Title:

"What are the current and future requirements for MRI interpretation skills in radiotherapy? A critical review"

Initial and name of each author, with highest academic degree:

Midon AM; undergraduate student

Bridge P; MSc

Warren M; MSc

Name and address of the department to which the work should be attributed:

Directorate of Medical Imaging and Radiotherapy, School of Health Sciences, University of Liverpool, Brownlow Hill, Liverpool, L69 3GB, United Kingdom.

Name, address, telephone number of the author responsible for correspondence and to whom request for reprints should be sent:

Pete Bridge, School of Health Sciences, University of Liverpool, Brownlow Hill, Liverpool, L69 3GB, United Kingdom.

Tel: +44 (0) 151 795 8366

E-mail: pete.bridge@liverpool.ac.uk

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Aston Marques Midon studied at the University of Liverpool under the Ciencias sem Fronteiras programme, a Brazilian Government-sponsored student mobility scheme.

Abstract

Purpose:

Increasing usage of Magnetic Resonance Imaging (MRI) in radiotherapy and the advent of MRI-based Image Guided Radiotherapy (IGRT) suggests a need for additional training within the Radiotherapy (RT) profession. This critical review aimed to identify potential gaps in knowledge by evaluating the current skill base in MRI amongst therapeutic radiographers as evidenced by published research.

Methods:

Papers related to MRI usage were retrieved. Topic areas included outlining, planning and IGRT; diagnosis, follow-up and staging related papers were excluded. After selection and further text analysis papers were grouped by tumour site and year of publication.

Results:

The literature search and filtering resulted in a total of 123 papers, of which 66 were related to “outlining”, 37 to “planning” and 20 to “IGRT”. The main sites of existing MRI expertise in radiotherapy were brain, CNS, prostate and head and neck tumours. Expertise was clearly related to regions where MRI offered improved soft-tissue contrast. MRI studies within RT have been published from 2007 onwards at a steadily increasing rate.

Conclusion:

Current use of MRI in RT is mainly restricted to sites where MRI offers a considerable imaging advantage over CT. Given the changing use of MRI for image-guidance, emerging therapeutic radiographers will require training in MRI interpretation across a wider range of anatomical regions.

Keywords: magnetic resonance imaging; radiotherapy; training; planning; image-guided radiotherapy

Introduction

Advances in anatomical and functional imaging have provided increasingly valuable tools in Radiotherapy (RT) treatment planning and delivery (1) for the reduction of dose to Organs at Risk (OAR) and improvements to dose conformity. Computed tomography (CT) remains the most widely used imaging modality in RT. It is widely available, provides electronic densities of tissues for RT dose calculation and does not suffer from geometric distortion. (2) In recent decades (3) the increased soft tissue differentiation of Magnetic Resonance Imaging (MRI) has brought additional benefits to RT planning. MRI provides superior contrast resolution to CT and reduces a patient's exposure to radiation. It is unsurprising, therefore, that an increasing number of studies report attempts to integrate both imaging modalities and, in many cases, substitute CT with MRI. (3, 4)

Emerging research in RT suggests a valuable role of MRI in image-guided radiotherapy (IGRT). IGRT optimizes the precision and accuracy of dose delivery by decreasing positioning uncertainty, shrinking margins and thus reducing radiation dose to normal tissue. A range of IGRT technology is being tested clinically, using both CT and MRI principles. The increased soft tissue contrast arising from MRI, coupled with the reduced ionising radiation dose, makes MRI an attractive option for image-guidance. (5, 6) In combination with ultra-fast planning technology, MRI-guided IGRT (MRIGT) is ideal for the initiation of daily plan adaptation based upon anatomical changes (7)**.** Additionally, new research into functional MRI, response assessment and motion tracking could see adaptive radiotherapy become more focussed upon exploiting individualised tumour characteristics. Despite the potential advantages of MRI over CT, there are still challenges to its exclusive use in RT planning. The lack of electron density information and presence of geometric distortions are challenges to both calculation of dose distribution and accurate localisation. (2, 4) In addition, addressing the deficiency of detailed MRI knowledge among therapeutic radiographers may require substantial training, particularly in those sites not traditionally associated with MRI use. (2) This review aims to evaluate the current skill base in MRI amongst therapeutic radiographers by investigating the body of relevant research. This, in turn, may help to identify the requirements for additional MRI interpretation skills and thus establish the future training needs of the radiotherapy profession.

