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IPEM Topical Report: A 2018 IPEM survey of MRI use for external beam radiotherapy treatment planning in the UK

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3 **IPEM Topical Report: A 2018 IPEM survey of MRI use for external beam radiotherapy**
4 **treatment planning in the UK**
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Abstract

Introduction/Background:

The benefits of integrating MRI into the radiotherapy pathway are well published, however there is little consensus in guidance on how to commission or implement its use. With a view to developing consensus guidelines for the use of MRI in external beam radiotherapy (EBRT) treatment planning in the UK, a survey was undertaken by an Institute of Physics and Engineering in Medicine (IPEM) working-party to assess the current landscape of MRI use in EBRT in the UK.

Methods:

A multi-disciplinary working-party developed a survey to understand current practice using MRI for EBRT treatment planning; investigate how MRI is currently used and managed; and identify knowledge gaps. The survey was distributed electronically to radiotherapy service managers and physics leads in 71 UK radiotherapy (RT) departments (all NHS and private groups).

Results:

The survey response rate was 87% overall, with 89% of NHS and 75% of private centres responding. All responding centres include EBRT in some RT pathways: 94% using Picture Archiving and Communication System (PACs) images potentially acquired without any input from RT departments, and 69% had some form of MRI access for planning EBRT. Most centres reporting direct access use a radiology scanner within the same hospital in dedicated (26%) or non-dedicated (52%) RT scanning sessions. Only two centres reported having dedicated RT MRI scanners in the UK, lower than reported in other countries. Six percent of radiotherapy patients in England (data not publically available outside of England) have MRI as part of their treatment, which again is lower than reported elsewhere. Although a substantial number of centres acquire MRI scans for treatment planning purposes, most centres acquire less than five patient scans per month for each treatment site. Commissioning and quality assurance of both image registration and MRI scanners was found to be variable across the UK. In addition, staffing models and training given to different staff groups varied considerably across the UK, reflecting the current lack of national guidelines.

Conclusion:

The primary barriers reported to MRI implementation in EBRT planning included costs (e.g., lack of a national tariff for planning MRI), lack of MRI access and/or capacity within hospitals. Despite these challenges, significant interest remains in increasing MRI-assisted EBRT planning over the next five years.

Introduction

Due to its superior soft-tissue discrimination, compared to computed tomography (CT), magnetic resonance imaging (MRI) has been used as a tool in external beam radiotherapy (EBRT) to aid in the delineation of tumours and normal tissues since the mid-1980s (Curran *et al* 1986, Rai *et al* 2017, Kupelian and Sonke 2014, Raaymakers *et al* 2009, Pollard *et al* 2017). The benefits of MRI within EBRT have been evidenced in many tumour sites including the brain (Beavis *et al* 1998), head and neck (Močnik *et al* 2018, Liney *et al* 2013), breast (Shang *et al* 2017, Giezen *et al* 2011), prostate (Ménard *et al* 2018), cervix (Metcalf *et al* 2013) and liver (Voroney *et al* 2006, van de Lindt *et al* 2016). The inability to distinguish tumour from normal tissues on CT in the abdomen has led to a recent increase in interest in abdominal MRI for EBRT treatment planning, with 4D MRI suggested as a motion management strategy (Paganelli *et al* 2018b, Stemkens *et al* 2018).

In addition to anatomical information, MRI allows the ability to undertake multiparametric imaging within a single appointment slot. Specifically functional MRI (defined here in the context of EBRT as non-anatomical imaging that is used to assess physiology, such as diffusion weighted imaging (DWI) and dynamic contrast enhanced (DCE) imaging) adds to the information offered by CT for accurate target and normal tissue delineation in radiotherapy (RT) treatment planning.

The American Association of Physicists in Medicine (AAPM) Task Group (TG-101) (Benedict *et al* 2010) on stereotactic body radiotherapy (SBRT or SABR) states that MRI is a gold-standard for visualization of brain tumours and is “increasingly used in SBRT applications including prostate, spinal tumours, chest, and solid abdominal tumours”. With the development and clinical implementation of hybrid MRI-RT delivery devices (Mutic and Dempsey 2014, Keall *et al* 2014, Fallone 2014, Lagendijk, J J W, Raaymakers, B W, van Vulpen 2014), the impetus for more centres to routinely use MRI in RT planning continues to grow (Erler *et al* 2018, Glide-hurst *et al* 2016).

There are, however, well reported challenges to clinical implementation of MRI for EBRT treatment planning, including: assessment and assuring geometric fidelity; integration and compatibility of a flat-couch top and lasers; assessment and management of image registration errors; and the additional costs to train and resource staff.

