Three Basic Steps for Applying Digital Images to Oral and Facial Surgery

Michelle ZAWARTKA[1], Jing WANG[2], Bin ZHENG[1]

In this paper, the authors discuss three basic steps related to the application of digital technology to reconstructive oral and maxillofacial surgery (OMFS), in an effort to improve surgical outcomes. These steps include acquiring digital images, processing images in order to build three-dimentional structures, and mapping images to patient anatomy for guided surgery. For each step mentionioned, available technologies and barriers that need to be overcome are discussed. Digital technology is still under development and it has begun to merge into surgical care. Surgeons and computer scientists are required to work together to find solutions when facing such challenges.

Key words: *3D reconstruction, digital images, image-guided surgery, image segmentation, oral and maxillofacial surgery, surgical innovation*
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In the era of digital technology, medical images are used in conjuction with radiology. Although mainly used by radiologists for making a diagnosis, imaging can now be used in the operating room where it can assist surgeons in performing surgical tasks more effectively and safely. To integrate medical images into surgical procedures three steps are necessary to transform images into reality which include, acquiring a series of two-dimensional (2D) digital images from patients for reconstruction of three-dimensional (3D) anatomy; creating 3D images for pre-surgical planning; and mapping the image to the surgical site to guide on-going surgical procedures in the operating room. In many ways, oral and maxillofacial surgeons are leading innovation in terms of integrating digital technology into their surgical practice. This paper will review the major achievements of surgeons and scientists for improving surgical outcomes through advancements in digital technology in the field of reconstructive oral and maxillofacial surgery (OMFS). Digital technology is still under development and challenges are unavoidable as it begins to merge into surgical care. For each achievement mentionioned, the limitations and barriers that need to be overcome are discussed.

1 Surgical Simulation Research Lab, Department of Surgery, University of Alberta, Edmonton, Alberta, Canada.
2 Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, P.R. China.

Corresponding author: Dr Bin ZHENG, Endowed Research Chair in Surgical Simulation, Department of Surgery, Faculty of Medicine and Dentistry, University of Alberta, 162 Heritage Medical Research Centre, 8440 112 St. NW. Edmonton, Alberta, Canada T6G 2E1. Tel:780 492 6963. Email: bin.zheng@ualberta.ca

Acquiring digital images

An important step for reconstructing anatomy of a patient undergoing an oral or facial procedure is to correct the malformation or defects on the skeletal structure. Traditionally, the facial skeletal structure was visualised by plain radiograph images. The anatomy of a patient was flattened in the anterior, posterior and lateral radiograph films in order to provide 2D images. Surgeons needed special training to identify key landmarks, which provided rough information regarding guiding surgery. Having 2D images to guide a 3D plan and surgery may be problematic. A major issue with 2D images is that they are incomplete, providing insufficient data on the depth and shape.

Computed tomographic (CT) images can slice the human body with controlled radiographs and provide cross-sectional images on the head of a patient[1]. The reduction of a radiation signal occurs when it passes through tissue. Instead of having the image placed on a film, it can be picked up by a charged coupled detector (CCD) and can be saved in the digital format for further manipulation[2]. A series of cross-sectional CT images provide the foundation for supplementary image processing, including 3D reconstruction, segmentation,

Fig 1 Three-dimensional facial image acquired using the 3DMD system for pre-facial surgical planning.

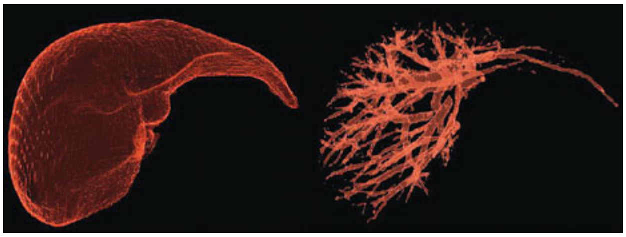

Fig 2 A new segmentation algorithm developed in the SSRL displaying the hepatic venous system inside the liver.

fusing of images and instrument navigation. This allows the details of depth and shape to be seen.