Methods

A review of the literature was performed using the University of Liverpool "DISCOVER" database search engine. This covered the most relevant databases for radiotherapy including MEDLINE, Scopus and ScienceDirect. Relevant evidence was identified using the terms "radiotherapy" AND “magnetic resonance imaging” combined with “outlining”, “target”, “planning” and “image-guided radiotherapy”. Sources were also limited by the subject “radiotherapy” and “magnetic resonance imaging”. Articles were excluded if they solely concerned diagnosis, follow-up or staging. Non-English or Portuguese articles and duplicate articles were also excluded.

The evidence was subjected to abstract analysis before being grouped into three categories: Outlining, Planning and IGRT. “Outlining” articles comprised those which concerned delineation of tumour volumes and localisation. “Planning” articles addressed registration, MRI dose calculation, synthetic computerized tomography (sCT) and MRI-based planning. IGRT articles focused on the use of MRI in IGRT including recent uses, trends, feasibility and safety.

Once articles were grouped, full text analysis affirmed group allocation (outlining, planning or IGRT) and further grouped evidence by sub-themes for analysis. Sub-themes concerned individual tumour sites or “technical” aspects; the latter subgroup comprised articles that addressed the principles of MRI use for outlining, planning or IGRT. These included: “dose calculation using MRI”, “synthetic CT (sCT)”, “issues and challenges for using MRI in RT planning” and “registration”. Any articles failing to fit in any of these categories were grouped as “others”.

Results

The literature search and filtering resulted in 66 articles related to “Outlining”, 37 to “Planning” and 20 to “IGRT”. As expected, most papers were related to “Outlining” (Table 1) where most papers focused on the brain and central nervous system (28.8%), prostate (21.21%) or head and neck (HN) tumours (19.7%). A similar picture was seen in the “Planning” branch (Table 2) with brain/CNS tumours comprising 29.7% of the papers, followed by prostate (21.6%) and HN tumours (8.1%). The “Planning” and “IGRT” groups included “Technical aspects” articles while in “Outlining” there were none. All the “IGRT” papers were related to technical aspects and not specific tumour sites.

It is clear from the results that some disease sites remain poorly studied in relation to MRI and RT. Gynaecological tumours were the focus for approximately 18% of the “Outlining” papers (Table 1), comprising 9.1% breast, 7.5% cervix and 1.5% ovary tumours. Otherwise in the “Planning” branch there was just one paper outside the three main MRI regions of brain, prostate and HN. An overview of all articles obtained in this search can be seen in Table 3.

More than half of the “Planning” papers concerned sCT (techniques and its uses) and registration (54%), while dose calculation comprised 38% (as seen in Table 4).

Table 5 shows the publication chronology of the retrieved papers; it can be seen that the majority of publications occurred within the last decade. Approximately 90% of papers were published after 2007, and 60.1% of papers from 2012 onwards (Table 5). It is also interesting to note the growth in research across the different themes (Figure 1). MRIGRT is clearly the most rapidly growing development, along with "Planning", which has accounted for 70% of the publications since 2012. The latter explosion in publication rate is associated with ongoing efforts to overcome the lack of electron density information in MRI, including use of pseudo-CT scans.

There were 3 articles that did not fit in any category of "MRI Planning" in technical aspects (Table 4). One concerned the use of MRI in RT simulation, another addressed the use of functional MRI in intensity modulated radiotherapy treatment planning, and the last one concerned the use of fluid-attenuated inversion recovery (FLAIR) imaging in planning.