Even though there are arguments for MRI to be integrated into a CT workflow for EBRT treatment planning and a growing interest in the potential of MRI-only treatment pathways (Edmund and Nyholm 2017, Johnstone *et al* 2018), uptake of MRI scanners dedicated for RT has been slow. Recent surveys carried out in Australia and Canada reported similar low rates of uptake, with only two (Batumalai *et al* 2016) dedicated MRI scanners for RT throughout the 37 independent RT providers in Australia (The Royal Australian and New Zealand College of Radiologists 2017) and four (Campbell *et al* 2018) systems in the 57 RT departments in Canada (Canadian Association of Radiation Oncology 2018). A recent marketing survey on the uptake of MRI on a per patient basis showed that across the USA in 2017, 24% of radiotherapy treatment courses were planned with MRI as part of their treatment (IMV 2018) up from 12% in 2010. In 2018, an internal survey at Liverpool Cancer Therapy Centre,

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3 Sydney Australia with a dedicated scanner found that 32% of all RT patients received MRI
4 (Liney 2018).
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7 As a response to the increasing evidence of the benefit of MRI for treatment planning, the
8 Institute of Physics and Engineering in Medicine (IPEM) have commissioned a working party
9 to review the current practice of MRI in EBRT planning in the UK and to provide guidance on
10 its use. The first task of this working party was to undertake a survey of the use of MRI in
11 EBRT in the UK, the results of which are reported here. The specific aims of the UK survey
12 were to: understand current practice of the use of MRI for EBRT treatment planning;
13 investigate how MRI is currently used and managed; and identify knowledge gaps in the
14 field. The results of this survey will be used to inform guidance on the use of MRI for EBRT
15 treatment planning in the UK. This survey considered the use of MRI for photon EBRT
16 treatment planning. Proton therapy, Gamma Knife, intraoperative RT and brachytherapy
17 were considered specialist treatments and thus beyond the scope of this work.
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23 **Method**

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25 A survey was developed by a nine member, interdisciplinary IPEM working party tasked with
26 producing guidelines on the use of MRI in EBRT treatment planning. The survey was
27 designed with the intention that it would be most effectively completed by an
28 interdisciplinary group at each institution to capture a range of aspects of clinical use. The
29 survey comprised of 10 sections:
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- 32 1. MRI access
 - 33 2. Clinical sites in which MRI is used for EBRT treatment planning
 - 34 3. MRI equipment
 - 35 4. MRI pulse sequence details
 - 36 5. MRI to CT registration
 - 37 6. MRI commissioning and quality assurance (QA)
 - 38 7. MRI safety
 - 39 8. Workflow, staffing and training
 - 40 9. Barriers to implementation of MRI for EBRT planning
 - 41 10. Future applications of MRI
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48 The Jisc Online Surveys platform (<https://www.onlinesurveys.ac.uk/>, Jisc, Bristol, UK) was
49 used to create the survey (which is displayed in supplementary data in appendix 1). This
50 facilitated electronic distribution, online response review and the ability to download the
51 complete dataset for offline analysis. The survey was validated through a pilot study at the
52 institutions represented in the Working Party to ensure that it could be completed in
53 approximately 20 minutes. The survey was sent to 71 UK departments, comprising of 63
54 National Health Service (NHS) centres and eight private groups. An electronic link to the
55 survey and a covering note was sent to heads of both RT Service and RT Physics in June
56 2018. A subsequent reminder email was sent to non-responders two weeks later. In order to
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3 maximise the participation rate, further encouragement was given to non-responding
4 centres using personal contacts in July 2018. The survey was closed after a total of eight
5 weeks. Responses from satellite centres (or linked sites in the case of private groups) were
6 combined to give a single response.
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10 Institutions were asked to estimate total patient numbers per month who received MRI as
11 part of their RT planning. For NHS England centres these figures were used to estimate the
12 percentage of RT patients per clinical site receiving MRI scans as part of their treatment
13 planning. This was possible as Public Health England report the total number of RT
14 treatment episodes per clinical site (National Cancer Registration and Analysis Service 2017).
15 Within the UK the NHS management is split between the 4 countries and NHS for the other
16 countries do not report these figures. The following assumptions were made: 1) annual
17 number of episodes per disease site in England were taken as reported by Public Health
18 England in 2016/2017 and was only reported for adults; 2) estimated number of patients
19 per month receiving MRI scans for EBRT planning purposes for all centres in England, as
20 reported in the survey, were multiplied by 12 to get an annual figure; 3) estimated annual
21 figures were adjusted for total response rate in England (88%) assuming that the
22 distribution of throughput in the responding centres was representative of that in all
23 centres.
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30 The choice of MRI pulse sequences varied between institutions for each of the tumour sites.
31 Due to the wide range of sequences used, and vendor-specific naming conventions,
32 sequences have been summarised by weighting and acquisition method, specifically as: T1-
33 weighted (T1w) or T2-weighted (T2w); 2D or 3D; whether contrast agent was included; and
34 whether fluid or fat suppression was used. Only tumour sites which were acquired at a
35 minimum of five centres were included for this analysis, namely: brain, head and neck,
36 spine, prostate, gynaecological, liver and rectum/anus. Multiple responders specified the
37 use of diagnostic sequences for MR treatment planning.
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42 The terminology for MRI scanners dedicated to RT treatment planning is ill defined but they
43 are often referred to as MRI simulators or MRI sims in the literature. For clarity within this
44 manuscript, the term 'dedicated MRI for RT' is used and means an MRI scanner with such
45 auxiliary equipment that patients can be scanned in the treatment position, for example, a
46 flat-top couch and indexed immobilisation equipment.
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50 **Results:**

