Radiotherapy and Oncology 86 (2008) 25–29
www.thegreenjournal.com

MRTgRT

MRI/linac integration

Jan J.W. Lagendijk[a,*], Bas W. Raaymakers[a], Alexander J.E. Raaijmakers[a], Johan Overweg[b], Kevin J. Brown[c], Ellen M. Kerkhof[a], Richard W. van der Put[a], Björn Hårdemark[d], Marco van Vulpen[a], Uulke A. van der Heide[a]

[a]*Department of Radiotherapy, University Medical Center Utrecht, Heidelberglaan, The Netherlands,* [b]*Philips Research, Hamburg, Germany,* [c]*Elekta Oncology Systems, Crawley, UK,* [d]*RaySearch Laboratories, Stockholm, Sweden*

Abstract

***Purpose/objectives*: In radiotherapy the healthy tissue involvement still poses serious dose limitations. This results in sub-optimal tumour dose and complications. Daily image guided radiotherapy (IGRT) is the key development in radiation oncology to solve this problem. MRI yields superb soft-tissue visualization and provides several imaging modalities for identification of movements, function and physiology. Integrating MRI functionality with an accelerator can make these capacities available for high precision, real time IGRT.**

***Design and results*: The system being built at the University Medical Center Utrecht is a 1.5 T MRI scanner, with diagnostic imaging functionality and quality, integrated with a 6 MV radiotherapy accelerator. The realization of a prototype of this hybrid system is a joint effort between the Radiotherapy Department of the University of Utrecht, the Netherlands, Elekta, Crawley, U.K., and Philips Research, Hamburg, Germany. Basically, the design is a 1.5 T Philips Achieva MRI scanner with a Magnex closed bore magnet surrounded by a single energy (6 MV) Elekta accelerator. Monte Carlo simulations are used to investigate the radiation beam properties of the hybrid system, dosimetry equipment and for the construction of patient specific dose deposition kernels in the presence of a magnetic field. The latter are used to evaluate the IMRT capability of the integrated MRI linac.**

***Conclusions*: A prototype hybrid MRI/linac for on-line MRI guidance of radiotherapy (MRIgRT) is under construction. The aim of the system is to deliver the radiation dose with mm precision based on diagnostic quality MR images.**
 Radiotherapy and Oncology 86 (2008) 25–29.

Keywords: MRI; IGRT; Accelerator; Position verification

The ideal radiotherapy dose distribution is tailored to the tumour clonogenic cell density and radiosensitivity [2]. From TCP model analysis it is shown that, in case of a homogeneous tumour, a large macroscopic tumour (the GTV) needs the highest dose, a smaller GTV a lower dose and the tumour infiltration in normal tissue (CTV minus GTV) requires the lowest dose (around 70% of a GTV dose [9]). The definition of such a dose distribution is complicated by daily positioning uncertainties which lead to PTV margins (ICRU 50 [10,27,34]). Because of normal tissue involvement in the PTV, conflicting dose constraints occur, e.g. the rectum in the PTV for prostate treatments or the parotid glands in the PTV of head and neck cancer [31]. This often means that the tumour dose is limited by normal tissue tolerance. Studies on the pattern of failure after radiotherapy show that the location of recurrences is mostly local and inside the original GTV [4,6,8,37] indicating the need for a GTV boost [7].

Image guided radiotherapy (IGRT) aims to decrease positioning uncertainty in order to reduce the PTV margins and thus minimize the dose limiting normal tissue involvement in the PTV. A large variety of IGRT technology is being tested clinically. Techniques based on cone beam CT, megavolt CT, ultrasound and implanted fiducial markers each try to find their own place with their specific capacities and limitations [11,16,18,20,26]. Problems in IGRT are still the combination of limited visibility of the tumour itself and the absence of real intrafraction imaging. In potential, diagnostic quality MRI (1.5–3 T) yields superb soft-tissue visualization and provides several imaging modalities for direct on-line imaging during movements. MRI for treatment guidance would thus offer visualization of both tumour and surrounding organs at risk which can lead to a further reduction of the margins. Therefore, at the University Medical Center Utrecht, a diagnostic quality 1.5 T MRI scanner integrated with a 6 MV radiotherapy accelerator for on-line, intrafraction IGRT is under construction. This is a joint effort between the Radiotherapy Department of the University Medical Center of Utrecht, the Netherlands, Elekta, Crawley, U.K., and Philips Research, Hamburg, Germany.

0167-8140/$ - see front matter doi:10.1016/j.radonc.2007.10.034

On-line, i.e. intrafraction, MRI allows the tracking of soft-tissue structures at a sub-second time scale [28]. This means that a radiation boost can be coupled directly to the target while taking into account the surrounding organs at risk. It also allows the investigation of new concepts such as a virtually margin-less boost to the prostate where the dose is not limited by the rectum for at least a part of the fractions [13]. Or as another example, boosting the GTV of a tumour of the cervix, shown in Fig. 1. This figure show how an adaptive strategy may reduce the margins but still leaves the rectum inside the PTV, limiting the GTV boost. Only high-quality soft-tissue imaging with mm precision can lead to a margin-less situation so that the GTV as shown in Fig. 1(d) can be boosted without overdosing the rectum.

