# 7 Computer-Assisted 3D Reconstruction in Oral and Maxillofacial Surgery

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## 7.1 Introduction

Cranio-maxillofacial surgery (CMF) represents a broad range of sub-specialties, such as maxillofacial oncological surgery (resection of tumors and reconstruction of the site with different types of grafts), craniofacial corrective surgery of malformative syndromes (i.e., craniosynostoses, or cleft lip palate), orthognathic surgery and distraction osteogenesis (to correct craniofacial deformities), cranio-maxillofacial trauma surgery and associated reconstructive maxillofacial surgery, and implantology. Surgical engineering in CMF surgery is present at all levels of the CMF clinical workflow, from diagnostic tools to preoperative planning, intraoperative guidance, and transfer of preoperative planning to the operative theater [1].

Virtual endoscopy (VE) and 3-D reconstruction can generate 3-D printed models from cranio-maxillofacial structures (soft and hard tissues) that can be used for preoperative planning, intraoperative navigation, and postoperative control. Surgery can be planned with these models with highly valuable information as the soft and hard tissue can be measured using the mirrored data set of the unaffected side; size and location of the graft can be chosen virtually. Intraoperatively, contours of transplanted tissues can be navigated to the preoperatively simulated reconstructive result. Preoperatively outlined safety margins could be exactly controlled during tumor resection. Reconstructions of oncologic and trauma patients can be designed and performed precisely as virtually planned. Image-guided treatment improves preoperative planning by visualization of the individual anatomy, intended reconstructive outcome, and objectivation of the effect of adjuvant therapy. Intraoperative navigation makes tumor and reconstructive surgery more predict-

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able by showing the safety margins, locating vital structures, leading reconstruction to preplanned objectives, as well as operating room time-saving as a custom-made adaptation of osteosynthesis material can be done previously [2].

## 7.2 Computer-Assisted Treatment

Computer-assisted technology was initially developed to provide neurosurgeons with accurate guidance during surgical procedures. Stereotactic procedures were introduced to neurosurgery in the early 1980s, and currently systems with and without robotic navigation are in use for specific medical indications. For oral and maxillofacial surgery nowadays, mechanical, electromagnetic, and optic systems are available to perform navigational surgery by frameless stereotaxy.

Clinical application of computer-assisted treatment is performed in three steps. The first step is the analysis of the problem, planning of treatment, and simulation of surgical procedures. The second step is the navigational surgery performed as frameless stereotaxy. The third step consists of post-therapeutic control.

Indications in traumatology are primary and secondary reconstruction of the orbit and the decompression of the optic nerve. Using frameless stereotaxy, the decompression of the optic nerve in trauma or tumor cases becomes a safe and predictable, as well as a minimally invasive procedure [3].

## 7.3 Frameless Stereotaxy

Optic navigation system includes an infrared light located on the tip of a surgical tool which allows correlation of anatomic situation and patient's spiral CT or MRI data set. Defined reference points exposable in the anatomic situation and visible in the data set of the patient are needed for registration of the system.

Registration with anatomical landmarks or skin Fiducial markers lacks accuracy, registration with devices fixed within the oral cavity interferes with surgical procedures [4, 5], while Fiducial markers fixed to bone screws are invasive and limited to one surgical intervention a few days after data acquisition (Fig. 7.1).

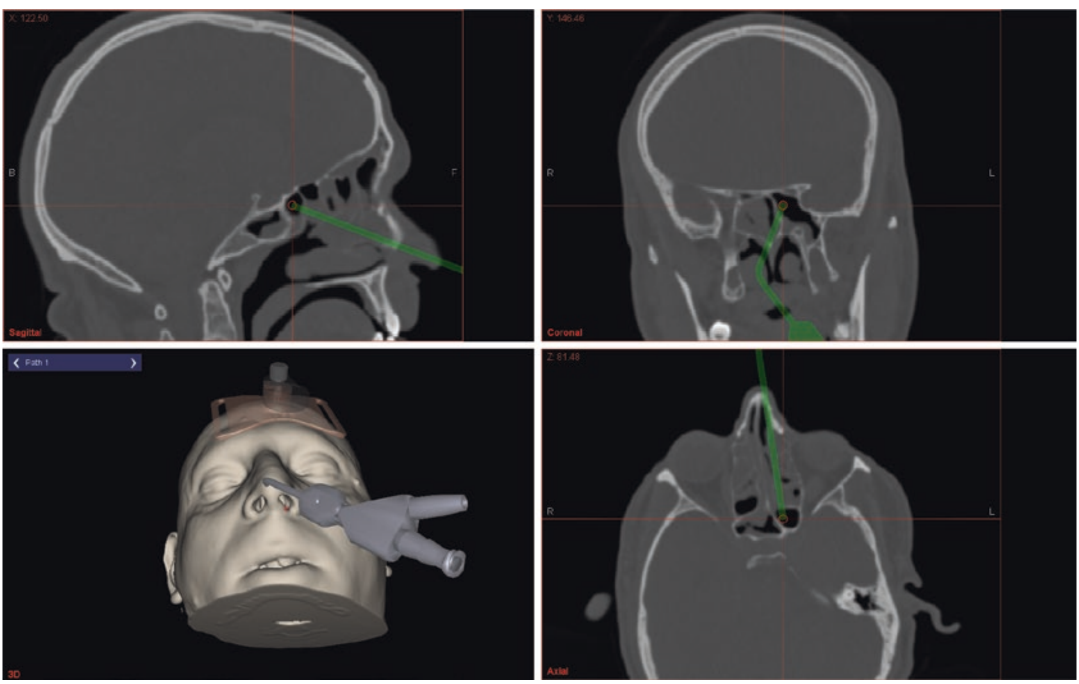


**Fig. 7.1** Registration of Brain Lab Screen Shot

The head of the patient is normally fixed to a Mayfield clamp, which is tracked by a dynamic reference frame to allow changing of the position during operation. Noninvasive tracking can be achieved by fixing this dynamic reference frame to the occlusal splint. With this technique, navigational surgery of the mobile mandible can be performed. Frameless stereotaxy allows the surgeon to localize any desired anatomical structure with the pointer and lead the surgical intervention to the preplanned and simulated result; the surgeon is also able to guide the tip of any tracked surgical tool drill, fraise, chisel, or endoscope or to localize the focus of a surgical microscope [6].

