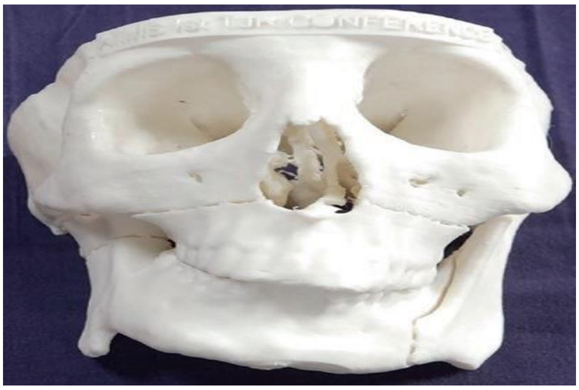


**Fig. 1: 3D-printed training model for concomitant orthognathic surgery with total temporomandibular joint replacement. The model is printed in acrylonitrile butadiene styrene (ABS) plastic. The model has been weakened at the LeFort 1 osteotomy level and TMJ ankylosis level to facilitate easy cutting of the models.**

**Planning Models**

The purpose of a planning model is to completely understand the patient's anatomy in a complex surgery. These models are also referred to as anatomical models, bio-models (3).

These models have been used for total alloplastic TMJ replacement cases for planning and intraoperative referencing.

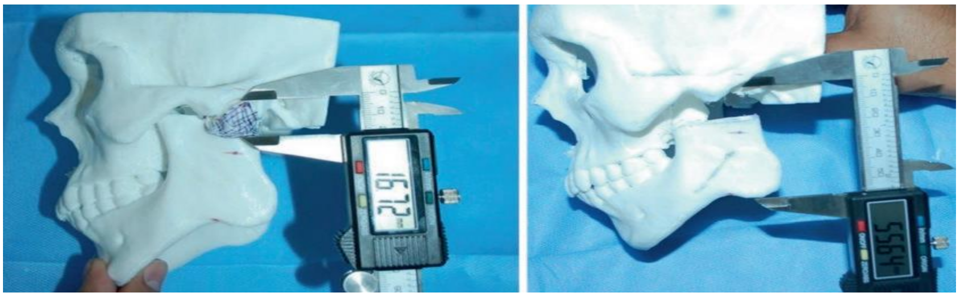


**Fig. 2: (a) This is 3D-printed model of a patient with TMJ ankylosis. Note the measurement being made of the ankylotic bony mass. (b) The available ramal length being measured after the ankylotic bone mass has been removed. This measurement is important to decide the size of condylar component for total TMJ replacement.**

### Simulation Models

A simulation model is used to perform a mock surgery before it is done on the patient. It helps to plan the procedure, foresee the hurdles and plan out techniques to circumvent them, also to evaluate the safety and predictability.

These models should be accurate with a patient like haptic feedback. Simulating models are used in complex total temporomandibular joint replacement cases and for correction of post-traumatic residual deformity cases.

**Fig. 3: A 3D-printed model used for simulating concomitant orthognathic surgery with alloplastic total temporomandibular joint replacement.**

### Patient-Specific Surgical Guides

These are patient-specific instruments used for making accurate osteotomies or to allow accurate placement of a device. These guides are made from a biocompatible, autoclavable material with a high accuracy. These guides should accurately conform to the structure to which they will be anchored (4).

The patient-specific surgical guides are widely used in guided dental implantology cases. These guides can also be used for bone graft harvesting from ramus of mandible (4).

### Patient-Specific Implants (Custom Implants).

## Design of Patient Customized Maxillofacial Implants

### Maxillofacial Imaging and Modelling

Medical images are commonly acquired using CT, since it is more suitable for bone than magnetic resonance imaging (MRI) and saved in DICOM (Digital Imaging and Communications in Medicine) format. The quality of CT images depends on the detector configuration, tube current, tube potential, reconstruction algorithm, patient positioning, scan range, slice thickness, and pitch **(5)**.

The DICOM files are 2D images (pixels), which are converted into 3D images (voxels) using suitable medical modelling software. The region of interest (ROI) is obtained by segmenting out unwanted regions and using region growing algorithms. The thresholding uses the Hounsfield value of the type of tissue under consideration. Each boundary pixel is examined during region growing; if no edges are detected, the pixel is added to the central region **(6)**.

All unwanted anatomical features that are not in contact with the ROI are removed by creating a mask. The masks can be edited to join unattached regions to ROI and separate regions that are not required. The 3D voxel model is converted into stereolithography (STL) file and transferred to medical CAD software. The STL file is first repaired (such as closing open faces); then the number of triangles is optimized (to reduce the file size), and the surface is smoothened**(6)**.

### Implant Design Considerations

### Mechanical Factors:

Maxillofacial implants must have the adequate load-bearing capability and yet prevent stress shielding of the adjacent bone; this requires the Young's modulus of the implant to be close to that of the bone **(7)**.

The type, magnitude, direction, and duration of loading should be considered while designing an implant. Stretch dominated failure is considered better than bend-dominated failures of implants **(8)**.

Their design should minimize osteolysis and implant loosening. Articulating loadbearing implants such as the temporomandibular joint should have enough fatigue strength to overcome cyclic forces due to masticating actions, and resistance to wear of rubbing surfaces between mandible condyle and mandibular fossa in the temporal bone. The joint motion range should be similar to that of the natural joint and replicate all the degrees of freedom exhibiting by it **(8)**.