Discussion

Limitations

This paper aimed to evaluate the current MRI skill base in RT as evidenced from a review of the literature. The greatest limitation of the study was that the findings are solely derived from published research, and thus may not correlate directly to the every-day clinical uses of MRI in RT. Topics that have been published are related to innovative practice or identification of issues, with an emphasis on reporting findings that could be implemented into clinical practice. This does not necessarily demonstrate that the findings have been implemented. A more valuable method to address the aim would be an international audit of MRI practice in RT, but the large scope of this severely limits the feasibility.

Site-specific MRI use

Radiotherapy is used in many tumour sites as adjuvant therapy, and sometimes as primary therapy. A single-day census of RT treatment in Australia showed that the most common sites are breast, prostate, head and neck, skin, lung, brain and rectum. (8) Additionally, the same study identified that the most common indications and usage of MRI fusion were prostate, brain, head and neck and rectum. (8) This supports the evidence within this paper with research papers related to prostate and intracranial tumours comprising over half of the sources. These sites clearly dominated the research papers with 24.4% of papers related to brain, 17.9% to prostate and 13% to head and neck tumours. The prevalence of these sites is explained by the superior soft-tissue visualisation offered by CT-MR fusion. This significantly enhances localisation of intracranial (4, 9), head and neck (2) and prostate tumours (10).

As with many other aspects of radiotherapy practice, research into prostate radiotherapy dominates this topic. MRI offers excellent soft tissue contrast on T2-weighted images and allows direct multi-planar image acquisition of prostate tumours without loss of spatial resolution. (11) Consequently, MRI outperforms CT in demonstration of internal prostatic anatomy, margins and the extent of tumours. (10) Use of Diffusion-Weighted Imaging (DWI) and Dynamic Contrast-Enhanced (DCE) images in RT delineation (8), and multi-parametric MRI (12) are key areas of ongoing research aiming to maximise this potential. Ongoing work into alternative MRI sequences (13) also suggests the need for a rapidly evolving and adaptable MRI-based skill mix within the workforce.

The need for precise determination of target volumes in RT planning arises from the consequences of a geographical miss of a tumour. Intracranial lesions are particularly well delineated on MRI (4) due to the increased contrast between white and grey matter. (2) However, data obtained by CT is still currently required for treatment planning as it provides the electron density for dose calculation. (14) Another exciting research theme seen in many of the review papers related to overcoming this problem through use of pseudo-CT (15) or synthetic CT. Efforts to move towards an MRI-based planning process will vastly increase the range of tumour sites that could benefit from MRI. MRI is already considered the gold standard for rectal imaging (16, 17) as it addresses many of the key CT limitations, such as definition of depth of invasion through the rectal wall into local structures (17, 18). The superior soft-tissue contrast provided by MRI also plays a vital role in the RT planning of head and neck tumours. (19) The research evidence certainly demonstrates the value of MRI for these specific sites in relation to outlining and planning. Some of the new developments, however, point to future use of MRI across a wider range of tumour sites. What is not known yet is which tumour sites will gain the most value from these developments and the implementation of MRIGRT.

Training implications: MRI image interpretation

This study has provided an overview of current MRI expertise in RT as evidenced by research studies. The areas of research evidenced by the study suggest that skills in MRI interpretation among the radiotherapy professional community primarily relate to brain, head and neck and prostate anatomy. As discussed previously, the imminent adoption of MRIGRT represents a significant departure from traditional MRI practice in radiotherapy. Current use is mainly restricted to sites where MRI offers a considerable imaging advantage over CT, where technical adoption is straightforward. With MRIGRT, usage will not be dictated solely by image quality but more by the gains arising from real-time image guidance. Introduction of new disease sites is likely to be linked to increased technical proficiency in organ motion tracking and advanced functional MRI sequences; particularly in support of adaptive planning techniques. It is likely, therefore, that the indications for MRI-IGRT will be radically different from current practice, which will clearly require an extension of the current MRI interpretation skill base. The emerging MRI-cogent workforce will not only require training in use of MRI equipment and techniques, but also a sound understanding of MRI image interpretation across a wider range of anatomical regions than is currently required.