Cone beam computerised tomography (CBCT) is a variation of CT imaging where the image is captured through a round- or rectangular-shaped beam of radiation instead of a fan-like shape[3]. This technique collects a large amount of information after a single-rotation scan and decreases radiation exposure. It has gained popularity and has been used in OMFS for preoperative assessment, dental implant planning and temporomandibular joint (TMJ) assessment[4]. CBCT has been found to be easier, cheaper and more efficient to use than regular CT machines[3-5].

Despite creating a 3D structure from CT images, a laser scan can also be used to create a 3D structure on the contour of the head. The laser measures complex geometries to create cloud points, which are then merged together to produce the final 3D digital representation[6]. It is of low power, fast and can be used in conjunction with CT imaging[2,7]. One benefit of laser technology is the ability to create plaster dental models for each individual patient[2,8].

Three-dimensional photography is a newly developed area in medical imaging, which allows high-quality analysis of the facial surface and soft tissue (Fig 1). This can be beneficial in children with facial deformities as it can be used in pre-surgical planning. It is able to estimate distances of specific landmarks on the face, and can assess and monitor preoperative and postoperative changes[9].

3D reconstruction and segmentation

In medical imaging, the process of creating 3D models from a set of images is called 3D reconstruction. First a series of 2D images are acquired, in which computer algorithms can read the pixels saved on each cross-sectional CT image and can connect them logically to create a 3D structure of the scanned anatomy. To build such a model, the pixels within the digital image need to be partitioned into multiple segments. This segmentation allows discrimination between different types of soft tissues and simplifies an image's representation for easier[10] analysis. A perfect analogy of this digital process is separating soft tissue from skeletal structure through dissection, layer by layer. In OMFS, reconstructing a skeletal structure from CT images is not as complex as one would think. This goal can be achieved with many commercially available programs like Mimics, Slicers and Maya.

During the process of creating a 3D structure, it is important to assign each pixel in the image to the correct object i.e. anatomic structures. This process is called segmentation. In some oral and facial cases, precise image identification can be challenging if an image has areas that share similar characteristics and can be affected by background noise, weak edges or poor pattern recognition[10]. This could be the case with a locally invasive carcinoma with an ill-defined border or in congested areas that have many structures in close proximity. With improved technology and computer algorithms, image segmentation can help differentiate these areas by using features including contrast, gray level and textural properties[10]. Using these techniques can help determine the size and border of a soft tissue tumour for appropriate excision or response to treatment[11].

For a carotid artery tumour, 3D reconstruction and segmentation are used to identify affected branches and to determine the best approach prior to surgery. At the Surgical Simulation Research lab (SSRL) at the University of Alberta, scientists have developed a new computer algorithm to segment the vessel system inside the liver (Fig 2). With this improved segmentation technology, surgeons can estimate safe distances to nearby vital structures and propinquity to areas of poor visualisation[12].

Besides examining the interior of an anatomic structure, 3D reconstruction helps improve quality of facial surgery. Facial defects can be more difficult to treat due to the closeness of neighbouring structures and the complexity and variation of surrounding tissues. Now with 3D images, visualisation of a patient's anatomy can be significantly improved, which can further improve the perception of surgeons on the surgical site for generating a better surgical plan[13,14]. Logan et al compared the use of virtual surgical planning (VSP) with freehand reconstruction of a mandible[15]. They found that the surgeons who used VSP had increased accuracy and consistency of their reconstructions. Surgeons also found the structure was more functional for future dental implants[1,15]. This can improve navigation, precision and decrease errors during complex surgery involving mobile structures[8,13,16,17].

In 3D reconstruction, clinicians have the ability to manipulate images on screen even before the physical model is printed out. The surgeon is able to rotate the 3D composite in order to identify landmarks, visualise unique anatomy and to define optimal cutting area for surgical planning. The proposed model can be virtually altered, allowing the surgeon to virtually cut bone, reshape the model and reposition segments immediately to find the optimal blood supply[8,16]. With virtual images, it becomes more accessible and easier to communicate surgical plans between specialties[7].