### iological Factors:

An implant is expected to perform its intended function for a long time, ideally the patient's remaining life. It should be designed for osteointegration, which helps in preventing loosening, necrosis, and infection. The suitable coating enables this and surface treatments such as grit blasting, acid etching, and anodizing, and inducing porosity in design. Porous implants should have permeability, tortuosity, topology, and interconnectivity to replicate the physical, biological, and structural properties of bone. These can be achieved by varying the relative density, pore size, strut size, and lattice unit structure of the implant **(9)**.

**Biomaterial Factors:**

The implant material must be biocompatible—it should not be toxic or cause any systemic effect while simultaneously getting readily accepted by the body and promoting osteointegration.

It has to be resistant to corrosion during sterilization and while inside the human body. Various types of biomimetic and biocompatible coatings such as hydroxyapatite, alumina, calcium phosphate, and titanium oxide, as well as surface texture alterations, enhance the above properties of implants **(10).**

Implants can also be made of biodegradable materials that have gradual solubility. While bone does not generally bond with metal, its attachment can be enhanced by inducing porosity into implants. This can be easily achieved using additive manufacturing techniques **(10).**

**Manufacturability Factors:**

A well-designed implant is useless unless it is produced with the desired quality at an affordable cost. While additive manufacturing provides great freedom in terms of the external shape and internal topology, it also imposes certain constraints such as the need for support structures (for overhanging features) that have to be removed later. These can be avoided by designing overhanging portions with an inclination angle greater than 45° **(11).**

Porous implants need to have provision to remove un-melted powder particles from the pores. The design of orbital implants that have thin and delicate features must be compatible with the dimensional accuracy that the selected manufacturing process can achieve and enable post-processing operations such as heat treatment, bead blasting, grinding, and grinding polishing and machining **(12).**

**Design Verification and Validation**

Design review coupled with verification and validation enables early identification and mitigation of potential flaws that could affect implant quality and reliability. Design verification is a process of checking each stage (during the design process) whether the design output is compatible with input requirements within an acceptable range **(13).**

The design verification for 3D-printed implants can include the following steps.

**Virtual Assembly:**

The 3D CAD model of the implant is superimposed over the anatomical model of the patient to check the geometric fit (shape and size). Software tools such as 3-Matic (Materialise, Belgium) show the positive and negative deviation between the two models. The implant design is then corrected to minimize discrepancy **(13).**

**Finite Element Analysis (FEA):**

It is a proven tool to reduce design cycle time and is performed using commercially available software such as Abaqus, Ansys, and Comsol. It involves preprocessing of implant model (mesh generation, imposing loads, boundary conditions, and material properties), computation of strains and stresses, and post-processing to view the results. The results can be improved by the coarse meshing of noncritical regions and finer meshing of critical areas. The FEA has been successfully employed to design customized mandibular implants under chewing conditions (14).

## Post-processing of Implants

### Heat Treatment:

It is primarily meant for stress-relieving thermally stressed implants and annealing for microstructure improvement. Implants made using laser-based technologies always have α′ microstructure, which has to be converted to α + β form before using in any patient. A vacuum furnace or a muffle furnace is employed for the heat treatment operations, in which the thermal cycles for stress relieving and annealing are determined as per the standards (15).

### Surface Smoothening:

The 3D-printed implants possess varying surface roughnesses, with side surfaces rougher than top ones. To make all surfaces uniformly smooth, abrasive blasting, tumbling, and grinding operations are performed. The abrasive particles used operations must be biocompatible and non-reacting with the implant material (16).

### Polishing/Buffng:

The implants that need to be very smooth (such as articulating surfaces in TMJ and hip joint) to prevent wear, metal debris, and ions that cause harmful effects to tissues are polished and buffed to obtain the required surface finish (17).

### Pickling and Anodizing:

The above operations result in surface contamination with shop floor grease, dust, inorganic and organic fluids, abrasive particles, and oxidation and corrosion. Pickling thoroughly cleans the surfaces by dissolving the impurities. This is immediately followed by anodizing to improve the aesthetics, make passive surfaces, redefine the oxide layer, or impart nanotubes on the surface. It is also useful for colour coding of implants to indicate different sizes and thicknesses (18).

### leaning and Packaging:

A multistage ultrasonic cleaner with distilled water, isopropyl alcohol, and other cleaning agents at elevated or room temperatures removes dirt from the outer surfaces of the implants and even from deep holes and cracks using cavitation action. This is immediately followed by sterilizing and packaging in a 10,000-class clean room or equivalent as per standards and relevant guidelines (19).

## Methods of Generating 3D Virtual Reconstructions

Volumetric imaging, like CBCT, MDCT, and MRI, provides the basis data for printing a 3D model. Based on the treatment plan, 3D imaging techniques may be fused and further processed for model preparation. However, in maxillofacial surgeries, most of the cases are provided with the data obtained by CT (20).

