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# Application and prospects of computer-assisted surgery in oral and maxillofacial oncology

Xin Peng [a], Julio Acero [b,*], Guang-Yan Yu [a,*]

[a] Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing 100081, China
[b] Department of Oral and Maxillofacial Surgery, Ramón y Cajal and Puerta de Hierro University Hospitals, University of Alcala, Ramón y Cajal Research Institute (IRYCIS), Madrid 28034, Spain

The primary treatment modality for tumors affecting the oral and maxillofacial region is surgery. Surgical treatment of tumors affecting this region is a challenge and poses relatively high surgical risk, especially in lesions affecting the deep regions of the head and the neck due to the complex anatomy of this region including structures of great importance such as the internal carotid artery, the internal jugular vein, and the cavernous sinus at the skull base, the cranial nerves and the orbital contents with the eye globes, extraocular muscles, and the lacrimal gland. Oncologic resection often results in devastating defects in the oral and maxillofacial region, which adversely affect patients' facial appearance and important functions such as speech, chewing, deglutition, or vision and significantly impact patients' quality of life. In order to obtain a good result concerning tumor excision in the oral and cranio-maxillofacial region as well as a correct aesthetic and functional reconstruction, an adequate presurgical evaluation of the patient and accurate planning of the surgical resection and the reconstructive approach must be carefully designed.

Conventional surgical workflow for tumor ablation and reconstructive surgery relies mainly on surgeons' experience and subjective judgment based on the clinical and 2-dimensional (2D) radiological findings. Furthermore, the "experience-driven" treatment is largely dependent on surgeon's clinical experience, therefore leading to uncertainties and relatively less predictable and accurate surgical outcomes.

The technological innovations related to the new digital age have impacted very especially in the field of cranio-maxillofacial surgery. Computer-assisted surgery combines traditional surgery with 3-dimensional (3D) imaging reconstruction technique and 3D mapping techniques with multimodal image-fusion technology for preoperative virtual planning of tumor excision and reconstruction, computer-assisted design and manufacturing (CAD/CAM) of 3D models of the patient or patient-specific implants, surgical navigation and digital intraoperative imaging, mixed reality, and robotic surgery. The new technologies marked a breakthrough in traditional surgery by providing more precise diagnosis and helping the surgeon to enhance treatment safety as well as to obtain better aesthetic and functional results after treatment of oral and maxillofacial tumors thus significantly improving the surgical outcomes and the patients' quality of life [1,2]. The application of 3D imaging reconstruction and positioning system provides the surgeon with a direct 3D visualization of the tumor and its relationship with adjacent vital anatomical structures such as the internal carotid artery, the internal jugular vein, or other vital structures. Accurate information on tumor extension or destruction of the adjacent hard and soft tissues helps to improve surgical safety by avoiding potential iatrogenic trauma to the adjacent vital structures thus minimizing damage to the physiological function of the adjacent original healthy tissue and the corresponding facial appearance [3,4]. Moreover, big data technologies and artificial intelligence will offer new applications in the field of surgery opening new frontiers in the diagnosis and management of tumors in this field.

Computed tomography (CT) scan, magnetic resonance imaging (MRI) and positron emission tomography (PET-CT) scan are the common diagnostic imaging modalities used to complement clinical diagnosis and staging of oral and maxillofacial tumors. While each single imaging modality has its benefits and limitations, multimodal image-fusion technique processes and integrates relevant valuable information by extracting and merging it from multiple modalities. This allows us to precisely visualize the tumor extension and its relationship with vital anatomical structures without having to shift between different imaging modalities. Multimodal image-fusion technology provides more detailed and accurate information with regards to extension, size, and location of the tumor, and more precise diagnosis increasing the sensitivity in the detection of cervical lymph node metastasis and occult primary tumors especially those located in deep spaces of the oral and maxillofacial region, therefore improving the final treatment outcomes. Furthermore, misdiagnosis due to local anatomical structural changes and tissue fibrosis following surgery and radiotherapy is reduced. This technology also provides reliable diagnostic information in areas affected by metallic artifacts caused by dental metallic restorations [5,6].