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52 An overall response rate of 87% of the centres contacted was achieved, with response rates
53 of 89% and 75% for NHS and private centres respectively. It should be noted that one
54 private provider replied on behalf of eight affiliated centres using unified MRI protocols.
55 Some inconsistencies in data reporting were observed but no data cleaning was performed
56 so results shown are as reported by centres.
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Access to MRI

It was reported that all responding centres use MRI for EBRT treatment planning in some form: either from a Picture Archiving and Communication System (PACS), potentially acquired in another institution (94% of responders); some form of direct access to an MRI scanner (69% of responders); or a combination of both. Of the centres that are using images from PACS for treatment planning, only 12% perform any image QA.

For the centres reporting some form of direct MRI access, the main access comes from radiology scanners within the same hospital, either on an ad hoc basis (52% of responders), with dedicated RT sessions (26% of responders) or with both ad hoc and dedicated sessions on a radiology MRI scanner (16% of responders). Only two responders have a dedicated MRI scanner for RT. Finally, two responders have arrangements to have MRI scans acquired at a different institution.

Clinical sites in which MRI is used for EBRT treatment planning

The breakdown of the number of centres acquiring MRI for each clinical site is shown in Figure 1. The most common treatment sites where MRI is used in RT treatment planning were brain (52% of responders) and prostate (52% of responders). Over 20% of responding centres acquire MRI for liver, spine, head and neck and gynaecological treatment sites. Less common treatment sites were rectum/anus, nodes, lung, pancreas, sarcoma and brachial plexus (all acquired at less than 15% of responding centres).

Nineteen percent of centres acquire MRI for brain patients in the treatment position. For the other most common clinical sites (where more than five centres acquire MRI scans) a mean of 49% of centres scan their patients in the treatment position, ranging from 38% for ano-rectal patients to 62% for liver patients.

Figure 1 also shows the breakdown of the number of centres acquiring MRI routinely, on an ad hoc basis, or for research purposes only. Some centres selected more than one option and in this case the centre was double or triple counted in figure 1. The most common treatment site to routinely acquire MRI scans for treatment planning is the brain, with 75% of the 34 centres who acquire brain MRIs doing so routinely for all patients. Although prostate MRI acquisitions are also relatively common, only 22% of the 34 centres who reported acquiring MRI for prostate did so routinely for all their prostate patients. Pancreas, lung, sarcoma and brachial plexus are acquired at five or fewer centres, either on an ad hoc basis or solely for research purposes.