Various software import DICOM data from three-dimensional imaging and translate it to axial, coronal, and sagittal images and manage and analyse this imported data according to software capabilities. DICOM files from MDCT contain voxels with gray values that are proportional to the attenuation coefficient in the corresponding tissue of the patient, ranging from −1000 Hounsfield Unit (HU) (air) to +3000 HU for compact bone. In CBCT, the amount of X-ray attenuation is defined by gray values, called voxel values. DICOM file manipulation can be efficiently done by CAD software to create highly accurate virtual models of patient-specific anatomy **(20).**

## Image Processing

Today, different 3D software is available, being widely used in maxillofacial reconstructions. Mimics software is one of the most utilized tools for maxillofacial reconstructions. The software platform consists of three orthogonal MPR sections providing axial, coronal, and sagittal views. The imported data can be segmented to a specific region of interest (ROI). Segmentation can be fully automatic, semiautomatic, or manual. The most popular and well-known segmentation method used to date is automatic thresholding **(20).**

When using this thresholding method, tissues with the same gray value pixel intensity are shown simultaneously. To remove unrelated and unnecessary anatomy, one can use the option region growing tool segmentation separates pixels that comprise an ROI. The process is iterative and progresses until no more pixels can be added. Following region growing segmentation, operator input is often needed to confirm the boundaries of the selected mask. Split mask technique can be performed when separation of connected adjacent anatomies is required. The operator can also combine pixels, modify boundaries, or erase regions manually. A binary keeps or discard is assigned to each voxel to modify boundaries **(20).**

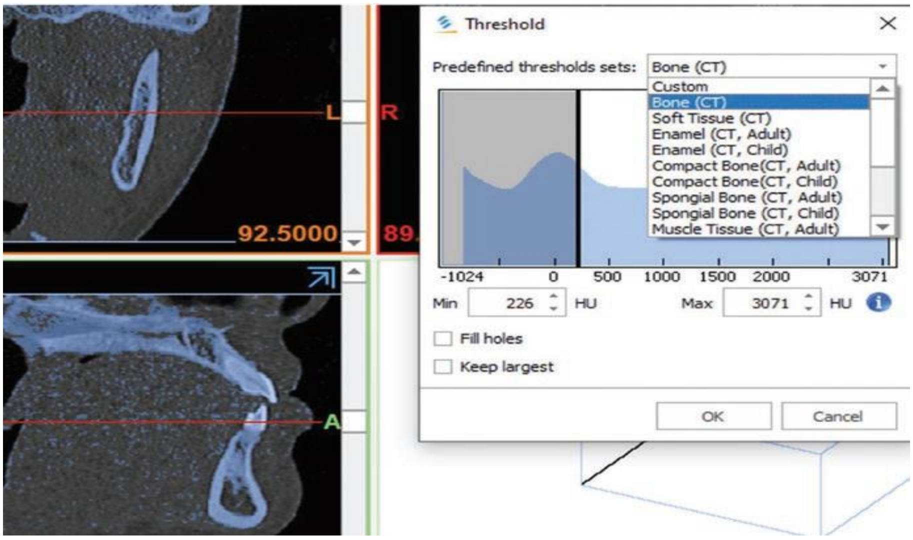



**Fig. 4: Image processing requires multiple steps to calculate a 3D model. (a) Selection of a predefined threshold set using inbuilt thresholds within Mimics. Note the difference in default threshold value for enamel, compact bone, and soft tissue in adult and child patient. For maxillofacial bone, the threshold ranges from 226 House Field Unit (HU) to approximately 3071 HU. Thresholding is applied to the entire dataset and delineates pixels based on their gray values but not on spatial location. (b) Region growing segmentation is**

applied to separate pixels that comprise a region of interest (ROI). One or more seeds are selected within the desired anatomy, and neighboring connected pixels are added automatically by including same gray values. (c) Split mask technique aids in separation of adjacent anatomical structures with the same pixel values. In this case, the mandible is separated from other osseous structures. (d) If any errors in segmentation is detected, the selected mask can be manually edited. (f) By confirming the segmented anatomy, the 3D model is calculated automatically (21).

