Three-dimensional virtual surgical planning in head and neck oncology surgery

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DOI:
10.33612/diss.604892431

Publication date:
2023

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General introduction

3D Virtual Surgical Planning

In head and neck oncology the treatment often involves surgical removal of the tumour, especially when facial bones are involved. Surgical treatment of tumours located in the head and neck area can result in significant facial deformities and impaired function, like diminished capacity of speech and swallowing. In addition, surgery can be complex due to anatomical constraints and impairment of function following treatment, thereby lowering the quality of life perceived[1–4]. Nowadays head and neck oncology surgery relies on the use of three-dimensional virtual surgical planning (3D VSP), mainly when removal of bone is concerned. 3D VSP is used to improve the treatment in terms of accuracy, predictability and safety[5]. 3D VSP enables, among other things, very precise single-stage resection and reconstruction surgery. Advantages of using 3D VSP becomes apparent in the operating room as decisions regarding resection margins, location of osteotomies, precise placement of osteosynthesis materials, insertion of reconstruction flaps and implants are already decided upon before the surgery. Because of the high accuracy and predictability, 3D VSP enables the use of bone containing multi-segment composite flaps and/or implants in one combined ablative and reconstructive procedure. Current methods for 3D VSP enable multi-modality fusion of images. A cone beam CT (CBCT) often serves as the basis of a multi-modal 3D VSP, extended with data such as MRI or PET or a combination of aforementioned. Nowadays this data fusion of images is not restricted to specific scans, software, or workflow. However, the availability of data fusion enables addition of information to the 3D plan and with that new treatment and evaluation methods. While 3D virtual surgical planning has become the standard approach during the last decade in head and neck oncology, some questions remain unanswered. Introducing new technologies can solve some of these questions.

Mandibular planning, what is left for improvement?

Surgical resections of tumour in the mandible have been planned using 3D VSPs to ensure sufficient margins and plan one stage reconstructions. For reconstruction of continuity resections with intra-extraoral communicating wounds a free vascularised fibular flap is indicated[6]. 3D VSP enables high accuracy and predictability during ablative surgery [7–10]. However, there are also patients where a continuity resection is indicated because of osteoradionecrosis (ORN). ORN of the mandible is a late complication of radiotherapy (RT), where the risk of developing ORN is associated with the RT dose. Currently, the position of bone cuts for mandibular segmental resection are based on the clinical inspection of the lesion and pre-operative imaging. Moreover, surgeons often struggle with the decision of where to make cuts in the mandible and the resulting margins.

To be able to make use of the advantages of a 3D VSP and make the surgical treatment more predictable, the resection margins must be determined preoperatively and incorporated into the 3D VSP. Although there is not yet a standardized method, incorporating radiotherapy data (RT) into the 3D VSP is the logical next step. The technique to do so has already been described, it enables 3D visualization of RT dose fields in relation to the 3D model of the affected bone[11]. Applications of this technique can be used to avoid high-risk areas for osteoradionecrosis (ORN) or to determine the most optimal implant position. However, we do not yet know how useful it is to use this technique. The next step is to validate this method for use in the clinical practice, as there is not yet a strict relationship between the RT dose received on the mandible and the risk of ORN. In this thesis we aim to identify a possible relation between the received radiotherapy dose, exposed bone volume and the progression of ORN after segmental mandibular resection.

Maxillary planning, what is lacking?

In maxillary surgery the use of 3D VSP has become the gold standard as well. The accuracy of 3D VSP ensures high accuracy of surgical resections with tumour free margins[5,12,13]. As some maxillary defects are not suitable for reconstruction with bone flaps, a prosthodontics solution like an obturator prosthesis could be indicated. A challenge still exists in repairing defects in patients treated with obturator prosthesis, namely to secure the prosthesis in the maxillary defect. To enable retention for the obturator prosthesis, one strategy involves placing zygomatic implants in order to restore the jaw[14]. The main advantages of the use of zygomatic implants include the possibility to obtain immediate prosthetic support. Multiple studies have reported that immediate prosthodontic rehabilitation after ablative surgery is of benefit for the patient[15–17]. However, placement of zygomatic implants is challenging due to the limited intraoperative visibility. Accurate freehand placement of zygomatic implants is considered difficult due to the risk of malposition of the implant. In addition, it is challenging to place two zygomatic implants at the defect side because of the long drill path. A 3D VSP is used to successfully perform a one-stage tumour resection, including placement of zygomatic implants for an implant-retained prosthetic-obturator. Using a 3D VSP we gain control of each step of the surgery, including placement of the zygomatic implants. In this thesis we introduce a workflow using 3D VSP and develop surgical guides to accurately and predictable place zygomatic implants using surgical guides.