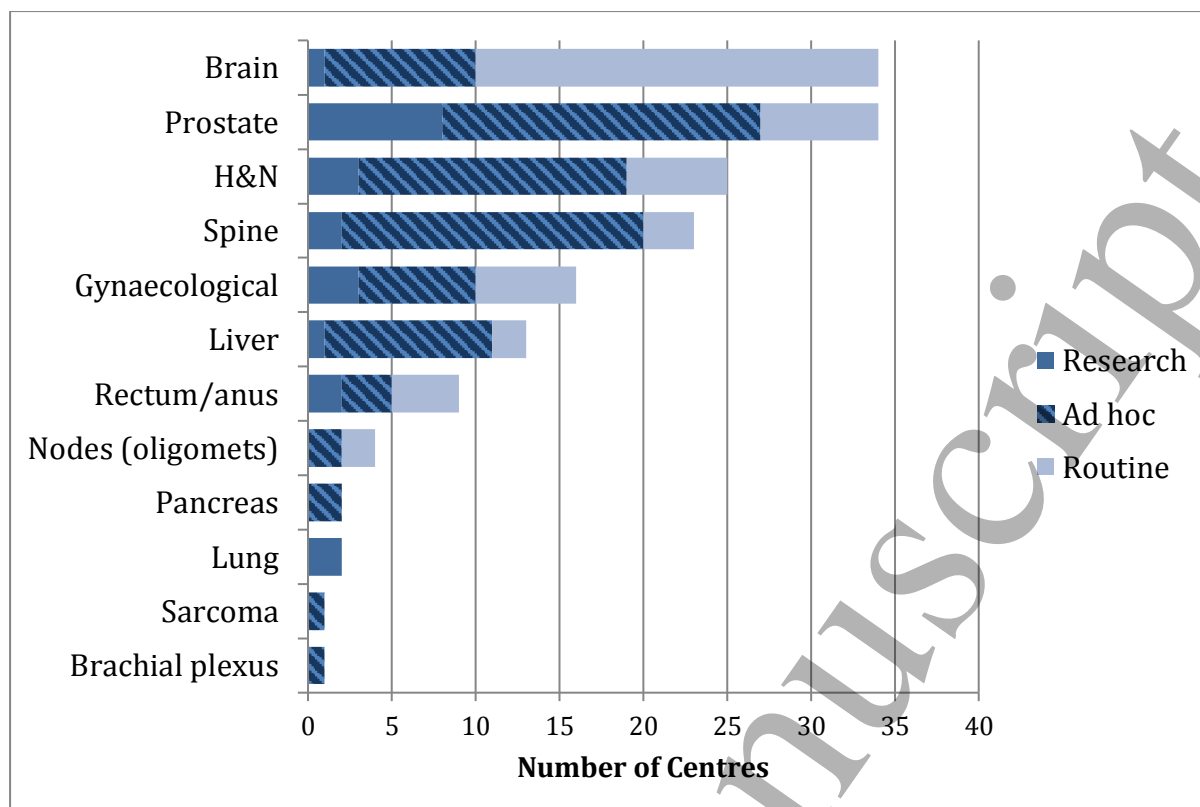


Figure 1 - Distribution of MRI acquisition category (acquired for Research, on an ad hoc basis or routinely for all patients) for all treatment sites reported

The breakdown of the number of patients scanned at each centre per month per treatment site is shown in Figure 2. Several centres that reported access to MRI did not report the actual numbers of patients scanned per month and hence the distributions in figures 1 and 2 differ. Although a substantial number of centres acquire MRI scans for treatment planning purposes, most centres acquire fewer than five patient scans per month for each treatment site. Only three centres scan more than 20 brain patients per month, three centres scan more than 20 prostate patients per month and one centre scans more than 20 gynaecological patients per month.

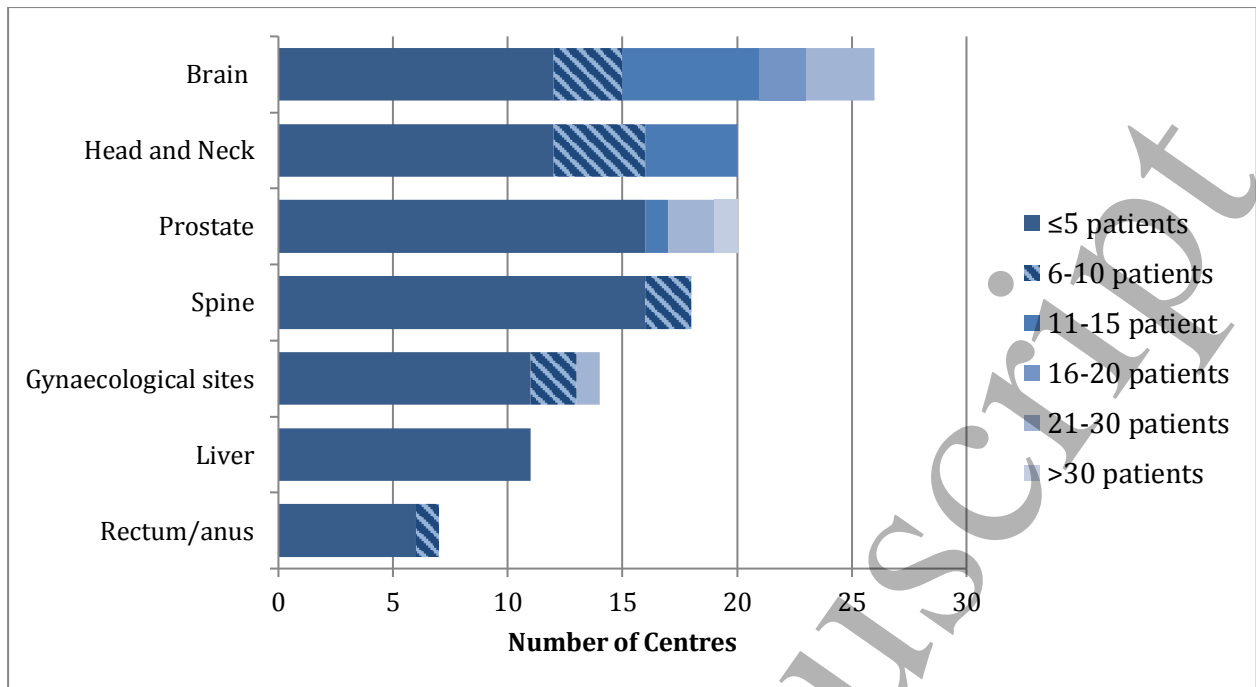


Figure 2 - Number of patients scanned at each centre per month for most common treatment sites (excluding sites acquired by fewer than 5 RT centres).

