ELSEVIER

Seminars in
RADIATION
ONCOLOGY

Magnetic Resonance Imaging for Target Delineation and Daily Treatment Modification

Rojano Kashani, PhD,* and Jeffrey R. Olsen, MD†

Magnetic resonance (MR) imaging has become a prevalent modality in radiation oncology owing to its excellent soft-tissue contrast and ability to provide functional information. Recent technological developments have combined MR imaging with treatment delivery systems, to provide in-room MR guidance for patient setup and treatment delivery. Availability of in-room MR imaging enables direct visualization of soft-tissue targets and nearby organs at risk, thus providing a platform for fast and accurate target and organs at risk delineation for plan adaptation and target tracking during treatment. This article describes the 2 clinically implemented MR image-guided radiotherapy systems and their role in target localization and in-room treatment adaptation. Clinical data from early adopters of these systems is reviewed.
Semin Radiat Oncol 28:178-184 © 2018 Published by Elsevier Inc.

Introduction

Radiation therapy has seen significant technological advancement over the past few decades. With the introduction of intensity modulated radiation therapy (IMRT), implementation of in-room image-guided radiotherapy (IGRT), and advances in motion management techniques, it is now possible to deliver highly conformal doses, with high precision, to many body sites. Increase in the use of stereotactic body radiation therapy (SBRT), where ablative doses of radiation are delivered to the target in a few fractions, requires even higher precision, reproducible localization, and detailed attention to motion management.[1] Current standard image-guided radiotherapy techniques such as cone-beam computed tomography (CBCT), megavoltage CT (MVCT), or kV radiographs, provide sufficient accuracy in many treatment sites such as bony spine or highly visible lung tumors. These techniques, however, may be suboptimal for delivery of SBRT to soft tissue targets, especially those affected by interfraction and intrafraction motion and deformation such as abdominal and pelvic targets. Current treatment strategies rely on use of surrogate markers such as implanted fiducials for localization and gating, but do not allow direct visualization of the targets and organs at risk (OARs). For such cases, in-room magnetic resonance (MR) has the potential to improve target localization through direct visualization, and allow daily plan adaptation based on visualized target and OAR anatomy. In addition to superior anatomical imaging, MR imaging also provides functional information, which can be used in various radiotherapy applications. Metcalfe et al[2] provided a comprehensive discussion of concepts related to functional MR imaging techniques such as dynamic contrast enhanced MR and diffusion-weighted MR, and their expanding role in treatment planning and plan modification. With in-room MR image-guided radiotherapy systems (MRgRT) released for clinical use, the full potential of MR in the overall treatment process can be realized.

Here we discuss the use of MR for in-room treatment control through improved localization and implications on margin reduction, as well as use of MR for in-room target and OAR delineation for treatment modification. We also discuss the current state of clinical MRgRT, and present a summary of published clinical results from the early adopters of this technology.

MR Implementation for Radiotherapy Planning

Interest in incorporating MR for radiotherapy planning has increased steadily over the past 2 decades, making it part of

*Department of Radiation Oncology, University of Michigan, Ann Arbor, MI.
†Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO.
Conflict of interest: Jeffrey Olsen reports honoraria, travel, and research funding from ViewRay Inc. prior to May 2016.
Rojano Kashani reports honoraria, travel funds, consulting fees, and research funding from ViewRay Inc (current) as well as honoraria and travel funds from Varian Medical Systems prior to Jan 2017.
Address reprint requests to Rojano Kashani, PhD, Department of Radiation Oncology, University of Michigan, 1500 E Medical Center Dr, UMH B2C432, Ann Arbor, MI 48109. E-mail: rkashani@med.umich.edu

https://doi.org/10.1016/j.semradonc.2018.02.002
1053-4296/© 2018 Published by Elsevier Inc.

routine target delineation and response assessment for several treatment sites in the central nervous system, head-and-neck, and pelvis.[3] Using a variety of scan protocols and techniques, MR imaging can provide anatomical, and functional information to be used in the planning and evaluation process.[2,4] Despite these advantages, there are limitations which prevent use of MR as the primary or the sole imaging technique for patient simulation in radiotherapy. Liney et al[4] presented a review and discussion of various aspects of MR in radiotherapy, and provided some guidelines for image acquisition and quality assurance (QA) for these systems.