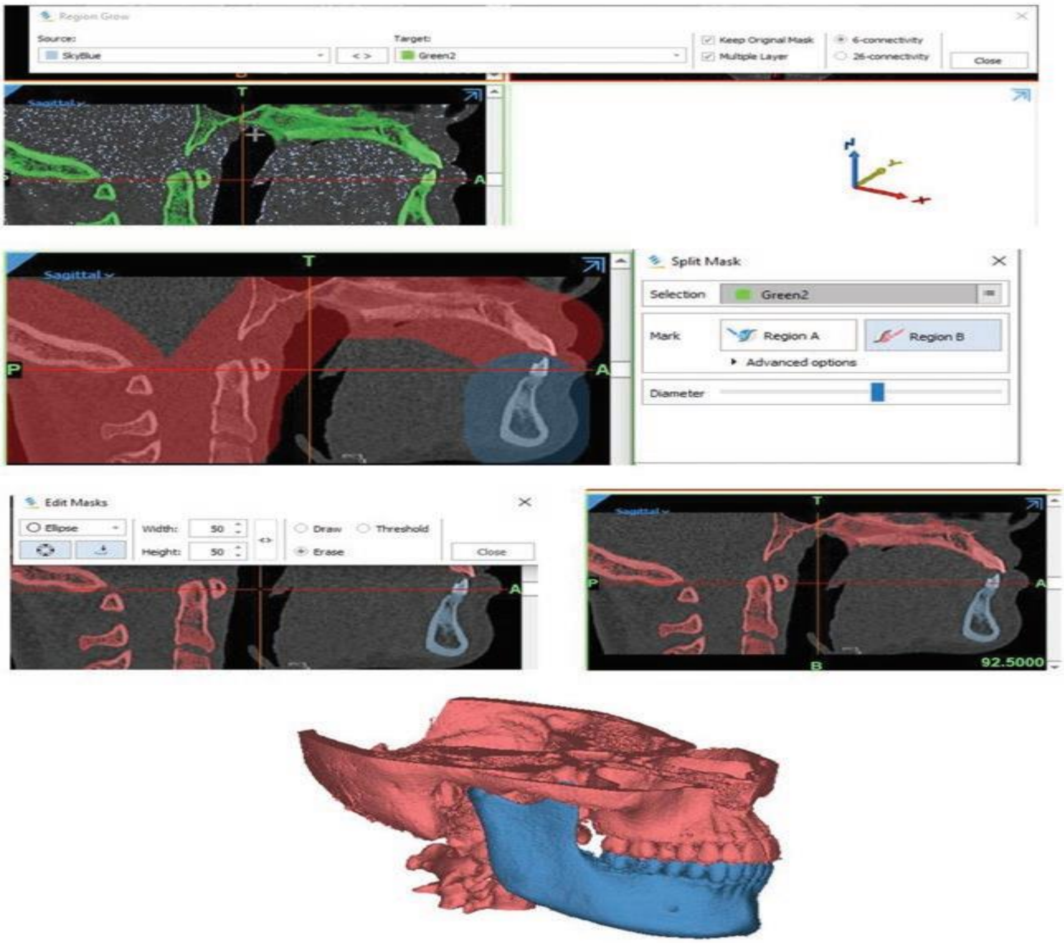



Fig. 5: (continued).

## STL File Preparation

DICOM images are converted to another file format as printers do not accept DICOM images. 3D printers understand individual objects. The most widely used file format for 3D printing is Standard Tessellation Language. The STL format defines collection of triangle surfaces, known as "facets," that fit together without any gap or overlap. Only certain software packages currently can create STL file. Free software such as Mimics® (Materialise, Leuven, 3001, Belgium) provide STL file formats (22).

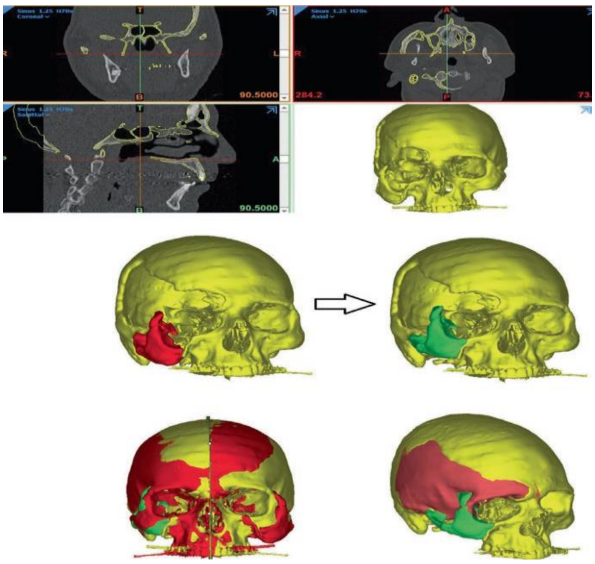
## Three-Dimensional (3D) Printing

Custom- made implants, drill guides, surgical guides, splints, and prosthesis can be printed with various materials according to patients' specific anatomy (20). In addition, 3D printing provides a novel method in biomedical research and medical education and enables improved education procedure for students and patients (23).

Fig. 6: Various 3D printed models using different additive manufacturing materials and printers. (a–c) Intermediate and final splint in orthognathic surgery, (d–f) mandibular titanium prosthesis for reconstruction of bony defects (23).

Clinical Cases

Craniofacial and Maxillofacial Defect Reconstruction in Traumatic Cases.



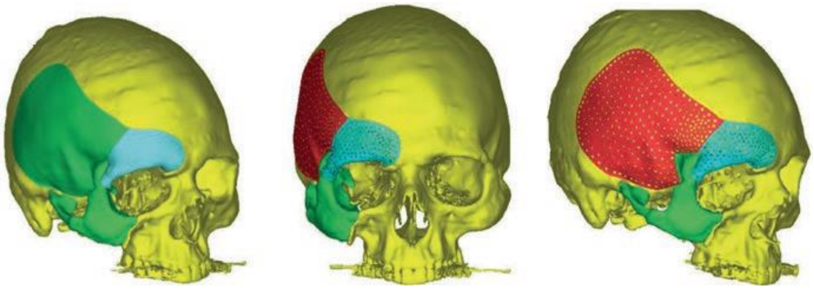


Fig. 7: Craniofacial reconstruction in a 49-year-old male referred with history of vehicle accident. Right parietal and parts of frontal bone were destructed, and the right zygomatic bone was dislocated distally. (a) DICOM data obtained from CBCT images were imported to Mimics® (Materialise, Leuven, 3001, Belgium) software. (b) The right zygomatic bone was manually segmented and repositioned in its proper anatomical location. To construct the defect in right frontal and parietal bone, (c) the skull was mirrored and (d) reconstructed from the normal left side. The frontal and parietal bone defects were designed separately using porous prostheses. The STL file was further sent for 3D printing (24).