In OMFS, reconstruction is not only performed to correct altered anatomy, but also to rebuild a structure that is missing from the face due to varied reasons. For instance, in a congenital malformation or an area destroyed from trauma, 3D CT images and reconstructions augment the surgeon's visualisation and assessment of the defect[18]. Ideally, in some of these situations, copying images from the healthy side can provide functional reconstructions (Fig 3). Using the mirror image is helpful for guiding the facial surgery, as the anatomy is symmetrical[19].

Three-dimensional image reconstruction and segmentation require the skills and training beyond that of a healthcare provider. There are multiple steps taken even before a surgeon is able to start a surgical plan. It is important to have multidisciplinary teams consisting of engineers, information technology (IT) personnel and health care workers working in collaboration with each other to obtain the final result.

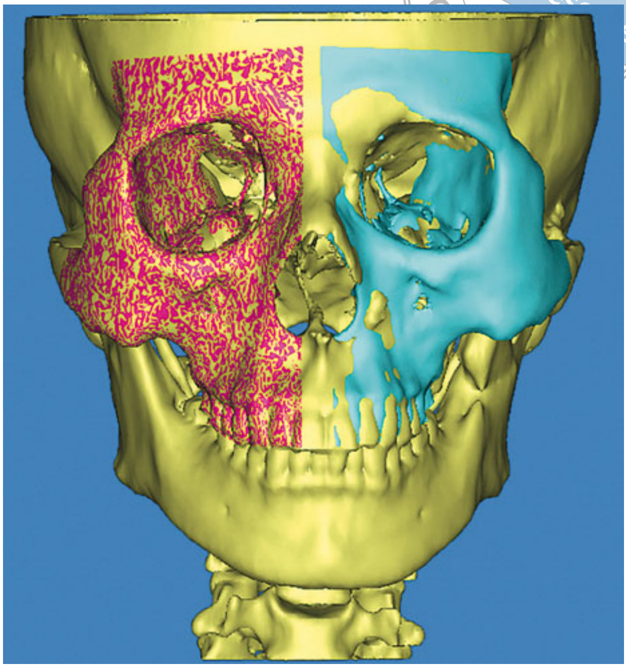

Fig 3 Defects of the left maxilla and zygoma on this trauma patient were reconstructed using 3D imaging by surgeons at the Peking University School and Hospital of Stomatology. The image was obtained by mirroring the anatomy of the right maxilla and zygoma.

Fig 4 Lesions on the right maxilla and zygomatic bone were reconstructed using a fibula bone printed by a 3D printer. The tangible model enhanced the surgical outcome and saved on operating time.

Mapping image to patient anatomy for guiding surgery

During the pre-surgery phase, mapping images to a unique surgical site can also be printed out as a 3D

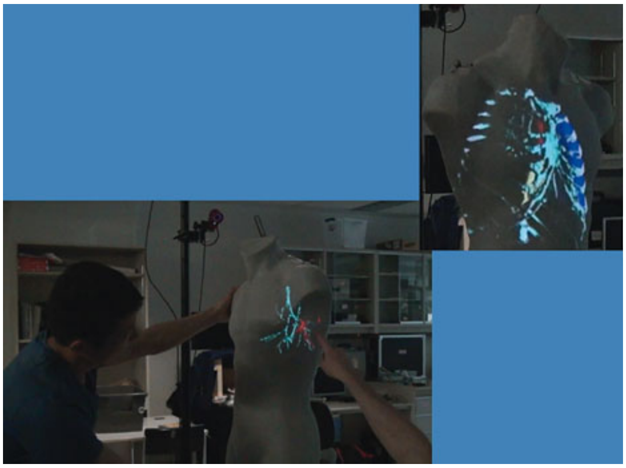

Fig 5 Scientists at the SSRL superimposed 3D images on to the chest area of a mannequin for pre-surgical planning.

