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Magnetic Resonance Image-Guided Radiotherapy (MRIgRT): A 4.5-Year Clinical Experience

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Abstract

Aims: Magnetic resonance image-guided radiotherapy (MRIgRT) has been clinically implemented since 2014. This technology offers improved soft-tissue visualisation, daily imaging, and intra-fraction real-time imaging without added radiation exposure, and the opportunity for adaptive radiotherapy (ART) to adjust for anatomical changes. Here we share the longest single-institution experience with MRIgRT, focusing on trends and changes in use over the past 4.5 years.

Materials and methods: We analysed clinical information, including patient demographics, treatment dates, disease sites, dose/fractionation, and clinical trial enrolment for all patients treated at our institution using MRIgRT on a commercially available, integrated 0.35 T MRI, tri-cobalt-60 device from 2014 to 2018. For each patient, factors including disease site, clinical rationale for MRIgRT use, use of ART, and proportion of fractions adapted were summated and compared between individual years of use (2014–2018) to identify shifts in institutional practice patterns.

Results: Six hundred and forty-two patients were treated with 666 unique treatment courses using MRIgRT at our institution between 2014 and 2018. Breast cancer was the most common disease, with use of cine MRI gating being a particularly important indication, followed by abdominal sites, where the need for cine gating and use of ART drove MRIgRT use. One hundred and ninety patients were treated using ART in 1550 fractions, 67.6% (1050) of which were adapted. ART was primarily used in cancers of the abdomen. Over time, breast and gastrointestinal cancers became increasingly dominant for MRIgRT use, hypofractionated treatment courses became more popular, and gastrointestinal cancers became the principal focus of ART.

Discussion: MRIgRT is widely applicable within the field of radiation oncology and new clinical uses continue to emerge. At our institution to date, applications such as ART for gastrointestinal cancers and accelerated partial breast irradiation (APBI) for breast cancer have become dominant indications, although this is likely to continue to evolve.

Key words: ART; MRI-guided radiation therapy; MRIgRT; online-adaptive radiation therapy; SMART

Introduction

Magnetic resonance image-guided radiotherapy (MRIgRT) has long been sought within the field of radiation oncology. MRIgRT offers superior daily visualisation of soft-tissue disease sites for improved set-up accuracy, daily imaging of sufficient quality for online adaptive radiotherapy (ART), and the potential for real-time target-based cine MRI (cMRI) gating for intra-fraction motion management without additional radiation exposure to patients [1–4]. Over the past two decades, advances in the integration of MRI and radiotherapy devices culminated in the clinical implementation of MRIgRT at our clinic in 2014 [5].

Since its initial implementation, MRIgRT use has expanded to multiple centres and countries. In our clinic, it

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has quickly become an integral treatment modality, and has been the focus of several prospective clinical trials and multi-institutional studies [4,6,7]. As the field acclimatises to the availability of MRIgRT, clinical use of this technology matures and new applications continuously emerge.

Previously, we described our early institutional experience with MRIgRT [8]; however, as familiarity with the technology is gained, use is honed to derive maximal therapeutic benefit. In this work, we present the longest single-institution clinical experience using MRIgRT. The goal of this paper is to describe our 4.5 years of use, including shifts in our practice patterns over time, to guide best clinical practice as MRIgRT gains traction in the global clinic.

