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Magnetic Resonance Imaging only Workflow for Radiotherapy Simulation and Planning in Prostate Cancer

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Abstract

Magnetic resonance imaging (MRI) is often combined with computed tomography (CT) in prostate radiotherapy to optimise delineation of the target and organs-at-risk (OAR) while maintaining accurate dose calculation. Such a dual-modality workflow requires two separate imaging sessions, and it has some fundamental and logistical drawbacks. Due to the availability of new MRI hardware and software solutions, CT examinations can be omitted for prostate radiotherapy simulations. All information for treatment planning, including electron density maps and bony anatomy, can nowadays be obtained with MRI. Such an MRI-only simulation workflow reduces delineation ambiguities, eases planning logistics, and improves patient comfort; however, careful validation of the complete MRI-only workflow is warranted. The first institutes are now adopting this MRI-only workflow for prostate radiotherapy. In this article, we will review technology and workflow requirements for an MRI-only prostate simulation workflow.

Keywords: Dose calculation; image-guided radiotherapy; magnetic resonance imaging; MRI-only radiotherapy; position verification; prostate cancer

Current Role of MRI in External-beam Radiotherapy for Prostate Cancer

In the diagnostic setting, the use of multiple functional and quantitative magnetic resonance imaging (MRI) techniques, multiparametric-MRI (mpMRI), has been advocated, leading to consensus-based guidelines for the diagnosis and reporting of prostate images on mpMRI to allow for standardisation. This has resulted in a reduction of interobserver variability and large-scale clinical implementation [1]. The Prostate Imaging and Reporting Data System (PI-RADSv2, [2]) includes clinical indications, image acquisition protocols, and a structured category assessment system. Recent studies show that MRI can be used prior to biopsy to allow for early detection of clinically significant prostate cancer and MRI-guided biopsies [3]. In addition, MRI is responsible for stage migration as it is highly sensitive in the detection of extracapsular invasion or seminal vesicle infiltration [4]. This impacts treatment choice for the individual patient.

Advances in imaging techniques in the last decades have impacted not only the diagnostic setting but also radiotherapy treatment strategies enormously [5]. Computed tomography (CT) is considered the primary technique in radiotherapy. Nevertheless, MRI is increasingly used in radiotherapy planning for patients with prostate cancer, especially for delineation of the target and surrounding healthy tissues, owing to its superior soft-tissue contrast compared with CT [6,7]. The differences between CT and MRI images of the prostate are illustrated in Figure 1. With CT, the boundaries of the prostate are hard to identify, whereas in MRI the prostate capsula and the internal structures are clearly visible. This is of primary importance for radiotherapy as it facilitates target delineation, which has been considered as the “major source of error in prostate external-beam radiation treatment” [9].

In addition to better visibility of the prostate and intraprostatic tumour lesions also seminal vesicles and the

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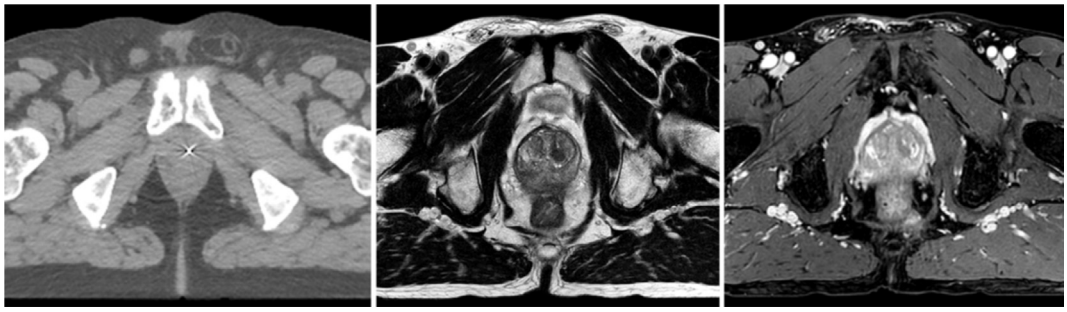