## 7.4 Image-Guided Navigation

Image-guided navigation leads to improvement in surgical accuracy with the aid of software that uses images captured from CT or MRI and a tracking system for the surgical instruments [7]. The accuracy of image-guided navigation in CMF depends on the imaging modalities [8], patient-to-image registration procedures, the navigation system used [9], data acquisition [10], interaction of the surgeon with the system, technical errors [11], and instrument tracking [12, 13]. The technical accuracy and the navigation procedures seem to be of minor influence [14]. Image-guided navigation requires a means of registering anatomical points in the medical image (CT or MRI) and a software program to locate the surgical instruments [15–17]. Knowing the exact position of the instrument is the key to the success of the surgical intervention. CT/MRI images are used as a map to provide the surgeon with a real-time representation of the surgical instruments in relation to the images of the patient. This real-time representation allows for tracking the instrument position during the surgery and their visualization on the computer [9]. During the surgical phase, the surgeon is given interactive support with guidance in order to better control potential dangers and avoid complex anatomical regions [18]. Navigation is possible through a series of sensors attached to the rotator instruments, the surgical template, and a cap fixed on the patient's head, and the data are captured by different systems. The obtained data are transferred immediately to the computer and enable the surgeon to view the real situation [19].

Image-guided navigation is especially useful in tumor resection involving complex anatomy areas modified by tumor growth [19, 20] (such as the orbit), in proximity to cerebral structures, and when cranial nerves could be injured [21, 22]. Image-guided navigation allows for the immediate reconstruction of the unilateral resected area with an autologous graft designed and positioned under navigation with a preoperative plan based on the mirrored healthy side [23]. Computer-assisted surgery (CAS) navigation in CMF tumor resection can also be combined with new imaging modalities, such as positron emission tomography. In this combination, the surgeon is simultaneously provided with anatomical and functional (metabolic) details. The resulting fused images offer improved localization of malignant lesions and improve the targeting of the biopsy, especially for small lesions [24].

Intraoperative navigation has also been used in the resection of the ankylotic bone in temporomandibular joint (TMJ) gap arthroplasty and for TMJ arthroscopy using optoelectronic tracking technology [25–27].

## 7.5 Periorbital Reconstruction

In craniomaxillofacial surgery, advances in imaging techniques spiral-CT, 3-D imaging, and associated technologies (stereolithographic models and CAD/CAM) have led to improved preoperative planning within the past years. To assess asymmetry, proper measurement of distances between anatomic structures will help to determine the severity of a facial deformity. Within the orbit, transverse, cranio-caudal, and posterior-anterior measurements allow to determine areas of deficient bone and to evaluate how much grafted bone volume or reconfiguration of periorbital bone is necessary. By this procedure, the surgeon himself is not limited to a subjective clinical estimation of the asymmetry, but he gets familiar with the individual discrepancies in all three dimensions. The diagnostic value of the multiplanar assessment including the 3-D images is one of the most important features of the system.

Additionally, to measure functions, the volume rendering tool allows evaluation of affected and nonaffected orbital contents with individual cubic millimeter volume measures. By this method, the orbit can be directly compared to the other side. The majority of orbital deformities or traumatisms are unilateral, so that most of the cases can be approached by this side-to-side comparison. A further development of the idea to compare one side to the other is the mirroring tool. The surgeon has to define the individual level to which the data set shall be mirrored from the unaffected to the deformed side, and he has to set the range, within which the mirroring process shall be performed.

The software guides the surgeon step by step through this procedure. The optimal virtual reconstruction can be done and stored. During the operation, these new contours can be navigated and serve as a control of the ongoing orbital reconstruction [28].

## 7.6 Infection and Airway

Maxillofacial infections begin from the dentoalveolar area and then spread into the adjacent bone causing perforation of the bone cortex into the subperiosteal region. Fascial planes of the head and neck are virtual spaces, bounded by muscle attachments and bone. These anatomical structures will govern in which direction the infection spreads to the deeper soft tissues spaces (parapharyngeal and mediastinum) (Fig. 7.2).

Parapharyngeal abscess often has little clinical signs until the airway is compromised, as the swelling is located at the oropharyngeal or parapharyngeal region, so it is very important to make a complete anamnesis to get all the history of the illness [29].

Ludwig angina is an infection of the submandibular space, first described by Wilhelm Frederick Von Ludwig in 1836. It is an entity difficult to manage due to the rapid progression and difficulty in maintaining airway patency, resulting in asphyxiation and death in 8–10% of patients [30].

There are good predictors of sublingual involvement during head and neck infections; the patient usually cannot protrude the tongue, and we can find associated dysphagia and odynophagia.

During physical examination, stridor, difficulty managing secretions, anxiety, cyanosis, and sitting posture are late signs of impending airway obstructions, and they indicate the need for an immediate artificial airway (tracheotomy) [31].