Materials and Methods

Setting and Patients

The Radiation Oncology department at Washington University in St Louis includes 21 disease-site-specific attending radiation oncologists who cover our main site as well as five satellite facilities. Our main facility is equipped with eight linear accelerators (linacs) including the Edge radiosurgery system, an MRI-guided linac (completing commissioning), and the Halcyon, in addition to a Leksell Gamma Knife ICON, a cobalt-60-based MRIgRT system, a single-gantry proton therapy system, and a full brachytherapy suite. All patients included in this study were treated with MRIgRT between 2014–2018 and were either part of prospective clinical protocols (institutional protocol nos. 201410002, 201401160, 201311081, 201611018, 201510101, 201412038), a prospective MRIgRT patient registry (registry no. 2013111222), or an institutional retrospective registry (registry no. 201301149). The dataset was interrogated to obtain clinical information, including demographic information, dates of treatment, disease site treated, dose and fractionation, and clinical trial enrolment. For each patient, the primary clinical rationale for the use of MRIgRT was evaluated (adaptive treatment, cine gating, daily MRI for improved setup accuracy). For patients receiving ART, we also examined the proportion of fractions adapted. These factors were then summated and compared between individual years of use (2014–2018) to identify shifts in institutional practice patterns.

Three clinical MRIgRT systems are commercially available and have been clinically used including a 0.35 T MRI-linac, an integrated 0.35 T-tri-Co-60 device, and a 1.5 T MRI-linac system [5,9,10]. The patients included in this experience were treated using the 0.35 T-tri-Co-60 system, although our clinic is commissioning its counterpart, the 0.35 T MRI-linac device. Detailed descriptions of the 0.35 T MRIgRT system, commissioning, quality assurance, and the imaging unit have been published [5,11,12]. In summary, the MRIgRT system is comprised of a tri-cobalt-60 radiation delivery device straddled by an open split-solenoid low-field (0.35 T) magnetic resonance imaging (MRI) device with a nominal dose rate of 550 cGy/min from three 27.3×27.3 cm^2 fields to the 105 cm isocentre [5].

Simulation, Planning, and Treatment Delivery

All patients treated with MRIgRT underwent computed tomography (CT) simulation and an MR simulation; details for multiple simulation and treatment techniques have been described [4,8,13]. Patient positioning during CT simulation was determined by the treating physician and emulated the position used during MRIgRT. Following simulation, CT and MR simulation images are transferred to an independent treatment planning system (TPS) for volume delineation. These images are then transferred to the MRIgRT dedicated TPS for plan creation. The dedicated TPS uses a Monte Carlo dose calculation algorithm and is capable of creating both conformal and intensity modulated radiation therapy (IMRT) plans [14]. Details on plan delivery including cine gating and ART planning and delivery workflows have been reported previously [2–4].

Statistical Analysis

Data analyses were performed using Excel 2013 (Microsoft Corporation, Redmond, WA, USA).

Results

Patient Characteristics and Disease Sites

Between January 2014 and March 2018, 642 patients with a median age of 64 years (range 64–90 years) were treated with 666 unique courses of MRIgRT. This included 240 IMRT, 266 stereotactic body radiation therapy (SBRT), and 160 three-dimensional (3D) conformal plans delivered over a total of 7884 fractions. The median number of fractions per patient was 10 (mean 12; range 1–44) with a median dose per fraction of 450 cGy (range 115–2000 cGy). Disease sites included the abdomen in 41.2%, breast in 31.4%, thorax in 11.6%, head and neck/central nervous system (CNS) in 2.6%, and pelvis in 13.2% of cases (Table 1, Figure 1). Of the abdominal malignancies treated, pancreatic and hepatobiliary primaries comprised the majority of patients (15.2% and 13%, respectively). Breast cancer treatment courses included accelerated partial breast irradiation (APBI; 30.5%) and whole-breast radiation (1%).

Rationale for MRIgRT

Physician rationale for use of MRIgRT was variable, but could be stratified into three principal reasons: (1) improved soft-tissue visualisation for set-up accuracy in 93 patients (14%); (2) cMRI gating for intra-fraction motion management in 383 patients (57.5%); and (3) online and offline ART in 190 patients (28.5%). Figure 2 provides a visual summary of these rationales. MRI visualisation and set-up was primarily used in the treatment of pelvic malignancies (65 patients), including prostate and bladder malignancies. Breast cancer was the most common disease treated over the total 4.5 years due to the advantage of cMRI gating, comprising the majority of treatment courses

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