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Integration of oncologic margins in three-dimensional virtual planning for head and neck surgery, including a validation of the software pathway

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ABSTRACT

Purpose: Three-dimensional (3D) virtual planning of reconstructive surgery, after resection, is a frequently used method for improving accuracy and predictability. However, when applied to malignant cases, the planning of the oncologic resection margins is difficult due to visualisation of tumours in the current 3D planning. Embedding tumour delineation on a magnetic resonance image, similar to the routinely performed radiotherapeutic contouring of tumours, is expected to provide better margin planning. A new software pathway was developed for embedding tumour delineation on magnetic resonance imaging (MRI) within the 3D virtual surgical planning.
Material and methods: The software pathway was validated by the use of five bovine cadavers implanted with phantom tumour objects. MRI and computed tomography (CT) images were fused and the tumour was delineated using radiation oncology software. This data was converted to the 3D virtual planning software by means of a conversion algorithm. Tumour volumes and localization were determined in both software stages for comparison analysis. The approach was applied to three clinical cases.
Results: A conversion algorithm was developed to translate the tumour delineation data to the 3D virtual plan environment. The average difference in volume of the tumours was 1.7%.
Conclusion: This study reports a validated software pathway, providing multi-modality image fusion for 3D virtual surgical planning.

1. Introduction

The use of three-dimensional (3D) virtual planning in oncologic oral and maxillofacial surgery provides more predictable outcomes in terms of tumour resection, free flap placement, and dental implant–based prosthetic rehabilitation (Gil et al. 2015, Anne-Gaëlle et al., 2011; Schepers et al., 2013). 3D planned tumour resection using either 3D printed resection guides (Wilde et al., 2015) or computer-assisted intraoperative guided resection (Bittermann et al., 2013) has been shown to provide precision for surgeons during ablative procedures. Currently, reconstruction of maxillary or mandibular discontinuities, with vascularised free flaps, is based more and more on 3D virtual planning using 3D printed surgical guides and/or intraoperative navigation (Ciocca et al. 2012, Tarsitano et al., Bittermann et al., 2013; Essig et al., 2013; Foley et al., 2013; Rana et al., 2015). An increase in reconstructive accuracy and preoperative insights are two examples of direct benefits from 3D virtually planned surgery. To translate this virtual planning to the actual surgical procedure, several methods are available. A commonly used method is the 3D-printed, bone-abutted surgical guide that is used for cutting and drilling. In addition to guided harvesting of the free flap, guided insertion of implants has been reported (Schepers et al., 2013). Computer-assisted surgery (CAS) with intraoperative navigation systems

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(e.g., Brainlab, Medtronic or Scopis) enables 3D virtual planning of tumour resection as well (Essig et al., 2011). These systems use intraoperative skull-anchored reference points for finding preoperative marked points on a magnetic resonance image (MRI) or computed tomogram (CT), and are very accurate for maxilla resection. However, these systems are not validated by the manufacturer for use in the mandible due to a lack of a fixed reference points, although the use of CAS in mandibular resection has been reported (Rana et al., 2015).

The use of a recently developed method that includes a patient-specific fixation plate enables such a rigid and predictable fixation in the mandible and maxilla; both free-flap reconstruction and implant insertion in that flap can be combined within a single surgical procedure (Narra et al., 2014; Schepers et al., 2015). This primary reconstructive technique has already been implemented for benign cases or patients with osteoradionecrosis. However, when it is applied to primary malignant cases, the risk of incorrect determination of the resection margins is a substantial clinical problem (Ciocca et al. 2012). The decision to extend the margins during the surgical procedure can imply that the surgical guides and customized fixation plate cannot be optimally used or are no longer serviceable.