Estimates of the percentage of EBRT patients for different clinical sites treated in NHS England institutions that benefitted from an MRI scan as part of their treatment planning, can be seen in Table 1.

Clinical site	Number of episodes in England 2016/17 ¹	Estimated number of MRI acquisitions in England in 2018 ²	Estimated percentage of patients receiving planning MRI
Brain	3512	3198	91%
Head & Neck	7029	1285	18%
Prostate	20278	1895	9%
Gynaecological	4073	910	22%
Rectum/anus ³	7168	368	5%
All sites ⁴	133498	7656	6%

Table 1 - Number of patients in NHS England receiving RT, estimated number having MRI acquired for RT and estimated percentage of patients having MRI for EBRT for treatment planning per clinical site. Data not publically available outside of England. ¹As reported by Public Health England on National Cancer Registration and Analysis Service website between 1/4/2016-31/3/17 (National Cancer Registration and Analysis Service 2017). Only clinical sites with data given on this report have been detailed here. ²As reported in this survey divided by 0.88 to adjust for response rate in England. ³Reported as colorectal by Public Health England. ⁴Total patients receiving RT for all sites was reported for 2015/2016 by Public Health England (Public Health England 2017).

MRI equipment

The most common MRI scanner field strength that centres had access to was 1.5 T (63% of responders). 23% of responders had access to both 1.5 T and 3 T MRI scanners, one centre reported access to a 3 T MRI scanner alone and one centre reported access to a 0.35 T MRI scanner.

Only 10% of responders use external RT lasers to setup patients on their MRI scanner. Three percent use lasers for all sites and six percent only use them when acquiring images for prostate and/or head and neck patients.

In order to acquire MRI in the treatment position 47% of responders reported using a flat top couch, with 34% having a commercial product and 13% manufacturing one in-house. Other common items of MRI equipment used for RT are commercial knee blocks (44% of responders) and coil bridges supports or holders (26% of responders). Around 20% of centres reported using ankle/foot supports, masks and vacuum bags. Only seven percent of responders use RT specific radiofrequency (RF) coil arrangements.

MRI sequence details

Responses from centres regarding their use of different MRI sequences are detailed in Figure 3. In general, there was little indication provided of acquisition plane, but where mentioned the transverse plane was specified. It was reported that for all tumour sites a combination of T1w, T2w, 2D and 3D sequences were acquired. A mixture of spin-echo (SE) and gradient echo (GE) sequences are used at institutions. There was wide variation in sequence choice with institutions reporting the use of combinations of sequences.

The responses show that fat suppression techniques are acquired in head and neck, spine, prostate and liver patients. Fat suppression techniques included: inversion recovery (IR) based techniques such as short tau IR (STIR) and spectral pre-saturation with IR (SPIR), frequency selective saturation and Dixon-based techniques (Del Grande *et al* 2014). Fluid suppression was acquired in the brain with 20% of responders using the FLAIR (fluid attenuated inversion recovery) sequence (Saranathan *et al* 2017).

Contrast agent was used for all clinical sites and was most common for brain imaging with 60% of centres using contrast for their brain patients. Imaging at multiple time points following contrast administration was noted for liver patients. DWI, which is sensitive to the free Brownian motion of water molecules in tissues (Malayeri *et al* 2011), was acquired for RT treatment planning in prostate and rectum/anus cancer patients.

Centres reported that MR images were acquired for gynaecological (20%) and prostate (7%) treatment planning in the presence of hip replacements to help improve delineation. In

addition, T2* weighted sequences, which are sensitive to magnetic field inhomogeneities, were used to identify fiducial markers in prostate patients at 11% of institutions.

