

Biomedical image segmentation using variational and statistical approaches

The role of imaging in adaptive radiotherapy for head and neck cancer

J. Castelli^{a,*}, A. Simon^{b,c}, O. Acosta^{b,c}, P. Haignon^{b,c}, M. Nassef^{b,c}, O. Henry^a,
E. Chajon^a, R. de Crevoisier^{a,b,c}

^a *Département des radiations, centre Eugène-Marquis, Rennes, France*^b *U1099, Inserm, campus de Beaulieu, 35000 Rennes, France*^c *Campus de Beaulieu, université de Rennes 1, LTSI, 35000 Rennes, France*

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Abstract

Radiotherapy (RT), alone or combined with surgery and/or chemotherapy is given to almost all head and neck cancer (HNC). The goal of RT is to increase as much as possible the dose in the tumor to cure the patient, while limiting the dose in the organs at risk, mainly the parotids gland to limit the xerostomia. HNC RT appears particularly challenging due to the complexity of the shape of the anatomical structures, which also changes during the 7 weeks of treatment. Advances in imaging-modalities, -processing and -integration at the different RT steps have been crucial to develop a new image and dose-guided adaptive RT (ART) strategy. Moreover, the integration of functional imaging such as FDG-PET (performed before and during the treatment) leads to an even more highly targeted and dose-escalated ART. This article is an overview of the place and role of imaging at the different steps of HNCART, from a medical point of view.

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1. Introduction

Radiotherapy (RT), alone or combined with surgery and/or chemotherapy is the treatment for almost all head and neck cancers. The goal of radiotherapy is to deliver a maximum dose to the tumor target volume, thereby curing the patient, while diminishing the dose to the organs at risk, thus decreasing the risk of toxicity. Recent improvements in radiation techniques have allowed for a reduction in toxicity, particularly the xerostomia by limiting the dose to the parotid gland [1–3]. This progress has been realized thanks to the combined improvement of imaging, computer science and technology of linear accelerators. Imaging plays indeed a crucial role in the three main radiotherapy improvement axis: delineation of the tumor, dose distribution thanks to the use of intensity-modulated RT (IMRT) and tumor localization at the time of the treatment providing a way forward to the new image guided radiotherapy (IGRT) strategies.

The RT reference imaging modality is X-ray Computed Tomography (CT), since the computation of dose distribution

is based on electron density maps assessed by the Hounsfield units of the CT image. Reference imaging for tumor visualization is, however, MRI and becoming increasingly used in the 18-Fluoro-deoxy-glucose (FDG)-positron-emission tomography (PET), thus implying the need for multimodal imaging fusion tools for accurate tumor delineation. Moreover, morphological variations can occur during the 7 weeks treatment course, so that the pre-treatment planned dose may not correspond to the actual delivered dose [4,5]. Adaptive radiotherapy (ART) is a new IGRT based strategy aimed at correcting these inters course morphological variations, by re-generating one or more plannings during the treatment course.

The adaptive RT is a new RT strategy that is still at a feasibility level and the first clinical results are not even yet available. Indeed, the presented head and neck adaptive RT workflow comprises different level of complexity, corresponding to the use of both constructor based and homemade software. The treatment (re-) planning are performed by using “standard” IMRT treatment planning system, and the daily bone rigid registration are performed using the LINAC based registration system (grey gradient based algorithm). The cumulative dose monitoring is not yet fully validated and is mostly performed by homemade software, when tested/evaluated by different teams.

* Corresponding author.

E-mail address: j.castelli@rennes.unicancer.fr (J. Castelli).

Head and neck cancer (HNC) is the main tumor site for ART. This article is an overview of the place of imaging at the different steps of HNC ART from a medical point of view.

2. Imaging for treatment

The general overview of image modalities and processing in HNC ART workflow is showed on Fig. 1. Twelve steps have been identified and will be described below. The specific adaptive RT loop (in green, steps 8 to 12) is based on a more standard IMRT workflow (in orange, steps 1 to 7), from the patient immobilization device realization to the fraction treatment.

2.1. Images acquisition, delineation and 3D reconstructions (Step 1–4)

Custom-fitted thermoplastic masks are first realized to immobilize the neck in the same position during the full treatment (step 1). In a standard RT treatment, only one CT acquisition is performed for the planning (step 2). Several target volumes will be consecutively delineated and defined on this planning CT (step 4): the GTV (gross tumor volume) corresponds to the macroscopic visible tumor on clinical examination and/or on different imaging, the clinical target volume (CTV) is the GTV plus a margin corresponding to the sub-clinical microscopic tumor spread. This CTV cannot therefore be fully imaged and mostly depends on the natural history of HNC. Five-millimeter margins are then classically added all around the CTV to define a planning target volume (PTV), taking into account both the anatomical structures displacement and deformations under the mask and the

patient position uncertainty under the linear accelerator. The total dose of RT will be finally delivered within this PTV. Organs at risk of toxicity (OAR) are also delineated on the CT. All these volumes are manually segmented by the radiotherapist (Fig. 2).