CAD designed models aid the surgeon to foresee the treatment plan, perform mock surgeries, and anticipate any potential problem that may be encountered at the time of surgery when restoring the traumatic defects. 3D printed prosthesis for maxillofacial defects can effectively adjust to the defect site and decrease intraoperative time. If the structure is porous, particulate bone graft may be used for further bone regeneration **(24).**

**Maxillofacial Defect Reconstruction in Tumor Cases**

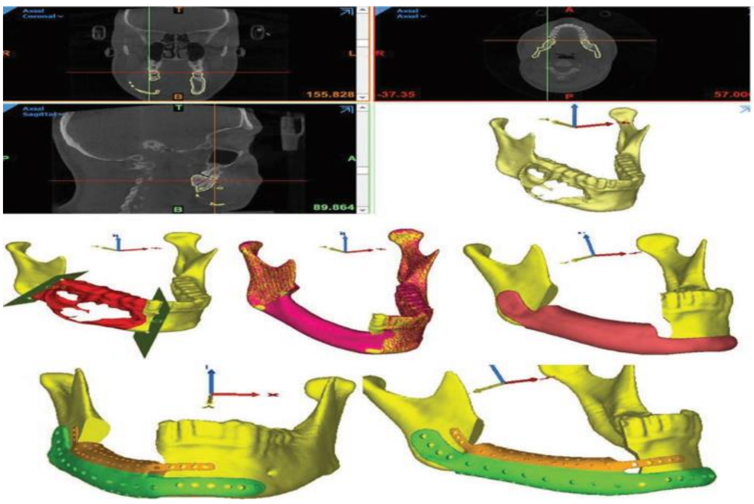


**Fig. 8:** ***Patient presented with ameloblastoma lesion in the right side of the mandible. (a) The Materialise MIMICS 21.0 software (Materialise NV, Leuven, Belgium) translated the CBCT DIOCM data into axial, coronal, and sagittal planes and 3D view. (b) The tumor region was detected, segmented in red, and virtual surgical resection guiding plans were placed anterior and posterior to the lesion borders in the body of mandible. (c) The mandibular bone defect was reconstructed by mirroring the normal mandibular body on the left side, and (d) the prosthesis was designed based on the remaining mandibular bone. (e) The final prosthesis design was divided into two porous sections*** **(25).**

Preoperative virtual planning helps the clinicians to better understand the resecting guiding plans, virtually perform mandibulectomy or maxillectomy, and further assess the spatial relationship of the resection defect site with the designed prosthesis to obtain standard occlusion, without compromising the beauty (25).

## Orthognathic Surgery and Splint Design

Conventional orthognathic surgery planning uses cephalometric analysis and mock surgery on stone dental models. Today, computer-assisted surgical planning virtually performs osteotomies in the maxilla and mandible, and the segments can be repositioned in any plane (26).

This computer-assisted surgical planning is highly accurate, providing a virtual plan that facilitates communication between treatment team and decrease operation time. Translating this virtual plan to real surgery is mainly done by CAD/CAM fabricated interocclusal intermediate and final splints, which further guide fragment repositioning (26).

Patients' CBCT data can be imported to treatment planning software applications to further design and fabricate surgical guides using CAD/CAM technology. 3D printed surgical guides can be mucosa, teeth, or bone supported and allow for more predictable implant insertion during the actual surgery. Although surgical guides can aid in predicting the optimum site for implant insertion, the surgeon should be prepared for any complications that may occur intraoperatively (27).

## Commonly Used 3D Printing Technologies in Oral Health

### 3D Printing

It is a technology, where a 3D printer lays down the material in sequential layers, i.e., one layer at a time in order to print an object. Since the process involves adding the material one layer followed by subsequent layering, it is called as additive manufacturing. Along with the x- and y-axis, the z-axis is seen, depth axis. z-axis is the height of the object that gives it a 3D shape (28).

### Intraoral Scanning

Intraoral scanner captures the optical images of the dental hard and soft tissues. The light source from the handheld scanner is directed over the area to be scanned, e.g., teeth, and gingiva etc. The image is captured by sensors, which is processed with the help of software by generating point clouds. The software then analyses these points, which help in creating a mesh framework giving the final virtual image of the scanned object (29).

### Desktop Scanning

This type of scanning is used to scan the object physically, i.e., scanning of impression can be in alginate or polyvinyl siloxane or the gypsum cast (30).

### STL File (Stereolithographic File or Standard Tessellation Language File)

STL is the global format for the 3D printing files. As the object is scanned with the scanner (intraoral scanner/desktop scanner), it is stored in the computer in STL file format (30).

### Stereophotogrammetry

It is a 3D camera technology where the cameras are arranged as a stereo-pair. Here, the 3D coordinate points are marked on an object (e.g., face) followed by photographs taken from different angulations and positions. The image is then calculated by collecting the points which are obtained along the X, Y, and Z system of coordinates **(31).**

### Computer-Aided Design (CAD)

The CAD program is used to begin processing and preparation of the file for printing or milling. It is a software on the computer that prepares the STL file for 3D printing of the intended object **(30).**

### Resolution

It is one of the ways to measure the print quality of a 3D printer. It is of two types horizontal and vertical resolution **(30).**

### Rapid Prototyping Models in Oral and Maxillofacial Surgery: History, Definition, and Indications

Rapid prototyping (RP) creates a three-dimensional model with a layer-by-layer process of adding based on 3D computer-aided design (CAD) data. This technology is also referred to as "layer production," "solid free form production," or "3D printing". Digital Imaging and Communication in Medicine (DICOM) format files are created and converted to Standard Tessellation Language (STL) format files using computer-aided design (CAD) software. These files are then uploaded to a 3D printer, and a rapid prototype (RP) model is created **(32).**

These models can be fabricated using various additive manufacturing methods, including material extrusion approaches such as fused deposition moulding (FDM), vat polymerization (i.e., stereolithography), powder bed fusion (e.g., selective laser sintering and selective laser melting), and binder or material jetting **(32).**