Computer-assisted design (CAD) technology enables clinicians to perform virtual surgical planning (VSP) including virtual tumor

* Corresponding authors.
E-mail addresses: j-acero@telefonica.net (J. Acero), gyyu@263.net (G.-Y. Yu).

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resection and reconstruction following 3D planning using computer software based on patient's CT scan or MRI datasets. VSP allows surgeons to design and plan osteotomy lines and reconstruction virtually, to ensure ideal restoration of facial symmetry, bone volume, and dental arch positioning to restore masticatory function allowing prosthodontic rehabilitation [7].

Based on the preoperative virtual surgical planning, osteotomy cutting guides and osseous flaps shaping guides can be designed and 3D printed, which allows accurate translation of virtual surgical planning into the surgical reality. The final virtual design of the reconstruction can be printed into rapid prototype models to allow preoperative contouring of individualized reconstruction plates or titanium meshes. Current technologies also allow the virtual design and direct 3D manufacturing of patient specific titanium plates or other customized implants, which reduces the dependence on the operator's experiences thus simplifying the surgical procedures, reducing total operating time, and enhancing final surgical accuracy and safety [8,9].

Surgical navigation technology connects both virtual surgical planning and actual surgical procedures by utilizing digital image processing and precise mathematical calculation in computer software and combining stereotactic technology. Navigation-assisted surgery (NAS) is especially useful in complex anatomical areas like the cranio-maxillofacial region and enables accurate positioning of each osteotomy plane during tumor resection, hence achieving precise resection margins consistent with the preoperative virtual surgical planning. Furthermore, surgical navigation also enables surgeons to transfer VSP and facilitates the positioning of implants (usually titanium meshes or plates or polyetheretherketone (PEEK) implants) and osseous flaps in real-time, therefore achieving normal occlusion and symmetrical facial contour. Previous studies showed that NAS significantly improved the accuracy of functional reconstruction in maxillary defect with free fibular flap, in which the average deviation between the actual position and virtual surgical planning of navigation-assisted maxillary tumor resection and primary reconstruction with free fibular flap was less than 5 mm [10].

Skull base tumors are often malignant in nature being preoperative diagnosis often difficult. Conventional needle aspiration biopsy provides poor diagnostic yield and is relatively of high risk due to the deep tumor location and the potential relationship to critical anatomical structures. As mentioned, preoperative tumor mapping can be performed and important anatomical landmarks including neighboring vital structures can be identified based on the preoperative high-resolution CT DICOM data. Utilizing the image-guided surgery software, the trajectory path and depth of needle aspiration can be planned preoperatively and executed using navigation-assisted core needle, which further enhances the safety and diagnostic yield. Similarly, based on the tumor mapping and identification of the adjacent vital structures, through real-time display, intraoperative navigation can contribute to a safe resection ensuring to obtain accurate surgical margins while protecting the adjacent vital anatomical structures like blood vessels and nerves, thus increasing the safety of the skull base tumor surgery. Intraoperative imaging, including CT and MRI, can be helpful in oral and maxillofacial oncologic and reconstructive surgery in order to check the accuracy of the reconstruction and also to confirm if the extension of the resection includes the planned margins [11–13].

Mixed reality technology is an emerging holographic technology, which permits users to interact with the projected real-time 3D holograms in reality. Through intraoperative image registration, operators and assistants are able to directly visualize the holograms of tumor and adjacent anatomical structures on the surgical field, thus improving surgical accuracy. The combination of mixed reality and surgical navigation technologies can provide complementary advantages of both technologies, in which the inaccurate and length registration in mixed reality can be overcome by the advantage of surgical navigation which provides accurate registration. Mixed reality combines the advantages of both virtual reality and augmented reality technologies, which allows users to interact with the projected holograms in real time. Mixed reality has been applied in maxillofacial tumor resection surgeries, and accurate tumor resection is achieved, in which the average deviation between preoperative virtual surgical planning and actual osteotomy planes ranged between 1.68 ± 0.92 mm [14].