Manual segmentation in HNC is particularly complex implying a rather large knowledge of both HNC anatomy and natural history of HNC spreading, and is also time consuming (up to 3 hours per patient) [5]. Significant inter- and intra-observer variations in CT-based target delineation have been moreover shown due to the limit of the CT for accurate tumor visualization. MRI (T1 weighted with contrast imaging) presents a superior soft tissue differentiation than CT, without dental artefacts. In comparison with CT, MRI-based GTV has been shown to be smaller and with less interobserver variation than CT-based GTV [6]. Due to the necessity of electron density map, image co-registration between MRI and CT is necessary (step 3), leading potentially to new uncertainties. If the dosimetry should be calculated on CT due to the necessity to take account of electronic density, the dream of the radiation oncologist in head and neck, as in almost all tumor localization, is to use straightly and exclusively the MRI for both the planning and the tumor localization at the time of the treatment. Ongoing works aim to make MRI-based dose distribution feasible [7,8] and first results are encouraging, especially for the pelvis. Only one study was focused on intracranial lesions with very little difference between CT-based plans and MRI-based plans [9]. The integration of the MRI within the LINAC appears particularly complex. However, prototypes already exist and first results were published [10,11]. PET imaging is also particularly helpful in HNC delineation, for both the primary tumor and the lymph node [12].

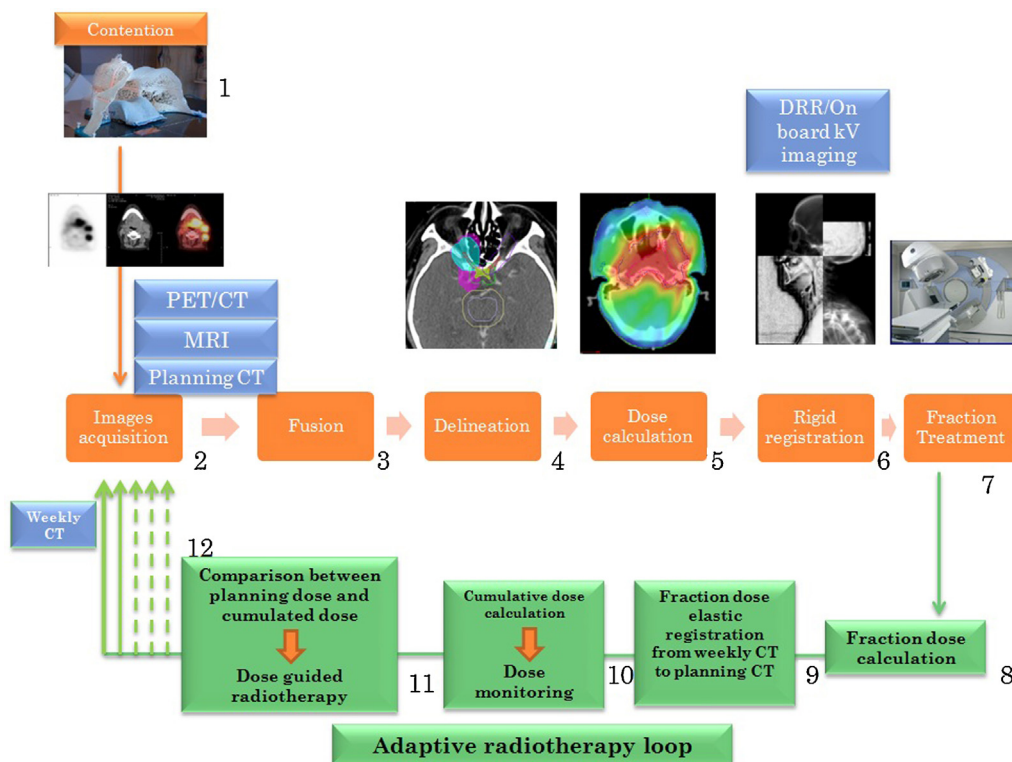


Fig. 1. Overview of image modalities and processing in head and neck adaptive radiotherapy. A total of 12 steps are individualized. In orange: the “standard” RT treatment workflow. In green: the specific adaptive and dose-guided radiotherapy workflow. DRR: digital reconstructed radiograph.

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