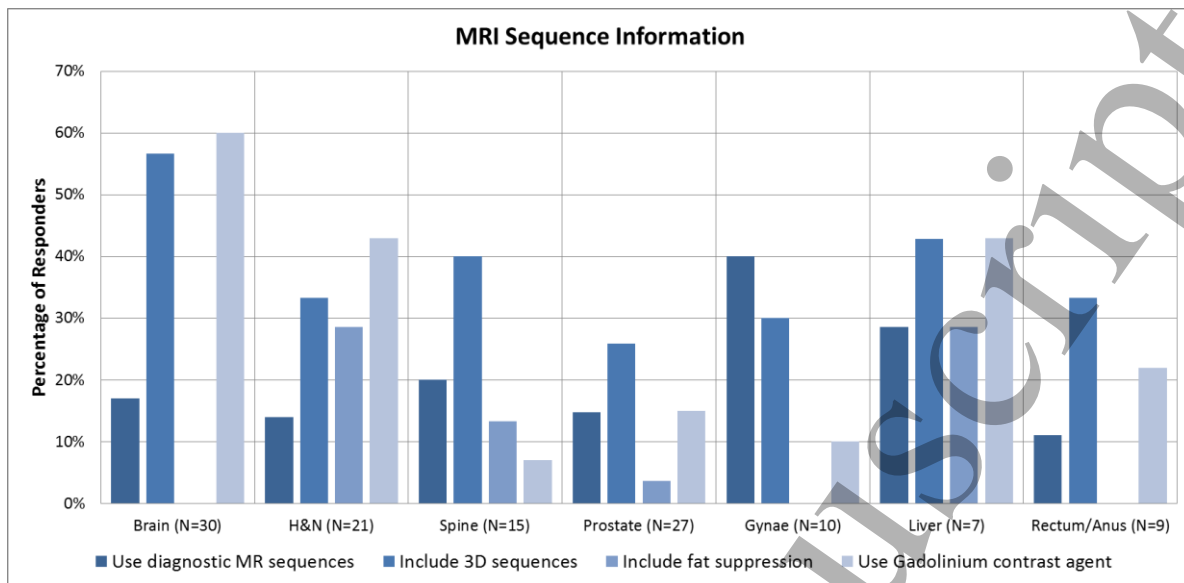


Figure 3 - MR sequence details for sequences which were common across the majority of tumour sites. The N represents the number of responses obtained for each tumour site.

MRI to CT registration

For MRI to CT registration for RT treatment planning, 69% of responders (all centres who have some dedicated MRI access) reported using rigid registration and 11% of responders use deformable image registration. Of the centres using deformable registration: two percent are using it for liver only, two percent for head and neck only, three percent reported to be in the commissioning process and five percent are using it for head and neck patients in a research only capacity. Overall, only two centres reported using deformable image registration clinically.

A variety of tests were identified for the commissioning of software used for MRI to CT registration. These tests and the number of centres which carry them out are summarised in table 2. The most common test reported was qualitative assessment of patient registrations (39% of responders), followed by assessment of checkerboard, overlap on phantoms and patients (26% of responders) and quantitative assessment of landmark alignment (15% of responders). One centre used a free-text entry box to report the use of a third-party service in commissioning of MRI to CT registration and one centre responded that they use "comparison versus an expert".

Commissioning tests

Reported access to MRI

reported	No access	Ad hoc	Dedicated access	Other arrangements	All responding centres
	(n = 19)	(n = 22)	(n = 16)	(n = 5)	(n = 61)
Quantitative assessment of physical phantom registrations	4				4
Quantitative assessment of digital phantom registrations	3	4	1		8
Quantitative assessment of contours on registered images	1	3	2		6
Quantitative assessment of landmark alignment (target registration error)	4	5			9
Qualitative assessment of patient registrations	5	10	7	2	24
Assessment of Jacobian determinant					0
Assessment of deformation map		1			1
Consistency, transitivity measurements		3			3
Assessment of checkerboard, overlap on phantoms, patients	5	6	4	1	16
End to end tests	2	3	1		6
Third party service				1	1
Comparison versus expert				1	1

Table 2 - The different tests carried out by centres when commissioning MR to CT registration software broken down by the reported access to MRI at each centre. Centres with no access to MRI may take images directly from PACS for use during treatment planning. Centres with other arrangements include service level agreements or access to privately owned MRI scanners on NHS premises.

Of the centres providing details of using MRI to CT registration, 84% do no quantitative assessment of image registration on a per patient basis and 14% do some form of quantitative assessment (one centre did not submit an answer). Of the centres using MRI to CT registration, seven percent perform quantitative assessment of image registration only if it fails a qualitative test and seven percent of those using MRI to CT registration perform a quantitative assessment of every image registration.

In addition, of the centres using MRI to CT registration, centres with greater access to MRI through dedicated RT sessions are more likely to undertake quantitative assessment (4/11) compared to those with ad hoc slots on a radiology scanner (2/15).

MRI commissioning and QA

In total, 46% of responders provided information on test objects/phantoms that they used for QA purposes. From these, 10/28 sites reported no access to test objects specific to addressing the RT planning workflow. The test objects reported can be seen in table 3.