Surgical robots enable precise manipulation of surgical instruments which is often beyond human capabilities, and reduce surgical complications, which is in line with the concept of minimally invasive surgery. The application of robotic-assisted surgery in oropharyngeal tumor surgery allows precise tumor resection by utilizing high-resolution images, without the need for transfacial incision and access mandibulotomy. In addition, this technology also reduces intraoperative bleeding, the need for elective tracheostomy, and postoperative complications, resulting in faster postoperative recovery. No recurrences were noted during a mean follow-up of 21.6 months, and patients were able to resume normal oral functions post-operatively [15]. However, due to the limited surgical access and delicate hard and soft tissues in oral and maxillofacial region, meticulous and careful handling is important. Therefore, master–slave robots might not be suitable for maxillofacial surgery, while the clinical application of robotic arm navigation system requires further studies and validation.

Despite of the numerous benefits of computer-assisted surgery, technological innovations have still limitations. Computer-assisted surgery primarily is a tool to assist surgeons and the ideal treatment outcomes require detailed preoperative planning. While computer-assisted maxillofacial surgery allows surgeons to evaluate the bony structures pre- and post-operatively, thus enabling objective measurements of the surgical accuracy, it is challenging to objectively measure the surgical accuracy in soft tissues due to the mobile and deformable nature of soft tissues. Nevertheless, the surgeons are still able to identify and orientate the tumor and adjacent vital structures such as carotid arteries, aided by computer-assisted surgery intraoperatively, thus improving surgical safety. Computer-assisted surgery can facilitate surgeons in the harvest of soft tissue free flaps, obtaining the accurate volume of the soft tissue free flaps for reconstruction of maxillofacial defects following tumor ablation. The application of computer-assisted surgery in soft tissue surgery and treatment of temporomandibular joint (TMJ) diseases requires further studies. The image-guided surgery software and clinical hardware are often expensive, while the technical execution is relatively complex and requires specific training. Insufficient clinical experience and any incorrect operation may even prolong the operating time and increase the complexity of the operation, therefore popularization of this technology remains challenging. Further application of robotic surgery is yet to be explored as it lacks proprioception and the feedbacks and sensitivity of fine movements remain relatively poor. The precise application of computer-assisted surgery technology relies on the development and integration of both medical and engineering industries. Although the current commercial CAS software is equipped with numerous functions, there are still a number of unsolved problems practically, thus requiring further software updates. The current surgical navigation is constantly being updated and upgraded to allow wider applications in different surgical scenarios.

Computer-assisted surgery in oral and maxillofacial oncology is promising, having contributed to improving the accuracy and safety of surgical procedures in this challenging area (Fig. 1). Many new applications are still being developed at present. Mixed reality technology, artificial intelligence and big data platforms for