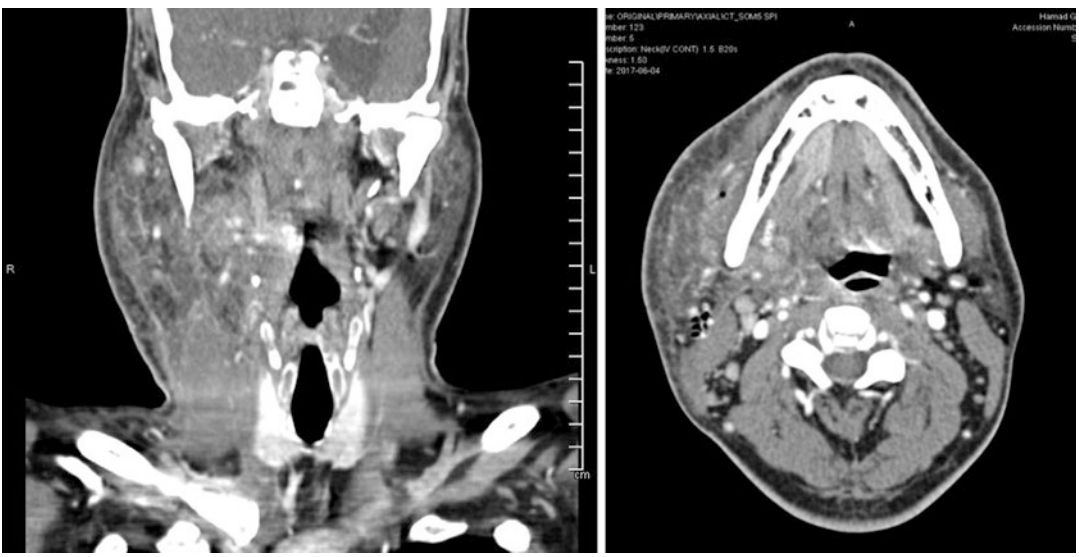


**Fig. 7.2** CT scan coronal and axial view showing airway displaced in a maxillofacial infection case. Right-sided subcutaneous swelling edema and fat permeation is noted encroaching and violating deeply through the stylomandibular tunnel reaching to the oropharyngeal airway which is mildly compromised

Surgical tracheotomy in head and neck infections is often difficult and occasionally life threatening due to the involvement of the neck and pre-tracheal tissues. Incising through the pretracheal fascia and exposing the pre-vertebral tissues to pathogens risks the spread of infection into the mediastinum. Mediastinitis, despite modern healthcare, still carries significant mortality [32].

Sublingual hematoma, after traumatic injuries on the tongue or the floor of the mouth, is a rare but potentially fatal cause of upper airway obstruction. This condition has the potential for quick obstruction of the upper airway due to the tongue's vast vascularization. The increased lingual volume displaces it in a posterior and cephalic direction, thus blocking the airway; prompt evacuation will lead to avoid morbidity and mortality related to this complication [33].

3-D reconstruction and virtual endoscopy (VE) applied to these cases can give valuable information to the surgical and anesthesia team about airway displacements, relationship between collections (pus or blood), and vital structures and can also help with 3-D locations of multiple collections from infections or hematomas to proper evacuation during surgery.

## 7.7 Congenital and Developmental Abnormalities and Airway

Despite publishing after Shukowsky [34], Pierre Robin has been credited with describing a cluster of craniofacial anomalies with potential and specific physiologic sequelae. In the literature, this grouping is known as Pierre Robin syndrome [35], Pierre Robin sequence [36], Robin anomalad [37], or Robin complex [38], each justifying their own specific nomenclature. Pierre Robin sequence may manifest as micrognathia, cleft palate and glossoptosis with airway obstruction [39]. Infants with complications of Pierre Robin sequence are at increased risk of airway obstruction and resultant hypoxia, failure to thrive, and cerebral impairment [40]. The concept of "sequence" suggests that one anomaly causes subsequent anomalies, and micrognathia is believed to be inciting anomaly in patients with Pierre Robin sequence [41, 42]. Pierre Robin sequence can be life threatening during the neonatal period with the onset of airway obstruction, which can occur at any time right after birth. If left untreated, prolonged airway obstruction can lead to acute or chronic hypoxia, cyanosis, apnea episodes, aspiration, respiratory tract infection, feeding difficulties, malnutrition, and failure to thrive [43, 44].

There are numerous potential treatment options, and they range from conservative nonsurgical interventions to surgical procedures including distraction osteogenesis (DO) [45]. The basic treatment of babies with suspected Pierre Robin sequence is to secure the pulmonary tract. Depending on the severity, tracheostomy is one of the options. In this decade, DO has been introduced for patients with the Pierre Robin sequence. DO makes a longer mandible and secures the upper pulmonary tract [46].

Mandibular distraction osteogenesis (DO) is currently the "gold standard" for the treatment of obstructive apnea secondary to micrognathia. It avoids the tracheotomy and/or other aggressive surgical procedures and treats the etiology of the disease, improving oxygen saturation and changes in feeding in a few days. For the surgical decision-making process, supplementary explorations are helpful, such as polysomnography, lateral cranial X-ray, and 2-D and 3-D CT scans. The horizontal or oblique distraction vector will be the vector of choice due to its positive effects on the sizes of the airway. It is a procedure whose results can be planned and reproduced, with minimum short-term complications [47].

Virtual technology can greatly improve the planning and execution of mandibular DO in Pierre Robin or syndromic patients [48]. The benefits of 3-D virtual planning in these cases fall into two categories:

1. Operative planning, the two key features of which are device and vector selection. Whether there is sufficient bone to place a device, and if so what would be the optimal angle and best location for the device. Virtual planning can help us to identify if the device

could be positioned appropriately. Once positioned on the virtual model, we could measure mandibular thickness at various holes and plan the appropriate screw length. Similarly, the inferior alveolar nerve and teeth buds could be viewed, identifying screw holes to avoid.

2. Surgical execution, the second major benefit, and the most novel aspect of this technique, is the ability to transfer the virtual plan to the operating room using operative guides and splints. Custom-designed cutting guides can be used in the virtual space and then provided as physical 3-D models. These will allow the device to fit in a proper position on the mandible during surgery, guide the osteotomy and the successful placement of the device to match our vector previously planned [49].


**Fig. 7.3** Orthopantomogram-like reconstruction obtained from the volumetric study, and it is a post-processing technique which is called curved MPR C-MPR, the bony element and osseous framework of the mandible, maxilla, teeth, lamina dura, and TMJ can be instantaneously evaluated without extra radiation to the patient

## 7.8 Temporomandibular Joint Ankylosis and Airway

Temporomandibular joint ankylosis (TMJA) is a disabling condition of the masticatory system that alters eating habits and speech ability. The features include hypomobility of the joint, micrognathia (TMJA is one of the most common causes for acquired mandibular hypoplasia), retrogenia, facial asymmetry, malocclusion, and airway compromise which in severe cases may manifest as sleep apnea/hypopnea syndrome [50] (Fig. 7.3) (Movie 7.1).

