MRI in radiotherapy

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Introduction
Over the preceding 20 years or so there has been an ever-growing interest in utilising MRI in the radiation treatment of cancer. This short article is a personal commentary into the background and challenges faced with its implementation into clinical practice and also a view of the current state of play and future direction in this field.

As the delivery of radiotherapy has become ever more conformal and targeted, the concept of 3D (and 4D) image guidance has grown in importance. When considering current imaging modalities, CT is the primary imaging modality. In combination with CT, PET and/or MRI may also be utilised. CT is the long established gold standard to aid 3D planning as it offers excellent geometric integrity and a direct relationship between Hounsfield units (CT number) and electron density, a critical parameter used in the dose calculations. However, as well as requiring the use of ionising radiation, the modality generates quite limited soft tissue contrast, making the distinction between tumour and normal tissue sub-optimal. As delivery precision improves, the ability to increase the therapeutic ratio through reduced treatment margins and potential dose escalation will rely on confident tissue delineation from high quality images. PET has been utilised to establish the extent of disease involvement through functional imaging but has poor spatial resolution, and will not be discussed further here. MRI provides high quality soft tissue imaging as well as high spatial resolution.

The pros and cons
MRI is a good candidate for treatment simulation as it provides excellent soft tissue contrast that can be varied considerably, enabling particular tissue characteristics to be highlighted. A typical MRI examination will consist of several sequences, each acquired in various favourable planes and with many different contrast weightings. Furthermore, MRI is able to provide functional imaging which may be beneficial in more advanced treatment regimens. These include, but are not limited to MR spectroscopy, which can provide metabolic mapping of tumour profiles through detection of chemically distinct shifts in resonant frequency, and diffusion weighting which can track restricted motion in tumours at the cellular level. Both contrast and non-contrast enhanced techniques can be used to probe tumour perfusion. Still other quantitative parameters (for example R2*) have been shown to correlate with oxygenation levels and thereby reveal hypoxia and radio-resistant sub volumes of tumour. Each of these techniques has the potential to complement the more routine anatomical images and provide the ultimate description of the intended treatment volume.

Figure 1 shows this concept in a brain tumour – the limitation of CT here is obvious compared to the extra information provided by the MRI examination that provides opportunities to ‘target, boost and avoid’.

For all its advantages, MRI has two distinct drawbacks, the first being the inherent geometric distortion in the images. Many of the earlier researchers were able to show alarming geometric inaccuracies on open low field systems that have long stayed in the minds of the radiotherapy community. MRI is prone to both system and patient related effects, the former due to non-uniformities in the main field and non-linearities in the imaging gradients, becoming worse as a function of distance from the isocentre of the magnet. The latter type of effect is introduced via the patient in terms of fat-water shifts and susceptibility effects. Most (but not all) of these effects can be mitigated by careful sequence and parameter selection and/or correction schemes provided by the vendor. Nevertheless, it is important to characterise any MRI system being used.

The second drawback stems from the lack of inherent electron density information. At present the current practice is still to fuse to CT for this purpose. However, many groups are looking into ‘MR only’ planning; segmentation and bulk density assignment is a popular approach but others are looking into providing this indirectly from mapping CT atlas data and directly from an MR signal surrogate. Related to this is the desire to generate so-called pseudo DRRs from MRI directly so that patients may be set up on linac beds with only an MR planning scan.

Current practice
Many studies have shown reduced user variability through improved delineation. MRI is now routinely used in many sites to assist in the contouring of PTV and OARs. Brain is usually the easiest site to begin with owing to its small central rigid volume that is easy to register without the need for extra localisation equipment. This site also lends itself to the full myriad of functional techniques (figure 1). The other sites of interest pose their own unique requirements but, commonly, the main issue is the compromise between maintaining a treatment position and the use of a suitable RF coil. Head and neck imaging should always be performed in the treatment position owing to the wide variation in neck flexation between planning CT and a diagnostic MRI.

Breast imaging, performed diagnostically well in the prone position with dedicated RF coils, may also be acquired in the treated (supine) position with good success. It is as yet unclear which position will win the day, as both are viable options.
A clear indication for the inclusion of MRI is in prostate planning of hip prostheses. Severe high Z-artefacts observed in CT are replaced by more localised susceptibility effects around the implant in MRI. Prostate planning may be done with fields of view big enough to encompass registration landmarks but not so big as to reveal distortions. More problematic is the potential for movement of the gland between CT and MRI, despite consistent bowl and bladder preparation. Gold seeds that show up on both MR and CT may be a useful way forward here. Continuing advances in both imaging speed and motion compensation schemes means more challenging sites such as lung may now be considered a realistic goal for MR planning. Often the poor relation in radiation treatment, brachytherapy has seen many groups actively pursuing MRI guided techniques. MR compatible applicators can be made more visible using catheters or changing the imaging sequences used. Often the planning systems do not correct for tissue heterogeneity, meaning it is a particularly attractive site to develop quickly into 'MR-only'.

Hardware
Manufacturers of MRI scanners are all actively pursuing radiotherapy specific products and road-maps. A major advance saw the introduction of a 70cm wide bore system, creating the room needed for immobilisation equipment to be used in situ. All the major vendors now provide flat tabletop couches, often with an integrated RF coil underneath, to simulate treatment position and facilitate the fusion with CT planning. Other RF coils that fit around immobilisation masks notably at head and neck sites are also commercially available (figure 2). Each vendor now offers this equipment for both 1.5T and 3.0T magnets. For many centres, this choice may ultimately be driven by cost, although the case at higher field strength for an MR-simulation system remains unproven and as yet there is no clear evidence as to the best field strength. Lasers as used for radiotherapy treatment positioning are now also being installed with MRI scanners which are used for radiotherapy purposes.

The full potential of MRI is yet to be exploited in radiotherapy. Some groups have begun to map patterns of failure with MRI data retrospectively. However, more clinical trials are required to establish how these multi-functional datasets can be put to best use prospectively. Until dedicated MR systems are installed as the ubiquitous planning scanners, many centres will be limited to the current practice of begging and borrowing limited time on radiology machines that are already full to capacity.

Future
Although this article has only considered planning aspects, the full role of MRI is actually to complement every part of the radiotherapy chain, from planning through to verification and follow-up. MR gel dosimetry is a technique that utilises radiosensitive materials that can be irradiated and then ‘read out’ by virtue of the changes in magnetic properties (figure 3). By careful calibration, a true 3D dosimetric analysis may be performed with good accuracy. The lack of ionising radiation means MRI is the ideal modality to repeatedly image the patient during the course of treatment and also for longer term follow-up. The combination of the anatomical and physiological imaging described earlier is ideal to verify the success or otherwise of treatments and potentially adapt fractions accordingly. Perhaps the ultimate combination of MRI and radiotherapy is the design of hybrid MR-linac systems, of which there are now three at various prototyping stages throughout the world. Here in Sydney the research bunker has been completed ready for the installation of the southern hemisphere’s only version (figure 4). A fourth system combining Cobalt sources (instead of a linear accelerator) with MRI guidance is already commercially available. With these systems comes the promise of real-time image guidance and adaption of tailor-made treatment plans on the fly. These exciting developments are sure to push both radiotherapy and MRI fields forward over the coming years.
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References