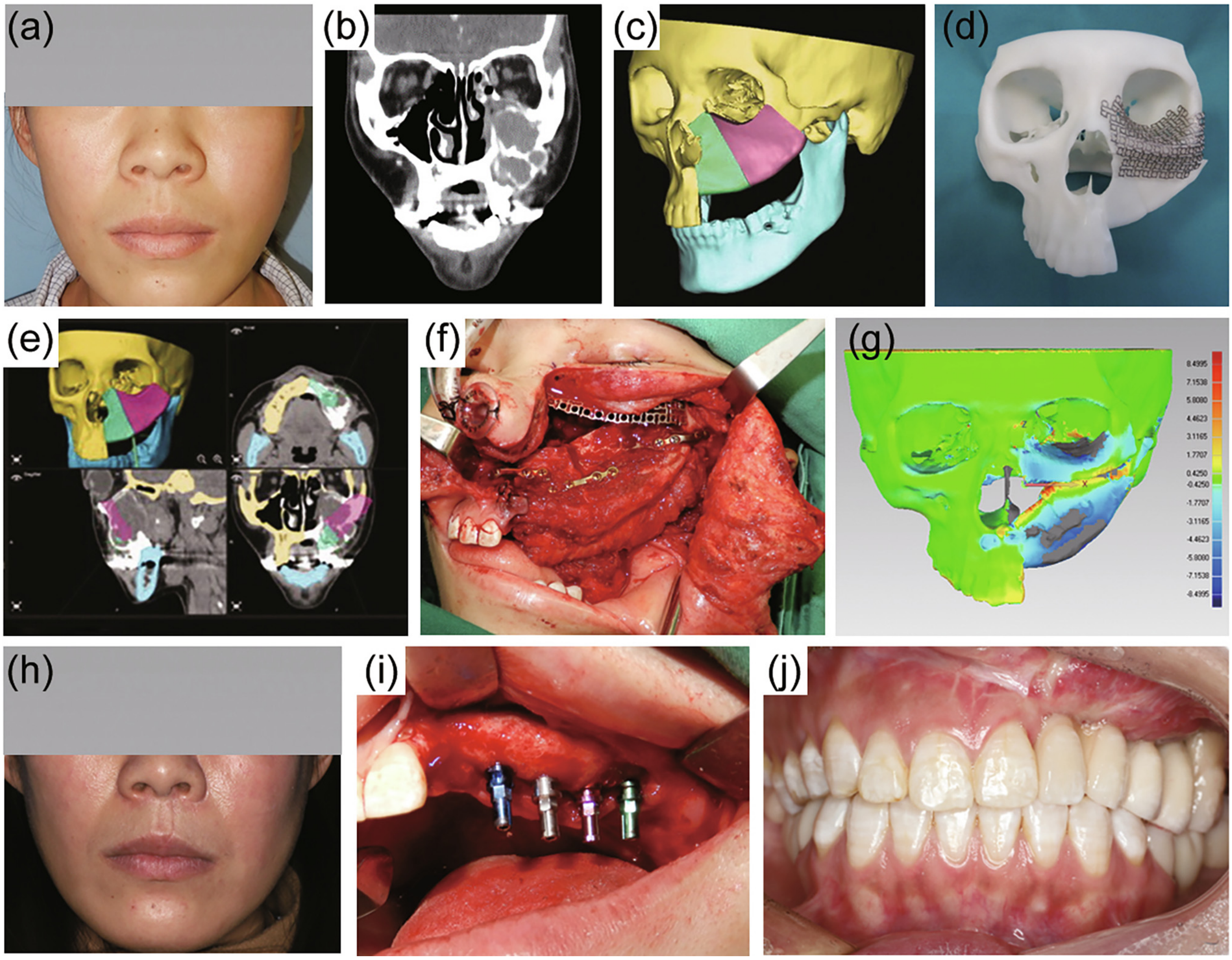


**Fig. 1.** A female patient diagnosed with myxoma. (a) Preoperative facial appearance. (b) CT showing osteolytic destruction of the left maxilla which involved the floor of the orbit. (c) Computer-assisted virtual planning included tumor resection with total maxillectomy and iliac bone free flap reconstruction. (d) 3D stereomodel was printed based on the computer-assisted design and a patient-specific titanium mesh was performed on the model for the floor of the orbit reconstruction. (e) The surgery was performed under the assistance of computer-assisted navigation system. (f) The maxillary defect was repaired with an iliac bone flap and the preformed mesh. (g) Color map of pre- and post-operative (1 year after surgery) maxilla model showed good consistency between virtual planning and actual surgery. (h) The facial symmetry was satisfactory at 1 year after surgery. (i) Dental implants were placed after the correct iliac bone flap healing at 2.5 years after surgery. (j) Postoperative intraoral view after dental prostheses were finished at 3 years after surgery.

diagnosis and treatment, and specific surgical robots for oral and maxillofacial surgery are prospective and potential research directions. Thus, strengthening the team with professional development training is necessary to popularize the use of computer-assisted technology and to improve the diagnosis and treatment in oral and maxillofacial oncological surgery.

## Conflict of interest

The authors declare that they have no conflict of interest.

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Xin Peng is Professor and Vice Director of Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology. His research interest includes oral and maxillofacial oncology, and application of computer technology.

Julio Acero is Professor and Head of Department of Oral and Maxillofacial Surgery, Ramón y Cajal and Puerta de Hierro University Hospitals, and Full Professor of Surgery at University of Alcala, Spain. He is the past President of the European Association for Cranio-Maxillofacial Surgery. His research interest lies in head and neck oncology.

Guang-Yan Yu is Professor of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology. He is the Honorary President and Past President of Chinese Stomatological Association. His research interest includes oral and maxillofacial oncology, and salivary gland diseases.