TMJA can be caused by bony or fibrous ankylosis of the TMJ as a sequel to trauma, infection, autoimmune disease, or failed surgery [51].

Posttraumatic ankylosis can be caused by different pathogenic mechanisms such as organization and ossification of hematoma, maltreated facial fractures, and systemic diseases such as ankylosing spondylitis, rheumatoid arthritis, psoriasis, and autoimmune disease that increase the effects of micro-trauma [52].

As observed in patients with micrognathia, the additional space occupied by tongue, soft palate, and redundant pharyngeal mucosa reduces the cross-sectional area of oropharyngeal airway by an average of 25%. Various cephalometric studies have demonstrated the effectiveness of mandibular advancement procedures on the improvement in oropharyngeal dimensions. When TMJ ankylosis occurs during the growth of the mandible, varying degrees of facial deformities result. Since these children grow with facial asymmetry, the position of the larynx may be altered. Classically, bird-faced deformities with convex facial profiles have been described in chronic long-standing TMJ ankylosis characterized by micrognathic mandible with receding chin and steep occlusal plane [53].

Facial asymmetry, malocclusion, anemia, and malnutrition may be the consequences of TMJA. It also leads to increased airway obstruction, obstructive sleep apnea, and cor pulmonale. Airway obstruction is secondary to structural encroachment on oro-pharyngeal and hypopharyngeal lumen, subatmospheric intrapharyngeal pressure, and hypotonicity of oropharyngeal muscles. All these structural deformities lead to difficulty in ventilation, intubation, and extubation [54].

It has been reported that the three-dimensional (3-D) reconstruction models based on MRI can play an important role in TMD diagnosis by revealing morphological features of TMJ, thus being a powerful tool for characterizing different patterns of TMJ pathologies [55]. The use of 3-D models can help to classify the morphology of the articular eminence by correlating signs and symptoms of temporomandibular joint dysfunction to articular disc displacement on MRI images [56]. Understanding of the TMJ anatomy, biomechanics, and the imaging manifestations of diseases is important to accurately recognize and manage these various pathologies.

The application of virtual endoscopy (VE) and 3-D printed models in TMJA reconstruction enhances the clinical accuracy, and the following advantages can be described: First, the contour of the selected graft or alloplastic material could be guaranteed adequate matching with the lateral surface of ramus in shape, guiding precisely the implantation the grafts in an ideal position. Second, the better fixation position of the bone grafts could be determined preoperatively without the damage of the anatomical structures (e.g., inferior alveolar nerve). Third, the osteotomy orientation and bone trimming would be guided accurately intraoperatively. Moreover, the length of the titanium plate and each titanium screws also could be confirmed, with no need to measure during surgery (decrease in operation time) [57].

Therefore, 3-D printed models make the TMJ reconstruction more predictive and easier, and avoid the unplanned graft selection and the fixation of the bone graft. Custom-fitted implants for joint reconstruction also decreased the preoperative workup time of the design and the manufacture of the TMJ prosthesis and increased the accuracy of the model surgery [58] (refer to Chap. 11 for more details) (Fig. 7.4).

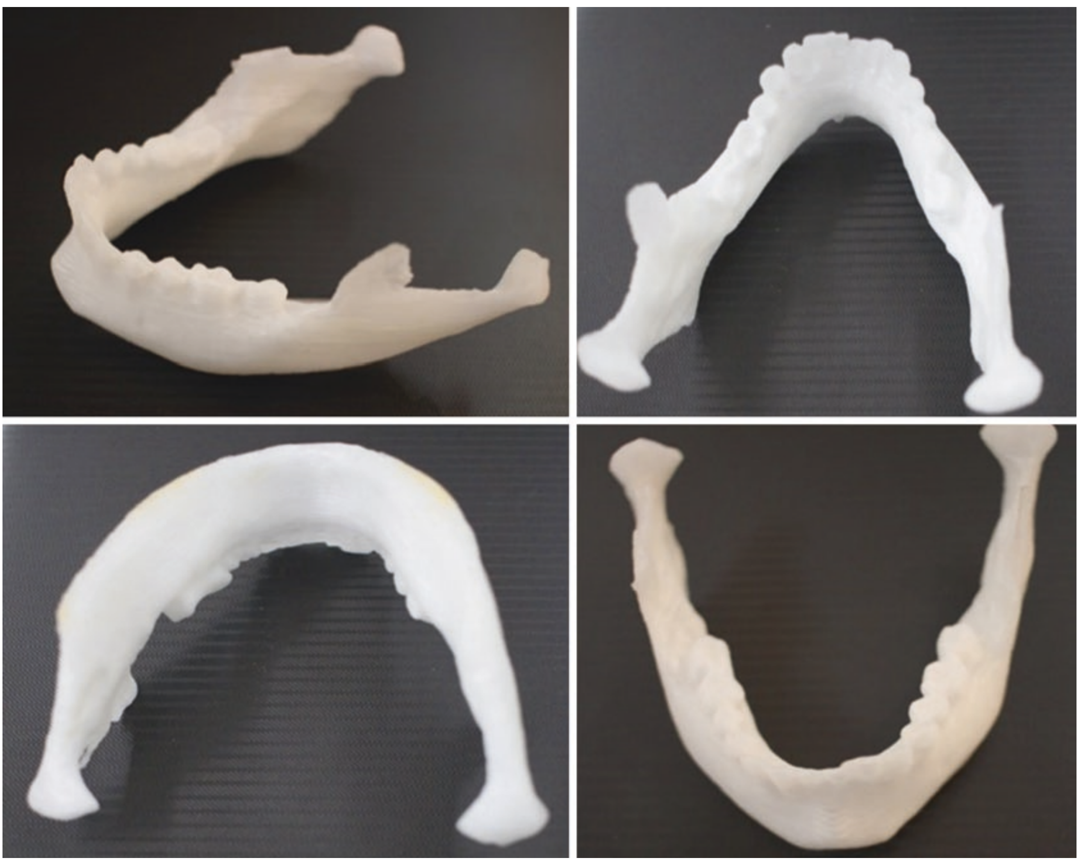

**Fig. 7.4** Printed 3-D model for the mandible from different perspectives

## 7.9 Oral and Maxillofacial Tumor Surgery and Reconstruction

Oral cancer is the sixth most common cancer worldwide. The factors responsible for difficult airway during perioperative period in oral cancer patients are as follows: [58].