This paper briefly presents the design of the system and the status of the prototype. Also the impact of the 1.5 T magnetic field on IMRT dose distributions for a hybrid MRI accelerator will be presented. Finally the implementation of MRI guidance in the radiotherapy clinic will be discussed.

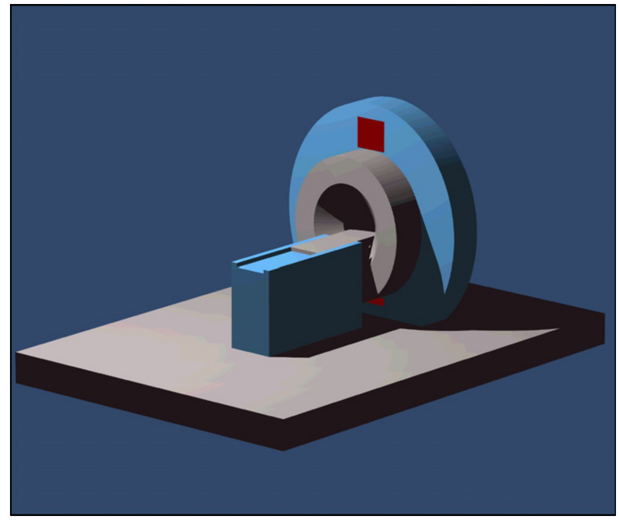

Fig. 2. Schematic design of the MRI accelerator. Gray the MRI, blue the accelerator gantry and red the accelerator head, rotating around the MRI in the midplane of the MRI.

Design

The system is based on a 1.5 T Philips Achieva MRI scanner with diagnostic imaging quality. The Magnex closed bore magnet is surrounded by a single energy (6 MV) Elekta accelerator (Fig. 2). Active magnetic shielding is used to create a zero magnetic field at the location of the gun of the accelerator, and a minimal magnetic field at the location of the accelerator tube. In this way the MRI and the accelerator are magnetically decoupled. This decoupling minimizes the accelerator induced, susceptibility based, geometry distortions in the MRI. Residual magnetic field contributions from linac parts can be compensated by adding additional magnetic sources in the rotating linac structure in such a way that their combined magnetic effect is independent of the position of the linac. A major concern is the calibra-

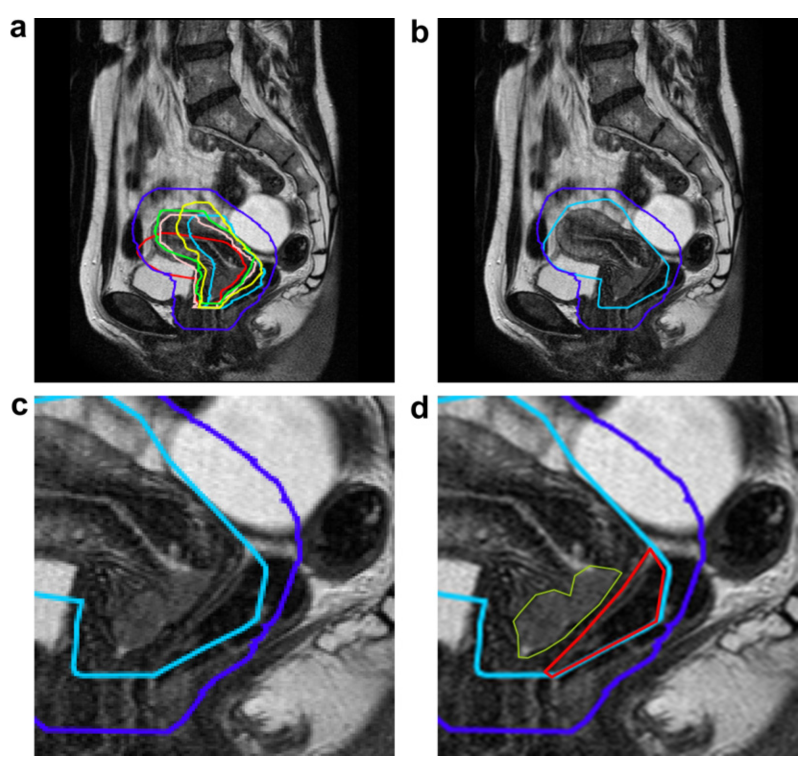

Fig. 1. (a) Repeated MRI for carcinoma of the cervix with the five delineated CTVs and the clinically used PTV (dark blue), (b) margins for the adaptive PTV (light blue) based on the series of MRI compared to the clinically used PTV, (c) zoomed MRI show overlap of both the adaptive and the clinical PTV with the rectum, (d) The GTV volume (green) that requires a boost without overdosing the rectum (red).