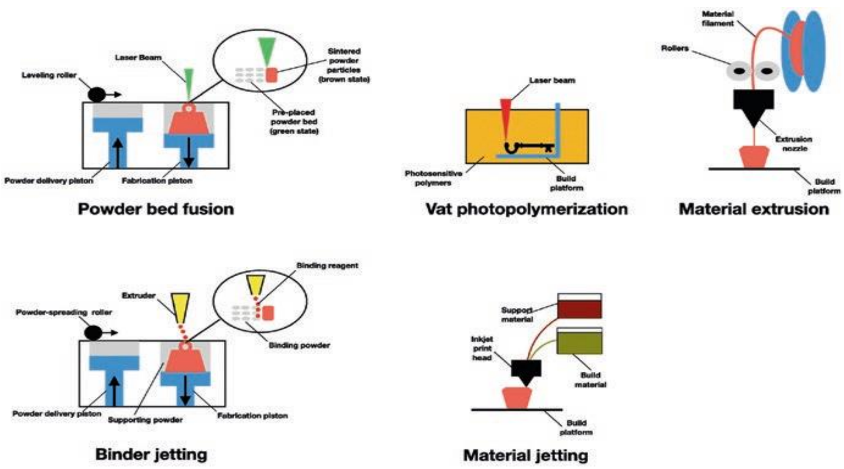



**Fig. 9: Schematic drawing of additive manufacturing methods that can be used to fabricate rapid prototyping models. (a) Powder bed fusion (b) Vat photopolymerization (c) Material extrusion (d) Binder jetting (e) Material jetting (2).**

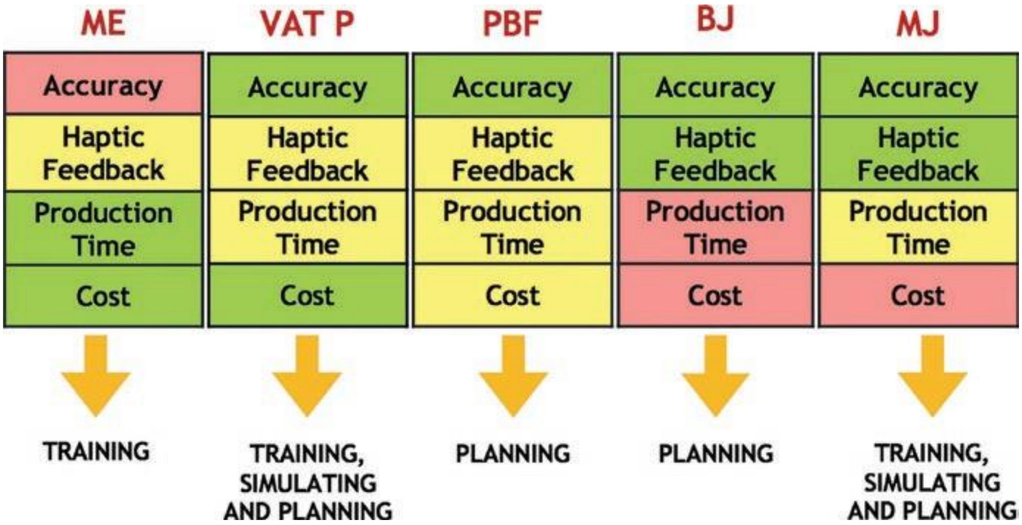



**Fig. 10: Briefly describe the pros and cons of using each method to fabricate rapid prototyping models for different oral and maxillofacial surgery procedures. Red color refers to an improper and green to the optimal situation. The yellow color means the intermediate status. ME material extrusion, VATP vat polymerization, PBF powder bed fusion, BJ binder jetting, MJ material jetting (2).**

## Different Material and Their Properties

### Polyetheretherketone (PEEK)

Polymers with easy processing, good chemical resistance, and light weight are attractive materials for use in bone replacements. Biodegradable polymers, such as polylactic acid, polyglycolic acid, and their copolymers, are commonly used to make scaffolds for tissue engineering applications and have poor mechanical strength.

Nondegradable polymers, such as polyethylene and polyetheretherketone (PEEK), find applications that require long-term stability. High-density polyethylene (HDPE) is commonly used to repair tendons and catheter tubes, while ultrahigh molecular-weight polyethylene (UHMWPE) is used as a carrier in joint prostheses **(33).**

Polyetheretherketone (PEEK) is a semicrystalline polyaromatic linear polymer. PEEK is biocompatible, mechanically strong, nonallergenic, and nonmagnetic and also is considered as a high-performance polymer due to its excellent chemical resistance, high melting temperature (340 °C), superior radiation and sterilization resistance, high modulus of elasticity (3.7–4.0 GPa), and tensile strength (103 MPa). PEEK is comparable to cortical bone regarding its elasticity. PEEK has radiographic translucency and produces no artifacts on radiographic imaging. On the other hand, titanium is not translucent and may cause diagnostic difficulties. PEEK does not undergo exothermic reactions like methyl methacrylate does. It has been used as an alloplastic biomaterial in craniofacial reconstructions. PEEK implants provide permanent long-term results and are easily trimmed intraoperatively if needed **(34).**

Despite these advantages, however, bio-inert PEEK is unfavourable for osteoblastic cell adhesion and has no bioactive potential **(34).**

**Titanium**

Titanium is one of the most common metallic materials used in the additive manufacturing, due to its good chemical properties, such as high corrosion resistance. Titanium showed low infection rate, high biocompatibility, biological inertness, significant corrosion resistance, and beneficial handling characteristics. However, it does not have good thermal or electrical conductivity and is expensive (35).