(a) Presence of cancer growth itself
(b) Anatomical changes and fibrosis due to prior surgery or radiotherapy
(c) Lengthy surgical procedure
(d) Bulky flap reconstruction
(e) Edema around the airway due to surgical manipulations
(f) Risk of bleeding, mainly because of surgical causes or multiple attempts of airway manipulation
(g) Risk of pulmonary aspiration.

Airway management in head and neck tumor patients undergoing major surgical procedures, including microvascular free tissue transfer, has often been routine tracheotomy. The necessity of this procedure has, however, been questioned [59]. Tracheotomy itself is not without complications, with rates as high as 4.1–8% in some series. Possible complications include hemorrhage, obstruction, cannula displacement, local infection, pneumonia, fistula, tracheal stenosis, and tumor recurrence due to tumor seeding [60]. Brickman et al. argued that maxillectomy and microvascular free tissue transfer do not negatively impact a patient's oropharyngeal airway, so elective tracheotomy should only be considered in patients with additional risk factors, such as cardiopulmonary diseases [61]. Recently, a tracheotomy scoring system to guide airway management after major head and neck surgery has been proposed, whereby tumor site, mandibulectomy, neck dissection, and reconstruction are scoring factors [62].

Tumor ablation leads to head and neck defects, which brings about significant esthetic and functional deficits. After tumor resection in the cranio-maxillofacial area, the patient needs reconstruction of hard and soft tissue defects with the use of soft tissue grafts, bone grafts, flaps, and surgical plates which have been extensively used in head and neck reconstruction to stabilize bone segments [63, 64] (Fig. 7.5).

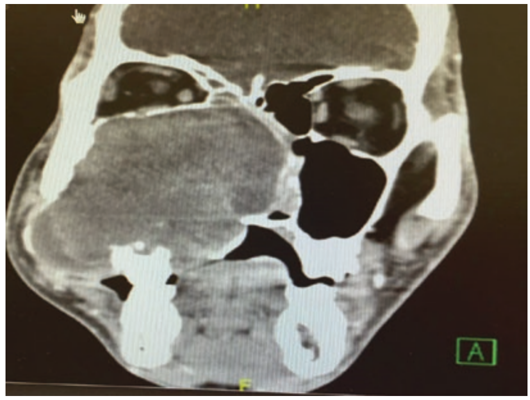


**Fig. 7.5** Face CT scan coronal view showing soft tissue mass lesion epicentered over the right maxillary antrum causing its expansion violating and encroaching and partially obstructing the upper airway and ipsilateral nasal cavity

The use of 3-D printed models facilitates the assessment of tumor extensions, the anatomical areas involved to plan the resections and visualize which structures will be involved in the resection's margins. These resections can be done on 3-D models previously and are valuable tools in order to plan contouring maxillofacial reconstruction preoperatively because the conventional surgical plates are mass-produced with universal configurations that should be manually bended to match the individual bone anatomy. The plate-bending procedure could be time- and energy-consuming, especially for inexperienced surgeons, so this technique also has a significant potential to shorten the length of operating room (OR) time for the surgical team and consequently reduce operative cost in the hospital [65]. The application of 3-D printed patient-specific surgical plates in head and neck reconstruction is feasible, safe, and precise [66] (refer to Chap. 11 for more details) (Fig. 7.6).

## 7.10 Maxillofacial Trauma

Patients with maxillofacial trauma present serious challenges for the physician because airway management in these patients can be complicated by their injury [67].

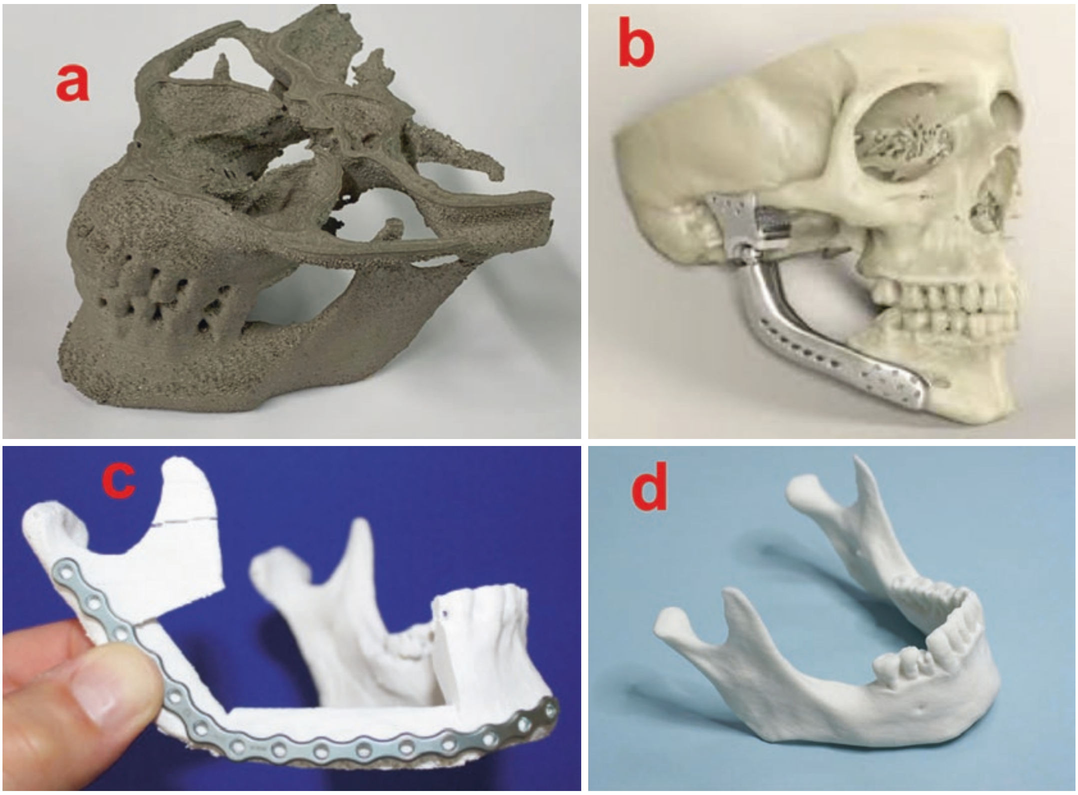


**Fig. 7.6** 3-D printed model for the mandible is of utmost benefit for planning for the reconstruction and plate and screws fixation in a step prior to the real surgical intervention. Rehearsal, measurement evaluation, and functional assessment will help the surgeons for better surgical outcome, and it is of high impact upon the teaching part for the junior staff colleagues