Fig 6 Scientists at SSRL superimposed 3D images on to the abdominal area of a human subject for pre-surgical planning.

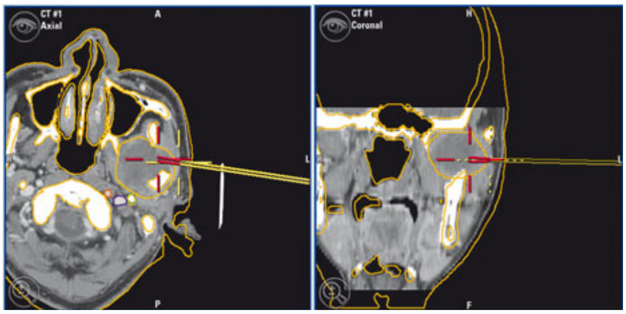

Fig 7 3D images helped guide the biopsy of a tumour on the base of a patient's skull. The navigation technique tracks the position of the biopsy needle and prevents injury to important vessels and nerves surrounding the surgical area.

model. When using the fibula free flap method to replace a mandibular lesion, a 3D printed model can transform images into a tangible model (Fig 4). Based on these models, taking precise measurements and preparing implants can be accomplished to plan an entire surgical procedure with more confidence[8,20]. Having the ability to manipulate and appreciate palpable structures to learn a patient's anatomy has aided in ensuring precision during harvesting, shaping and placement of fibular sections[15]. With the dramatic evolution of pre-surgical planning, the duration of the operation has decreased, which has improved surgical safety[16,21].

More challenges for image mapping to patient anatomy occur during surgical phases. Instant display of the image on top of the surgical anatomy can be a thoughtful technique for improving surgical safety and accuracy while in the operating room[22]. There are two challenges that need to be overcome when applying 3D images directly to the operating site in order to guide surgery. First, it is necessary to project the images on top of the anatomy with a high level of accuracy. This would include having a 1:1 size ratio and tracking any movement of the site during surgery. Second, the movement of surgical instruments also need to be tracked[21]. Once the position of the instrument tip can be monitored and the positional data is superimposed onto the pre-constructed 3D image, then the system can warn the surgeon if the instrument reaches a high-risk area. At the SSRL, the technology for superimposing a patient-specific 3D image on top of the patient's body for surgery in the thoracic (Fig 5) and abdominal cavity (Fig 6) has been developed. This development will help guide surgery and hopefully be pivotal in the future of OMFS.

Mapping 3D images to the real surgical site can significantly improve patient safety during OMF surgery (Fig 7), for example, when performing surgery at the base of the skull i.e. a transphenoidal hypophysectomy for a pituitary mass, the global positioning system Suretrack (StealthStation System, Medtronic, Minnesota, USA) can help locate the lesion[8]. Instrument positions are detected by cameras and displayed on the computer model and can increase reliability[1,21,23]. Similar systems have been developed, such as Instatrak, VoNaviX and Stryker Navigation System[8]. Yu et al compared preoperative and postoperative images via facial landmarks in cases that used the Stryker system and found that the error was < 1 mm and had improved accuracy[19]. Image mapping has been used in orthognathic surgeries such as cleft lip and palate reconstruction[17].

In summary, OMFS has pioneered the use of digital technology in surgery and have made excellent strides with regard to improving accuracy and functionality of reconstructed implants for oral and facial defects. It has improved treatment for patients creating individually customised implants. It shows promising techniques and technology for the future. It will also encourage the development of smaller, faster and inexpensive imaging equipment. Other specialties have the ability to take this technology and modify it for their own specific needs, with the hope that they can integrate it into their practice and improve their surgical outcomes.

Conflicts of interest

The authors reported no conflicts of interest related to this study.

Author contribution

Dr Michelle Zawartka for the literature review, data interpretation and for writing the manuscript; Dr Jing Wang for the graphic design, concept development and for critical comments on the manuscript; Dr Bin Zheng for the concept development, literature review, data interpretation, graphic design and for writing the manuscript and the final revision.

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