Titanium is lighter and stronger than the human skull bone. In addition, when made of Patient Specific Implant (PSI) and mesh, it fits perfectly with the edges of the skull defect and shortens the duration of operation. On the other hand, titanium implants trimmed during surgery sometimes erode the skin due to the increased tensile stress of the mesh shape, which results in an inappropriate contour (35).

**PMMA**

PMMA has an impact resistance comparable to human skull bones in any normal stress or impact (36).

Polymethylmethacrylate is a flexible acrylic resin that has the similar strength and protection as native bone tissue. Acrylic resins are stable, chemically inactive, unaffected by temperature, nonconductive, cheap, well tolerated by tissue, and easily applied and modified. However, lack of porosity, inhibits ingrowth of newly formed bone tissue into PMMA PSIs. PMMA interferes with osteo-conduction and vascularization, does not interact with the surrounding tissue, and may be more susceptible to infections than other alternatives (36).

**Clinical Workflow**

The design methods for the reconstruction of the cranio-maxillofacial defects are as follows. Mirrored imaging technique involves mirroring the intact side of the skull on the opposite side and subsequently applying a logical difference to the implant design. This method is suitable for skulls with low asymmetry and unilateral lesions and for significant defects that do not cross the midline (37).

Template-based technique use a reference skull, which can be an average skull, or a patient-like skull. Then, the spatial matching between the injured area on the patient's skull and the corresponding fragment in reference model is performed to design the implant geometry. This approach is suitable for very asymmetrical skulls and large and complex defects, even in the midline (37).

Anatomical reconstruction or free form modelling is a way to design implants using supportive geometry, for example, the residual geometry of the patient's bone, and free form modelling tools such as lines, plates, and curves provided by CAD software. An example of this method is the "curvature-based filling" function. This function uses the surface tangent along with the defect to reconstruct the surface. The results are similar to the original curvature (38).

The thin plate spline (TPS) or interpolation properties of the radial basis function includes interpolation functions that can approximate the surface of the skull in a defect by warping and deforming a target based on two sets of homologous points defined on a reference model and a target. This approach using an average skull can be suitable for defects of the midface. Because TPS is a superficial interpolation, it is not suitable when dealing with extensive defect areas **(38).**

**Application of VSP in Maxillofacial surgery**

**Bone Contouring in Oral and Maxillofacial Surgery: Definition, Indications, and Manufacturing Consideration:**

Maxillofacial PSIs can now be designed using preoperative imaging data as input to CAD software. The designed implant is then made using a CAM technique, such as 3D printing. The application of CAD/CAM technique also can simulate the surgery procedures accurately, which contributes to shorten the actual operative time **(39).**

An ideal implant should be patient-specific, as well as safe for the patient, inert, nontoxic, noncarcinogenic, cost-effective, and resistant to infection. It should adapt easily and blend naturally with adjacent areas. If the implant material can be folded and compressed, it can be inserted through a small incision, but at the same time, it must be resistant to stress and maintain its shape permanently. An ideal implant can be placed and fixed, which reduces mobility. It should also be easily replaceable if necessary **(39).**

**Indication of Facial Bone Contouring**

**Calvaria**

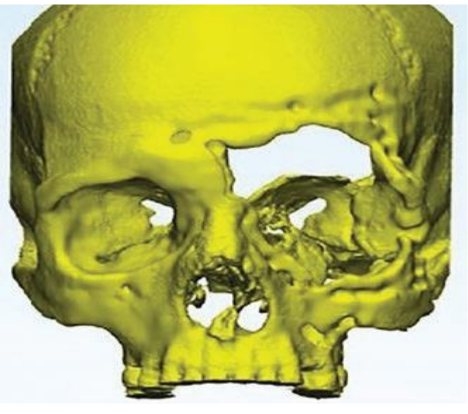
Cranioplasty is often performed after traumatic head injuries. Tumour resection or decompressive craniectomy is the main cause of skull defects. Congenital defects, infections, or complications of previous surgery can also cause these defects **(40).**

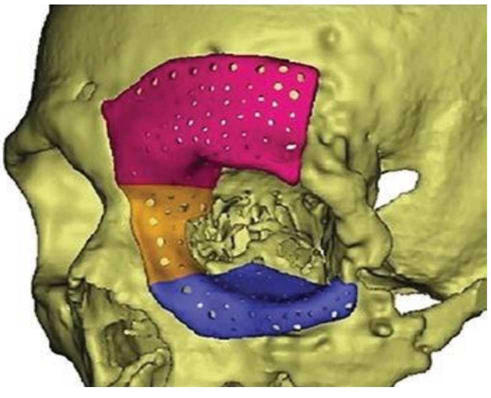
**Orbit**

The management of orbital fractures is challenging, because the functional and aesthetic clinical consequences may not always be immediately apparent **(41).**

The main advantages of custom 3D printing implants are shortening the surgical time and consequently shortening the anaesthesia and reducing its risks. Also, the accuracy of matching the implant with the bone defect improves the reconstruction of the orbital volume and in practice leads to better results for ocular motility as well as binocular vision **(41).**