The first priority in assessing and managing the trauma patients is airway maintenance with cervical spine control. This is based on the Advanced Trauma Life Support (ATLS) concept for managing patients who sustained life-threatening injuries [68]. Immediate management of maxillofacial injuries is required mainly when impeding or existing upper airway compromise and/or profuse hemorrhage occurs [69].

Safe and optimal airway management of patients with maxillofacial trauma requires appreciation of the nature of the trauma. There are several maxillofacial injuries that result from critical care errors, with airway management being the most common [70].

A patient with a supraclavicular injury is considered to have a C-spine injury, until proven otherwise by imaging [71]. Since a complete C-spine clearance may take several hours and sometimes days to achieve, the patient must be fitted with a neck collar for cervical spine immobilization [72].

Using a video laryngoscope, or awake intubation techniques instead of a conventional laryngoscope with a Macintosh blade, may be beneficial for intubating patients whose neck position needs to be in a neutral position and their cervical spine requires immobilization [73, 74]. The surgical airway is considered to be the last option in airway management; however, inpatient with facial trauma sometimes it is the best solution [74]. To be prepared well, a qualified surgeon should stand onsite during conventional airway management in order to be immediately in-charge. Performing a cricothyroidotomy or tracheotomy under local anesthesia is a lifesaving procedure in selected patients in the “cannot intubate, cannot ventilate” situation.

Surgical creation of an airway is a safe method for securing the airway when the procedure is done by an experienced surgeon. However, this approach has its drawbacks: it carries some of complications such as hemorrhage or pneumothorax, in an elective scenario [75].

According to Hutchison et al., there are six specific situations associated with maxillofacial trauma, which can adversely affect the airway [69, 76].

1. Posteroinferior displacement of a fractured maxilla parallel to the inclined plane of the base of the skull may block the nasopharyngeal airway.
2. A bilateral fracture of the anterior mandible may cause the fracture symphysis and the tongue to slide posteriorly and block the oropharynx in the supine patient.
3. Fractured or exfoliated teeth, bone fragments, vomitus, blood, and secretions, as well as foreign bodies, such as dentures, debris, and shrapnel, may block the airway anywhere along the oropharynx and larynx (Figs. 7.6 and 7.7).
4. Hemorrhage from distinct vessels in open wounds or severe nasal bleeding from complex blood supply of the nose may also contribute to airway obstruction.
5. Soft tissue swelling and edema, which result from trauma of the head and neck, may cause delayed airway compromise (Figs. 7.8 and 7.9).
6. Trauma of the larynx and trachea may cause swelling and displacement of structures, such as laryngeal fracture, tracheal laceration, or complete transection of epiglottis or arytenoid cartilages injury or vocal cord trauma, and thereby increasing the risk of airway obstruction.

**Fig. 7.7** 3-D CT reconstruction showing loose teeth and bone that can cause obstruction of airway

The maxillofacial surgery is done after stabilization of the patient; the radiographic tests are performed (VE and 3-D reconstruction of upper airway), and all the injuries are identified. In some patients, the surgery is performed at the same time as the surgery on other injured organs. The surgeon has to perform fracture reduction and internal fixation with plates and screws, repair soft tissue injuries, and restore the occlusion. In selected patients, naso-endotracheal intubation can be used for airway control during surgery [77].

Submental oro-tracheal intubation was developed in order to avoid the need for tracheotomy and to permit unfettered access to the oral region. This type of intubation is done (a) in patients with comminuted fracture of the midface or the nose, where nasal intubation is contraindicated, (b) inpatients who require restoration of the occlusion, and (c) patients whose condition permits extubation at the end of surgery [78]. The neck pathology and normal anatomy can be easily diagnosed using 3-D reconstruction of this submental region to prevent complication of submental intubation.

The patient with a difficult airway is also at high risk for postoperative complications. Following surgery, the mucous membranes are edematous, the soft tissues are swollen, and the airway may be compressed. Neck expandability is relatively low, and even a small hemorrhage in the region could result in airway compromise [79] (Figs. 7.10 and 7.11).

In intubated patients with maxillofacial trauma, extubation should be deferred until the edema subsides. During extubation, the patient