Field strength and its effect on image quality are perhaps the most important characteristics of MR to consider when using these images for target delineation or plan modification. The majority of current clinical MR imaging systems have 1.5 or 3 Tesla field strengths. The higher the magnetic field, the better the signal to noise ratio, which can be important for functional imaging.[4] However, increasing the magnetic field strength also results in larger susceptibility artifacts,[5] and potential increase in RF-induced heating in the patient. For in-room MRgRT systems, one should also consider the effect of the magnetic field strength on the electron return effect, and the dose calculation accuracy.[6-8] The effect of the magnetic field on the dose distribution can be accounted for using Monte Carlo algorithms, and incorporated into plan optimization. Developers of in-room MRgRT systems have selected various field strengths for their systems. Among the 5 systems currently in clinical use or under development, 2 systems use a 1.5 T MR,[9,10] whereas each of the other 3 systems use a lower magnetic field strength ranging from 0.35-T to 1.0-T.[11-13] Discussion of the design considerations that have led to selection of the magnetic field strength for each system is beyond the scope of this work, however, it is recommended that each clinic considers regulations, workflows, safety, and their clinical use cases and imaging needs, as part of their selection process.

Another important consideration in using MR for contour delineation and treatment modification, is the presence of geometric distortions in the image. Distortions that are caused by the system (ie, inhomogeneities in the magnetic field and gradient nonlinearity) are predictable and can be corrected for, whereas those caused by the patient, susceptibility artifacts, and chemical shift, are not predictable and more difficult to correct for.[4] One possible and commonly used solution to these issues, is to register the MR image to the simulation CT scan, which provides high geometric accuracy. This is an effective approach for the initial MR used for planning, but in the setting of in-room MR for contouring and plan adaptation, a new CT scan will not be available, and therefore, the magnitude and location of these uncertainties should be considered and accounted for through other means.[14-17] Aside from geometric accuracy, CT simulation scans also provide an accurate representation of the electron density distribution for dose calculation. When MR is used as the primary image for planning, such as in the case of in-room plan adaptation, electron density information can be generated using deformable registration of the simulation CT to the MR of the day, or through various methods of synthetic CT images from the MR.[18-24] These techniques have shown reasonable accuracy in the pelvis and have been used in the nonadaptive setting for MR only simulation workflows.[25]

Another consideration, both for simulation and for treatment delivery using MRgRT systems, is patient positioning and immobilization. Many of the standard immobilization devices are too large to fit inside the MR bore. Therefore, specialized immobilization devices that are both MR compatible and can fit inside the bore would be required. Furthermore, the placement of RF coils can interfere with the immobilization device or the patient. Specialized RF coils have been designed by some manufacturers for MR simulators, however, in many cases, radiation oncology departments do not have a dedicated MR simulator and acquire diagnostic MR images outside of the department.[3] If MR simulation cannot be performed with the proper immobilization, caution must be practiced during fusion of simulation MR with the simulation CT for planning.

In-Room MR for Localization

The definition of target volume in MR-guided radiotherapy is in principal no different than standard radiotherapy, and follows the conventions set by the International Commission on Radiation Units and Measurements (ICRU) reports 50 and 62.[26,27] As described by the ICRU, the gross tumor volume (GTV), should be encompassed by a series of safety margins accounting for various sources of motion and deformation, and the uncertainties associated with the treatment planning and delivery process.[26,27] The clinical target volume (CTV), which accounts for microscopic disease not visible on imaging, is a combination of geometric expansion of the GTV and anatomically guided extension to the lymph nodes and other regions considered to be at risk, and its definition depends on various clinical factors.[26,27] Although the availability of advanced in-room imaging techniques is not expected to have a direct effect on the CTV definition, the ability to visualize soft-tissue boundaries on in-room MR, will affect target definition, and the anatomical boundaries that dictate CTV contours.

In generating the planning target volume (PTV) from the GTV or the CTV, 2 additional margins are needed per ICRU report 62. First is the internal target volume (ITV), which accounts for variations in shape, volume, and position of the target caused by breathing motion, changes in filling of adjacent hollow organs, and other physiological effects. The second is the setup margin that accounts for variations in patient setup as well as mechanical and dosimetric uncertainties in the overall treatment planning and delivery process.[26-27] In practice, the ITV margin mainly focuses on addressing the motion and deformation caused by respiration only, and its definition and use varies depending on the motion management technique used clinically. The setup margin, should include both systematic and random errors in patient setup, and calculated based on population setup data as described by the van Herk margin formula.[28] The margin formula which is based on probability histograms of the cumulative dose in patient populations, is a widely accepted and effective way of accounting for both systematic and random errors in targets