	Test Objects	Manufacturer	Number of sites
Generic MRI test objects	ACR	Newmatic Medical, Grand Rapids, Michigan, USA	13
	Manufacturer's own test objects	n.a.	7
	Eurospin	Ultrasound Enterprises LTD, West Lothian, UK	1
	MagNET	n.a.	1
	MagIQ Leeds Test Objects	Leeds Test Objects, North Yorkshire, UK	1
Radiotherapy specific MRI test objects	In-house distortion test object	n.a.	9
	CIRS large field of view distortion	CIRS, Norfolk VA, USA	3
	MagPhan RT	The Phantom Laboratory, Greenwich NY, USA	3
	CIRS MRI linac dynamic	CIRS, Norfolk VA, USA	2
	Quasar MRID 3D	Modus Medical Devices Inc, London ON, Canada	2
	LAP Aquarius phantom	Lap Laser, Lueneburg, Germany	2
	Grade phantom	Spectronic Medical AB, Helsingborg, Sweden	2
	CIRS MRI distortion phantom for SRS	CIRS, Norfolk VA, USA	1
	STEEV end-to-end verification phantom patient	CIRS, Norfolk VA, USA	1

	Quasar GRID 3D	Modus Medical Devices Inc, London ON, Canada	1
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Table 3 - The make and number of test objects reported to be in use in the UK for assessing MRI scanners for EBRT.

In terms of the frequency of MRI QA specifically for RT purposes: 59% of responders provided no details; three percent indicated that they do not perform any additional QA for RT; two percent reported unknown arrangements with a 3rd party; and, three percent reported other arrangements, presumed not to fit in with the survey. From the 21 responders who provided information on testing frequency, “at commissioning” was the most common answer for the following tests: large FOV distortion (86%); small FOV distortion (76%); image quality (67%); laser positioning (38%); couch flatness (33%); couch movement (29%); and, 4D tests (10%). The laser positioning test is the only one reported to occur more frequently on at least a monthly or quarterly basis. Table 4 lists the MRI QA commissioning tests reported by centres broken down by the type of MRI access they have.

Commissioning tests reported	Reported access to MRI				
	No access	Ad hoc access	Dedicated access	Other arrangements	All responding centres
	(n = 19)	(n = 22)	(n = 16)	(n = 5)	(n = 61)
Image Quality	4	2	1	0	7
Small FOV Distortion	2	3	2	0	7
Large FOV Distortion	3	2	4	0	9
Laser Positioning	0	1	1	0	2
Couch Movement	1	2	0	0	3
Couch Flatness	1	3	1	0	5
4D tests	1	0	1	0	2

Table 4 - The different tests carried out by centres when commissioning an MRI scanner. Even sites with no regular access to MRI reported QA activity during commissioning.

MRI safety

The responses from centres regarding the identity of two MR safety-related staff roles, the MR Responsible Person and the MR Safety Expert, defined by the Medicines and Healthcare Products Regulatory Agency (MHRA, 2015) are detailed in table 5. The majority of centres reported additional safety features and practices over and above those which would be in place for a diagnostic scanner (see table 6).

Staff group	MR Responsible Person		MR Safety Expert	
	No. centres	% responders with MRI for RT	No. centres	% responders with MRI for RT
Diagnostic Radiographer	28	65%	3	7%
MRI physicist	5	12%	25	58%
Radiologist	4	9%	0	0%
Therapy radiographer	2	5%	0	0%
RT physicist	1	2%	0	0%
Diagnostic physicist	1	2%	5	12%
Varies by scanner, various owners outside department	1	2%	3	7%
3rd party, unknown staff group	1	2%	0	0%

Don't know	0	0%	3	7%
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Table 5 – Staff groups for MR safety-related roles.

Safety feature	No. centres	% responders with MRI for RT
Policies, arrangements	28	65%
Training	22	51%
3 mT (30 G) line marked on the floor	5	12%
Ferromagnetic detectors	2	5%
Field maps and profiles available in the control room	1	2%

Table 6 – Safety features present, in addition to those in place for a diagnostic MR scanner.

Workflow, staffing and training

The majority of responders (88%) reported that the responsibility of imaging patients was led by diagnostic radiographers. However, a substantial portion of responders (56%) indicated that diagnostic radiographers were supported by therapy radiographers in patient setup. This collaborative workflow was supported by education provided to MRI radiographers (about the specific imaging and positioning needs of RT), through a variety of methods (Table 7). Alternatively, in order to assist MRI radiographers, it was also reported that therapy radiographers who were present for MRI acquisitions undertook education in MRI safety, and screening through a mix of local induction and formal programs of study. Training and education for these enhanced roles for both therapy and diagnostic radiographers were undertaken through a mix of local induction and formal programs of study as illustrated in table 8.

Type of Training/Education	Number of Centres Using Method	Percentage of 43 centres with access to MRI in RT
Hands-on awareness from therapy radiographers	1	2%
Imaging needs for RT planning overview	23	53%
Observation of CT acquisition for patient positioning	7	15%
Specific setup and protocols on a per site basis	2	5%
Use of a single imaging isocentre for multiple sequences	2	5%
Use of RT lasers	3	7%

Table 7 - RT-specific Training and Education provided for MR Radiographers working on a dedicated MRI scanner for RT.