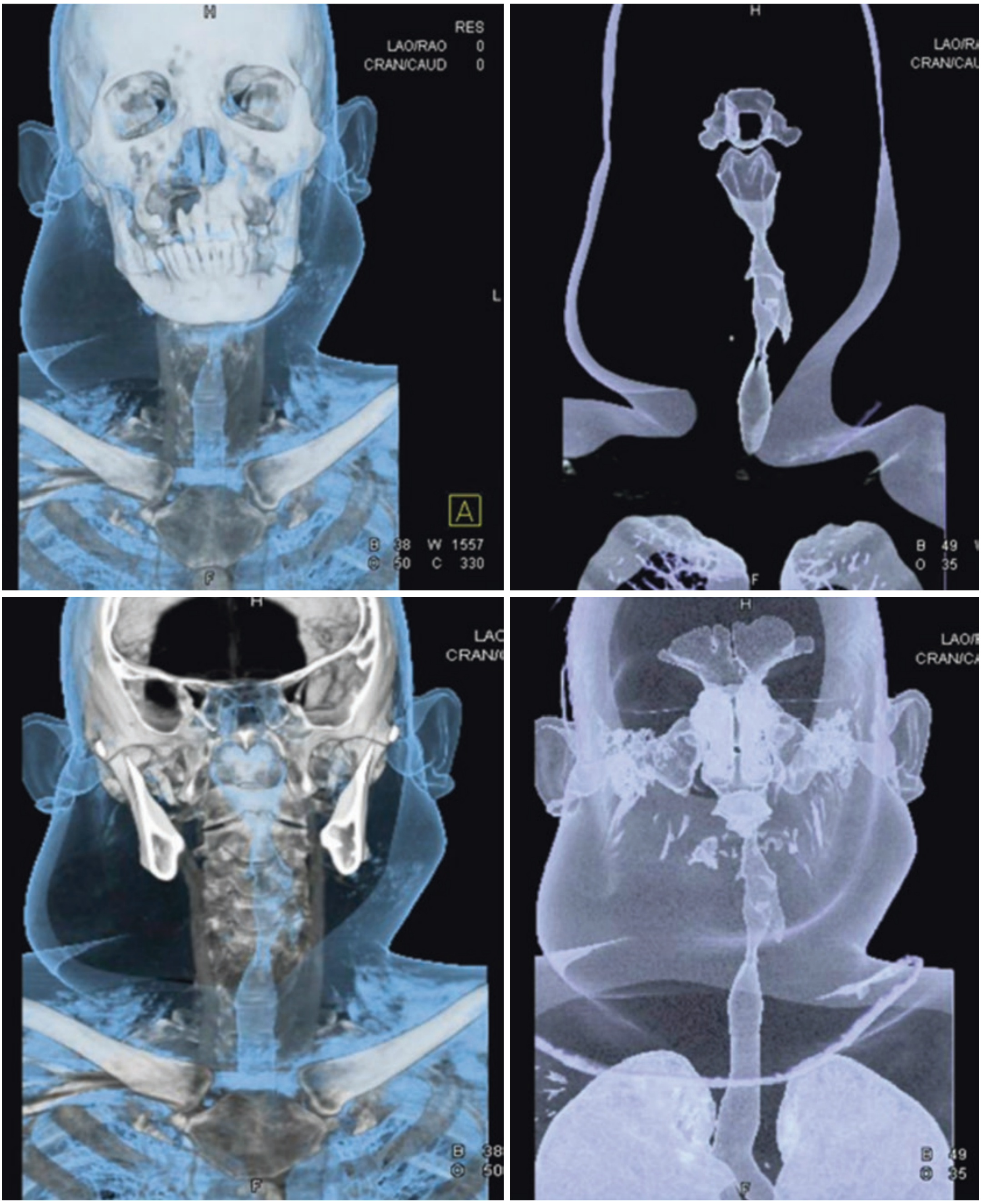


**Fig. 7.8** A cancer maxilla patient with loose teeth on the right side. Lymph nodal sizable metastatic adenopathy, resulting in significant airway displacement to the left demonstrated clearly on the VRT models

should be monitored closely and the care providers should be prepared for the possibility of reintubation. It is important to prevent nausea and vomiting because of the risk of gastric content aspiration [80] (Figs. 7.10 and 7.11).

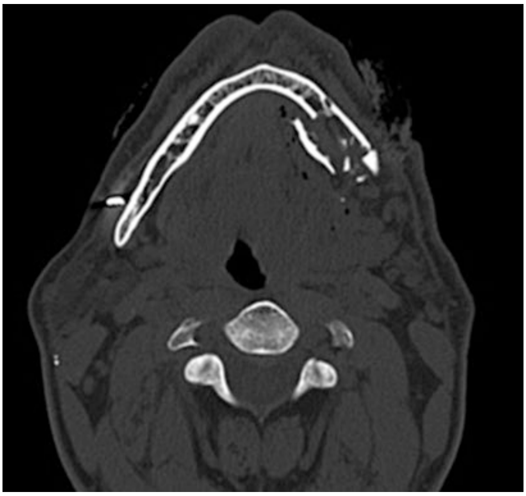

**Fig. 7.9** Mandible CT scan axial view bone window settings with comminuted fracture of the left hemimandible with soft tissue surrounding edema and swelling resulting in partial obstruction and significant encroachment of the related airways

Pedicle screw fixation in the upper cervical spine is a difficult and high-risk procedure. The screw is difficult to place rapidly and accurately and can lead to serious injury of spinal cord or vertebral artery. The use of an individualized design 3-D printing navigation template for pedicle screw fixation in the upper cervical spine has been reported as a safe procedure, with a high success rate in the upper cervical spine surgery [81].

## 7.11 Virtual Surgical Planning (VSP)

Virtual surgical planning and 3-D printed models have been found to be more attractive and useful techniques recently. The usefulness and improvement of these models are beneficial tools that may be used to help the surgeon in the pre-surgical and intra-operative phase because it offers the surgeons the accuracy and precession of normal anatomical repair and reconstruction.


**Fig. 7.10** (**a**) Upper lip and nose laceration preoperative. (**b**) Upper lip and nose laceration postoperative


**Fig. 7.11** (**a**) Facial laceration compromising the upper airway. (**b**) Facial laceration postoperative

### 7.11.1 Orbit and Sinus Surgery

Virtual surgical planning and 3-D printed models have been found to be especially useful for orbit and sinus surgery. The use of these models is beneficial that may be used to help the surgeon in the pre-surgical and intra-operative phases. This method can improve the precision and accuracy of the implant and hardware placement, preserving the neurovascular complex of the orbital area. Using virtual surgical planning in conjunction with 3-D, patient-specific implants can give surgeons an effective therapeutic solution in treating complex shape defects or secondary surgery for orbital reconstruction [82].