Training implications: relational anatomy

There is another potential aspect of practice that more widespread adoption of MRI-IGRT may influence. Historically since the adoption of CT-based radiotherapy planning there has been a reliance on axial, or transverse, imaging. The advent of cone-beam CT, which also required a large-scale upskilling of the workforce, still relied predominantly on interpretation of transverse images with limited use of orthogonal planes. Although volumetric acquisition and image reconstruction technology is capable of generating alternative imaging planes, this has largely been restricted to orthogonal images. Reliance on transverse images has, of course, arisen from the physical configuration of the CT scanner and linear accelerator. With MRI there is no such restriction with an unlimited range of imaging planes available for use. In diagnostic imaging it is common practice within some regions to select a non-axial, or even non-orthogonal, plane to best highlight the required anatomy or pathology. Findings from a recent 3D outlining evaluation (20) suggested that radiotherapy clinicians were less comfortable with sagittal and coronal images than with transverse. The extent to which new imaging planes will be adopted in MRI-IGRT is still uncertain, but it seems likely that the radiotherapy workforce will require training in non-transverse image interpretation. This is a significant paradigm shift that will require a more rigorous understanding of relational anatomy than a purely axial approach. Pre-registration courses, as well as CPD provision, will need to address this in the future if the workforce is to be adequately prepared for the MRI revolution.

Conclusion

It is clear that recent research related to MRI in radiotherapy is focussed on disease sites in which MRI offers an advantage over CT. Brain, prostate and HN tumours show important gains from the superior soft-tissue contrast of MRI. Radiotherapy professional MRI expertise in other tumour sites is not evidenced strongly by recent research publications. The advent of MRIGRT and MR-based planning may extend the indications for MRI use to a wide range of tumour sites, and it seems likely that the therapy radiography profession is currently under-prepared for this skill requirement. Future training in MRI image interpretation should not only build on the existing expertise but also cover a wider range of tumour sites and focus on non-axial planar interpretation. A national audit of current MRI expertise amongst clinical therapeutic radiographers would build on this review and further help to identify potential training needs.

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Table 1: Papers related to MRI and "Outlining"

Organs	Number of papers	Percentage
Prostate	14	**21.21%**
Brain/CNS	19	**28.80%**
Head and Neck	13	**19.70%**
Breast	6	**9.10%**
Rectum	4	**6.06%**
Cervix	5	**7.57%**
Ovary	1	**1.51%**
Liver	1	**1.51%**
Sarcomas	2	**3.03%**
CNS, HN, Prostate, Cervix	1	**1.51%**
Technical aspects	0	**0.00%**
Total	66	**100.00%**

Table 2: Papers related to MRI and "Planning"

Organs	Number of papers	Percentage
Prostate	8	**21.62%**
Brain/CNS	11	**29.73%**
Head and Neck	3	**8.11%**
Breast	0	**0%**
Rectum	1	**2.70%**
Gyneco (others)	0	**0%**
Technical aspects	14	**37.84%**
Total	37	**100.00%**

Table 3: All papers including MRI and IGRT

All articles	Number of papers	Percentage
Prostate	22	**17.90%**
Brain/CNS	30	**24.40%**
HN	16	**13.00%**
Breast	6	**4.90%**
Rectum	5	**4.06%**
Cervix	5	**4.06%**
Ovary	1	**0.81%**
Liver	1	**0.81%**
Sarcomas	2	**1.62%**
CNS, HN, Prostate, Cervix	1	**0.81%**
Technical aspects	34	**27.64%**
Total	123	**100%**

Table 4: Technical aspects of "MRI Planning" papers

Content	Number of papers	Percentage
Dose calculation	7	**18.92%**
sCT	10	**27.03%**
Registration	10	**27.03%**
Issues/Challenges	7	**18.92%**
Others	3	**8.10%**
Total	37	**100.00%**

Table 5: All articles year of publication percentage

Year of publication	Number of papers	Percentage
2012-2016	73	59.35%
2007-2011	34	27.64%
2002-2006	10	8.13%
2001 and older	6	4.88%
Total	123	100.00%

Figure 1: Year of publication by theme