Determination of oncologic margins is an applicable issue in primary malignant situations, as guidelines state that at least a 10-mm tumour-free margin is required in the case of erosive bone defects (Comprehensive Cancer Centers, the Netherlands, 2014). The potential discrepancy between planned and actual surgical margins is caused by a lack of 3D information concerning bony infiltration and tumour spread derivable from CT imaging. Hence, in current practice, the malignancy is removed during the first procedure with some uncertainty about the bony marginal status; the free-flap reconstruction is then placed in the resected area. 3D planning allows accurate surgical resections by means of 3D printed surgical guides. However, if the margin planning is not performed adequately, the 3D planning method results in uncertainty with regard to resection margins. It may be necessary to revert to the conventional surgical approach during surgery, or result in a positive bone margin. Current 3D virtual planning is regularly based on cone beam computed tomography (CBCT) or CT images. With CT imaging, the bony structures are segmented and included in the 3D virtual plan. However, because of the inherent properties of the acquisition device, MRI is preferable, to obtain more detailed soft tissue as well as tumour expansion and invasion information (tumour delineation) (Brown et al., 1994). Combining both tumour expansion and invasion information as derived from MRI with the corresponding bone anatomy from the CT provides essential decision making information concerning the degraded bony tissue and thereby the localisation of bone resection margins. To combine both image modalities, image fusion is required. By using multimodality image fusion and tumour delineation, the oncologic margins can be potentially included in the 3D virtual planning. The aim of this study is to provide a validated software pathway for the integration of tumour margins into 3D virtual surgical planning for both the maxilla and mandibula. This pathway can enable accurate primary reconstruction, even for the insertion of dental implants during primary surgery in benign and malignant cases. Development of a compatibility algorithm that enables multimodal image fusion and margin delineation during the 3D virtual planning is the first step. Acquiring data from animal cadavers with phantom tumour objects can provide insight as to whether the developed software pathway is reliable and will lead to reproducible margin data in 3D planning.

The primary outcome is a validated software pathway for comparison of the measured volume of the phantom tumour objects before and after the translation; the final aim is surgical plan software.

2. Material and methods

In this study, a validated software pathway was developed for combination of image fusion, oncologic margin delineation, 3D virtual planning of the resection, and 3D planned reconstruction of the defect. Fig. 1 represents a schematic overview of the software pathway. The already-available software architecture of both the department of radiation oncology and the 3D planning centre in the hospital was used. The Mirada (Mirada Medical, Oxford Centre for Innovation, United Kingdom) software was used for the data fusion and margin delineation. The 3D virtual surgical planning was performed with the Pro Plan CMF 2.0 (Materialise, Leuven) software. To translate the 3D tumour volume determined in the MRI to the 3D plan based on the CT file, a compatibility algorithm was developed in Matlab (Mathworks, Natick, MA, USA).

A series of five bovine cadaver mandibles were used to test and validate the software pathway. A standardised phantom tumour, in the shape of a plastic sphere filled with a solution of barium sulphite and water, represented a malignancy. The phantom tumours were fixed onto the cadaver jaws at different locations with two-component dental impression paste (Provil Novo Putty, Heraeus Kulzer GmbH, Hanau, Germany), as illustrated in Fig. 2. All cadavers with the phantom tumours underwent scanning with CT (Siemens AG Somatom Sensation 64) and MRI (Siemens Magnetom Aera, 1.5 T). Regular head and neck protocols were used for the CT imaging and MRI sequences. In addition to the 3D MRI sequence, the regular protocol, T1 vibe tra-isotropic, was used as a comparison.

Manual global positioning of the MRI images, projected onto the CT images, was performed for data fusion. This is a standard technique in image fusion and is typically supported by radiotherapeutic planning software. This was followed by automatic rigid registration with a focus on the selected region of interest, including the phantom tumour and surrounding tissues. The image fusion was visually inspected in order to detect any mismatches after the fusion process.

Delineation of the gross tumour volume (GTV) was performed by a contouring brush tool in the software. The phantom object, being a spherical object, enabled straightforward contouring. The sphere was amply selected on the MR images. The contour was decreased with an automated shrinkage tool until the exact borders of the phantom were found; then the total volume of the GTV was

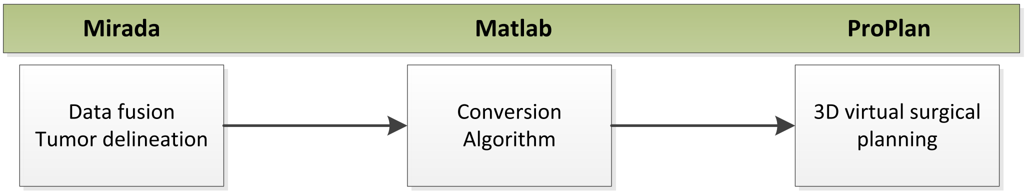

Fig. 1. Schematic overview of software pathway.