### 7.11.2 Maxillofacial Reconstruction

Virtual surgical planning (VSP) and 3-D printed models have proved to be very useful in complex maxillofacial reconstruction. In the area of mandibular reconstruction, this technique has been used in the shaping of free fibular flaps. With data obtained from high-resolution CT scans of the maxillofacial skeleton and lower extremity, stereolithographic models can be fabricated, whereas virtual surgery allows fabrication of mandible and fibular cutting guides and a plate-bending template for shaping the fibula to best approximate the desired shape of the reconstructed mandible [83]. By using these planning methods, intraoperative time is decreased as bending and shaping of the plate and fibula can now be done with precision to match the dimensions of the defect, and not freehand as is the traditional technique. This is extremely valuable in decreasing ischemia time; the accuracy of the fibular osteotomies allows better shape and optimizes the position of the bones for eventual prosthetics rehabilitation [84, 85].

### 7.11.3 Mandibular Reconstruction

The use of 3-D printed models and VSP in mandibular reconstruction consists of a planning phase, modeling phase, and surgical phase [86]. High-resolution CT scans of the craniofacial skeleton and lower extremities are obtained. These images are forwarded to a company specializing in VSP. After an online meeting to discuss the case, a virtual resection of the mandible is performed. The 3-D image of the fibula is superimposed on the defect, and virtual osteotomies are performed. In the modeling phase, a stereolithographic model is fabricated (3-D model printed), as well as cutting guides for the mandible and fibula. Finally, in the surgical phase, the mandible cutting guides are used to guide resection of the lesion. A temporary external fixator may be placed to ensure that the remaining segments are kept in proper position. Otherwise, more commonly, a reconstruction plate and drilling of holes at appropriate locations on the remaining mandible are placed prior to performing the osteotomies. The reconstruction plate is removed and the cutting guides are placed in preparation for the osteotomies. The fibula is shaped using the fibular cutting guide, prior to or after division of the pedicle. The shaped fibula is used to reconstruct the mandible [87].

### 7.11.4 Midface Reconstruction

Virtual surgical planning with stereotactic navigation and 3-D printed models has been used for midface reconstruction with free fibular flaps [88]. Physical models are created using rapid prototyping techniques. Titanium plates are then bent to match the contours of the fibular flap and facial skeleton. In addition, custom-cutting guides are fabricated for the fibular osteotomies. Navigation is performed with fiducial markers on the patient's forehead, subsequently replaced by a navigation array fixed to the patient's calvaria at the time of surgery. Virtual surgical planning has also been used for complex reconstruction of the midface and mandible with two separate free fibular flaps [89]. In extensive defects, where the native anatomy of the face is distorted by trauma or irradiation, the amount of bone required for reconstruction can be underestimated. Virtual surgical planning and 3-D printed models obviate this problem by allowing the visualization of the pre-injury 3-D anatomy to aid planning of osteotomies preoperatively, saving valuable surgical time [90].

### 7.11.5 Total Replacement of the Temporomandibular Joint

Custom alloplastic total joint replacement implants of the temporomandibular joint (TMJ) have been used for the treatment of TMJ ankyloses in a single-stage surgery. Similar to the workflow for other applications in VSP, fine-cut CT scans of the TMJ and maxillomandibular complex are obtained, followed by the creation of 3-D models by a company experienced in VSP. Through an interactive online meeting, virtual surgery is performed, consisting of the resection of the ankylosed segment. The joint replacement is then designed, first with planning of the fossa component with a custom-made flange to fit the patient's zygomatic arch, followed by design of the mandibular ramus component. Accurate visualization of the 3-D anatomy of the mandible ensures that the prosthesis and fixation avoid the inferior alveolar nerve and tooth roots. Finally, a virtual 3-D prosthesis is designed. Screw holes can be placed away from vital structures such as the inferior alveolar nerve and maxillary artery and over the best bone thickness for fixation. In addition, measurement of screw depth is obtained to ensure that screw placement is bi-cortical for all holes [91].

## 7.12 Three-Dimensional Printing in Maxilla Facial and Oral Surgery

(Refer to Chap. 11 for more details.)

## 7.13 Future Plan

Virtual surgical planning has a clear role in facial transplantation where bone is a necessary component in the completion of the reconstruction [92]. If a Le fort III segment is planned, cutting guides and templates are fabricated for the recipient and for the donor at the appropriate times. Additionally, VSP can be used in surgical navigation. The use of VSP for this indication ensures a more accurate outcome while minimizing ischemia time when microvascular flaps are used for the reconstruction [93]. Also future perspectives are simulation of multiple osteotomies and moving various fragments to achieve virtual surgery for any kind of oral and cranio-maxillofacial surgery [94].

## 7.14 Conclusion

In conclusion, MDCT examination, as well as the post-processing techniques, has the following points to be addressed and thoroughly commented on dental assessment (panoramic-like view using curved MPR to create an orthopantomogram (OPG) for absent teeth or loosening or loss of the normal lamina dura. Denture artificial teeth or loose implant/prosthesis. Temporomandibular joint (TMJ) (ankyloses, dislocation, osteoarthrosis, osteomyelitis, or fractures).

Computer-assisted surgery (CAS) planning was implemented in CMF surgery so that the complex anatomy of the patient can be understood, and that the surgical task can be improved preoperatively. Orthognathic surgery represents an important part of CMF surgery and allows for correction of different dental and maxillofacial dysmorphoses, asymmetric faces, or craniofacial syndromes by cutting and moving the maxilla and/or the mandible according to a treatment plan.

Navigation system indications in cranio-maxillofacial surgery, that is, navigational surgery, are a helpful tool for minimally invasive surgery, increasing radicality of tumor treatment, preventing damaging of vital structures, and leading the reconstruction to preplanned, defined results.

3-D printed models have been used in cranio-maxillofacial surgery, bringing many benefits during planning and surgical phases with mainly advantages reported as improvement in precision and reduction of surgical time.

This technique can be used for planning mandibular distraction osteogenesis in a neonate with Pierre Robin syndrome, tumor resection, and reconstructions. Three-dimensional models are fabricated based on CT scan data of the craniofacial skeleton and distractors to ensure that the planned osteotomies would allow achievement of the planned distraction vector. One valuable advantage in DO is to allow preplanning of screw position and lengths to ensure bi-cortical screw placement, away from the inferior alveolar nerve, improving the efficiency and accuracy of placement of the distractors [90].

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