Translation of 3D VSP into surgery

Any 3D VSP requires a means for translation from the software into real surgery. Both intra-operative navigation and 3D printed surgical guides have been shown to provide an accurate translation of the 3D VSP to the surgical procedure [7–10]. In applications where surgical guides are not usable or perform sub-optimal, surgical navigation is used to translate the 3D VSP towards surgery. Surgical navigation has its roots in neurosurgery, however it is widely used in many different disciplines nowadays. Including orthopedic surgery, ENT surgery, trauma surgery, and oral and maxillofacial surgery. Although the technique of navigation systems can be fundamentally different, they all serve the same purpose. Namely orienting the surgical instruments in relation to the patient and medical imaging during surgery, to guide the surgeon to the target of surgery. Within oral and maxillofacial surgery navigation is mainly used for maxillary, orthognathic and orbital surgery, however navigation is also used for tumour resection and reconstruction, zygoma, pediatric and foreign body surgery[18,19]. One of the main drawbacks of current surgical navigation systems is the constant need for observation of the navigation screen, which is located somewhere in the operating room. This has a negative influence on the eye-hand coordination, thus lowering the accuracy of surgical procedures[20]. Moreover, in current clinical routine 3D imaging data like CT/MRI, but also 3D VSP and surgical navigation is visualised on 2D screens using regular computer screens. This, combined with the foregoing, means that a surgeon must constantly interpret information from a 2D display, reconstruct a 3D image in his mind, and then translate it to the patient’s actual surgery. All this while having his instruments follow the planned path. Recently developed head-mounted-devices (HMD) enable augmented reality (AR) by projecting a 3D image using small stereoscopic transparent screens. These projections are experienced by the user as holograms. In this thesis we introduce a newly developed workflow which combines surgical navigation with AR. This workflow aims to improve translation of the 3D VSP into the operating theatre, possibly overcoming some of the limitations of current surgical navigation systems. With the development of 3D VSP, the challenge is to optimally utilize the possibilities of multimodality, which includes the use of imaging data on the one hand, but on the other, often forgotten but just as important, the development of visualization modalities.

General aim of the thesis

The general aim of this thesis is to develop and optimize the 3D VSP workflows used for resection and reconstruction surgery in the head and neck oncology surgery.

In **Chapter 2 and 3** an overview is given of the latest developments of 3D VSP and computer-aided-design (CAD) for reconstruction of mandibula and maxillary defects, with an aim of fully prosthetic rehabilitation. Hereby we define future developments.

In **Chapter 4** a possible relation between received radiotherapy dose, exposed bone volume and the progression of ORN after segmental mandibular resection is studied. It is hypothesized that 3D visualisation may aid in determining the location of the resection planes, especially when immediate bone reconstruction is considered.

In **Chapter 5** a complete 3D workflow for immediate implant retained prosthetic rehabilitation following maxillectomy is introduced. The workflow consists of a 3D virtual surgical planning for tumour resection, zygomatic implant placement, and an implant-retained prosthetic-obturator. It is suspected that when specially designed guides are used, implants can be placed with such precision that they are suitable for immediate loading of the prosthetic-obturator.

In **Chapter 6** the surgical workflow of guided placement of zygomatic implants introduced in chapter 5 is evaluated. Zygomatic implants have been placed in 10 patients using 3D printed drill guides after maxillectomy was performed.

In **Chapter 7** a newly developed augmented reality visualization for image-guided surgery is evaluated using a 3D printed phantom. It is expected that navigation tasks can be performed more accurate and faster by replacing the existing navigation interface with an augmented reality interface.

In **Chapter 8** we report on augmented reality navigated surgery for placement of zygomatic implants. It is hypothesized that using the visualisation technique developed in chapter 7, zygomatic implants can be placed accurately in human cadavers.

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