Fig 1. Comparison of axial CT (left), two-dimensional (2D) T2-weighted fast spin echo MRI (centre) and 3D balanced fat-suppressed gradient-echo MRI sequence (centre and right) images used in UMC Utrecht for treatment planning. In the MRI image, the internal structure of the prostate is readily apparent, while on CT bones and the intraprostatic fiducial marker are clearly visible. The figure has been reproduced from [8] with the author's permission.

surrounding organs at risk (OAR) are more readily visible on MRI compared to CT. MRI-based prostate target contours are smaller than CT-based delineations, especially at the location of the seminal vesicles and apex of the prostate and decrease interobserver variability [9,10]. In addition, MRI-based delineations for prostate cancer may result in lower urinary toxicity due to smaller clinical target volumes (CTVs) with comparable tumour control rates [11]. As a consequence, in most clinics, the best of both techniques is combined, and MRI is used in addition to CT for the delineation of the tumour and surrounding healthy tissues [12]. MRI is primarily for contouring of the gross tumour volume (GTV), prostate and OAR (such as rectum, sphincter, bladder, penile bulb, urethra, small bowel, bony anatomy).

Detection of tumour (GTV) has also opened up opportunities for focal treatment [13,14] or local dose escalation of intraprostatic lesion(s) [15–17]. This is based on the finding that local recurrences are most likely to occur at the location of an initial tumour [18]. Standardisation of GTV contouring is, however, required, and is the subject of ongoing research [19].

Rationale of MRI-only Simulation

Until recently, CT has been considered imperative to acquire electron density information for dose calculations and creation of reference images to allow for X-ray or cone-beam CT (CBCT)-guided radiotherapy. In most clinics, the best of both techniques is combined, and MRI is used in addition to CT for the delineation of the tumour and surrounding healthy tissues [12]. Thus, prostate cancer patients have to undergo two imaging examinations—CT and MRI—in preparation for radiotherapy treatments. These two examinations will be taken at different time points, and consequently, the geometry of the target and OARs will vary due to varying bladder and rectal filings or small patient set-up differences. This complicates the required multi-modality registration [20] and introduces ambiguities in the contouring process, most notably for OARs. This has been the rationale behind the development of a so-called MRI-only simulation [21] where all information needed for delineation, position verification, and electron density for dose calculations is derived from MRI images. Besides avoiding delineation ambiguities, an MRI-only workflow also offers substantial advantages with respect to logistics, patient comfort, and overall costs as the CT examination can be eliminated [22,23].

The MRI-only workflow can be used both for radiotherapy planning for conventional linear accelerators (linacs; X-ray or CBCT-guided) or MRI-guided radiotherapy (MRgRT). In the case of MRgRT, not only the radiotherapy preparation phase, but also the treatment phase, are MRI-guided [24]. The introduction of MRgRT makes MRI-based treatment planning increasingly important [25,26]. The present article describes the technology and adaptation required to enable an MRI-only workflow for external-beam radiotherapy for prostate cancer treatment. The focus on an MRI-only workflow is motivated by the fact that commercial solutions to generate synthetic CT images for prostate cancer are becoming available; this will facilitate clinical implementations in the near future.

The Ingredients for MRI-only Radiotherapy

When MRI is used for radiotherapy, it has different requirements than for diagnostic imaging, such as geometric accuracy, imaging in the treatment position, and large field of view (FOV) coverage [27]. In addition, electron density maps for dose calculations and reference information for position verification need to be obtained from MRI images. These aspects are considered necessary ingredients for MRI-only radiotherapy and will be revised in this section.

Geometric Accuracy

MRI images may be compromised by geometric distortions caused by the system (system-related distortions) and the patient (patient-induced distortions) [28–30]. This may impact the accuracy of MRI-based dose calculation as well as the spatial accuracy of MRI-based delineations. To correct for system-related distortions, modern scanners are equipped with state-of-the-art gradient systems, where geometric inhomogeneities have been minimised [23]. The scanners are also equipped with software for further correction of images [27]. Displacements after corrections

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