Orbital defect reconstruction with a patient-specific implant





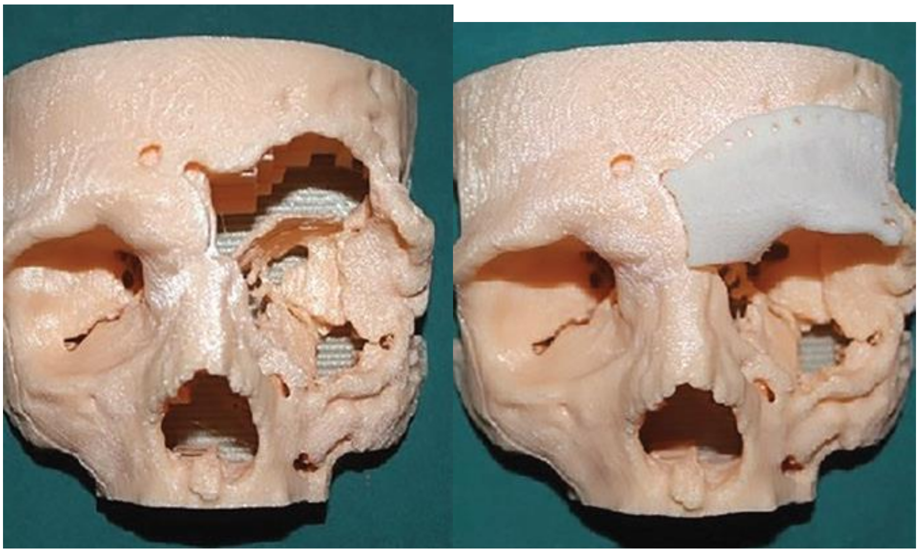


**Fig. 11: Shows the process of designing and manufacturing a patient-specific prosthesis in the orbital region. (a) Processing patient data from CT scan, (b) designing patient-specific prosthesis, (c) printed model of the patient's skull structure, (d) a piece of prosthetic model manufactured to match the patient defect precisely (42).**

### Malar

The zygomatic bone, located in the middle third of the face, greatly affects the harmony of the face with its volume and prominence; also, its complex three-dimensional anatomy and unique geometric shape increases the difficulty of reconstruction **(43).**

There are various approaches to zygomatic reconstruction, including autologous bone grafts, free tissue faps, prefabricated titanium plates and meshes, patient specific implants (PSIs), or a combination of the above **(43).**

The use of CAD-CAM reduces the difficulty of properly shaping the donor bone and reduces the surgical time. It also reproduces orbit zygomatic landmarks and orbital volume. Manual reconstruction requires multiple settings that are time consuming, while with CAD-CAM, these assemblies take only a few minutes **(44).**

Patient-specific prostheses designed to reconstruct the contour of several bones.

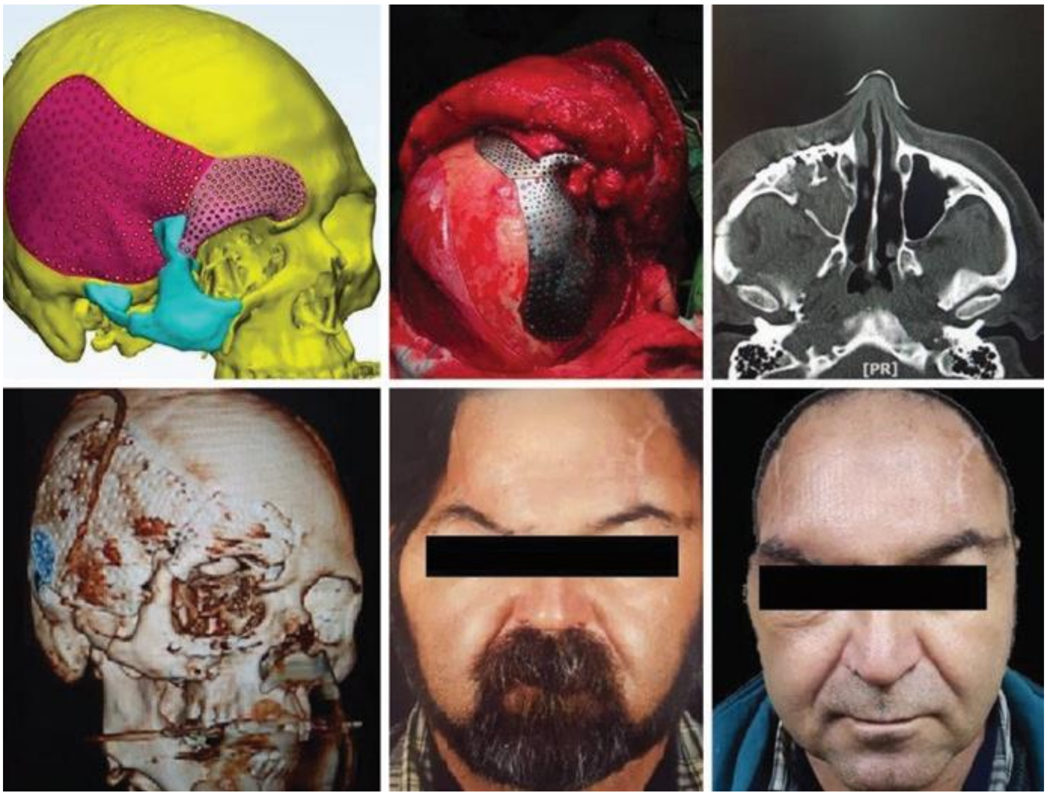



**Fig. 12:** Shows the prosthesis to replace the contour of the calvaria, orbit, and zygoma. (**a**) Prosthesis design. (**b**) Placement and fixation of the PSI. (**c**) Postoperative CT scan in the axial cut shows the zygomatic part of the prosthesis. (**d**) Three-dimensional reconstruction of the postoperative CT scan. (**e**) Preoperative photography of the patient, the defect is evident on the right side of the face. (**f**) Postoperative photography of the patient **(44).**

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