Type of Training/Education	Number of Centres Using Training/Education Method	Percentage of 43 centres with access to MRI in RT
Dedicated time shadowing in MRI	8	19%
External MRI courses	2	5%
In house tutorials	18	42%
Local work book activities	6	14%
MRI safety	17	40%
MRI screening	11	26%
Recognised postgraduate MRI Modules	3	7%
Study days	4	9%

Table 8 - Type of MRI-specific Training and Education Provided for Therapy Radiographers working on a dedicated MRI scanner for RT.

In terms of using the images for treatment planning, responding centres indicated a collaborative working practice with all except one reporting that contouring was led by a clinical oncologist. It was reported that the oncologist had support from: dosimetrists (40% of centres), radiologists (30% of centres), radiographers (23% of centres) and physicists (four percent of centres).

The majority of MRI physics support available for setting up a new service for MRI in RT was reported to come from MRI radiology teams in an ad hoc fashion either locally or provided from a different hospital (37% and 19% of responders respectively), or in the form of local RT physicists with some MRI education and experience (26% of centres responding). It was reported that 23% of responders reported that they had no MRI physics support.

Barriers to implementation of MRI for EBRT planning

Eighty-four percent of responders indicated the greatest challenge to incorporating MRI in the EBRT pathway was the lack of access to MRI. Finance also played a significant role in limiting the use of MRI in EBRT, with 33% of centres reporting that the lack of a RT MRI tariff and insufficient funding for staff and equipment as barriers to adoption of MRI in RT planning. Further challenges reported by 27% of centres include the gaps in knowledge and a lack of local support. Free text comments highlighted that some of these issues also resulted in challenges in strategic planning to improve MRI access within EBRT.

Future applications of MRI

Table 9 details the responses from centres about the anticipated role of MRI in EBRT at their institution within the next five years. There is an interest in increasing the role of MRI in EBRT in the UK: 37% of responders plan on implementing functional MRI; 38% intend on commissioning an MRI scanner dedicated for RT; 16% are planning for MRI-only RT; and,

10% are planning to commission an MRI linac. In terms of functional MRI, key issues that were highlighted in responses were: there is pressure to keep MRI slots as short as possible as well as a lack of knowledge of how to include functional information into the treatment planning process.

	Functional MRI (e.g. DCE/DWI)	MRI scanner dedicated for RT	MRI-only RT planning	MRI linac
Currently use	15%	3%	0%	3%
Plan to use/commissioning within five years	37%	38% (27% in addition to current MRI provision and 11% as a replacement)	16%	10%
No intention to use within five years	21%	48%	84%	87%
Don't know	32%	14%	0%	0%

Table 9 - Future plans for the role of MRI for EBRT in their institution, all results shown are percentages of responders. DCE – dynamic contrast enhanced and DWI – diffusion weighted imaging.

Discussion

It has been widely reported that MRI has an important role in planning of EBRT (Cancer Research UK 2015, The Royal College of Radiologists 2017, Schmidt and Payne 2015). Specifically, MRI delineation has been shown to reduce toxicity rates for prostate treatments both with a standard fractionation (Sander et al 2014) and when hypofractionated (HYPRO trial) (Wortel et al 2017). A recent Independent Cancer Taskforce stated not only that the greatest improvements in treatments over the next decade are likely to be imaging based, but also that approximately 15–20 dedicated MRI scanners for RT should be funded by an NHS England national RT capital fund to facilitate the benefits of MRI for EBRT planning (Cancer Research UK 2015). Furthermore, the Royal College of Radiologists (RCR) recently reported that MRI is beneficial for RT volume definition and that a dedicated treatment position MRI will give improved results compared to a registered diagnostic MRI scan (The Royal College of Radiologists 2017).

Although all responding centres used MRI in some capacity for EBRT treatment planning, only two UK centres indicated they have dedicated MRI scanners for RT, which is lower than that reported in Australia and Canada (Batumalai et al 2016, Campbell et al 2018). Moreover, in the UK, the use of MRI is limited in most centres, with over 75% of centres undertaking fewer than five patient scans per month for prostate, spine, liver, gynaecological sites and anal/rectal cancer patients. Based on the responses to this survey, we estimate that in England (data not publicly available for the rest of the countries in the UK) 91% of brain patients undergo MRI as part of their EBRT treatment planning, this figure

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3 is much lower at only 18-22% for head and neck and gynaecological patients. Despite the
4 reduction in toxicity discussed in the literature when MRI is used to guide radiotherapy in
5 the prostate (Wortel et al 2017, Sander et al 2014), less than ten percent of prostate
6 patients in England have MRI included in their RT treatment planning. For all patients in
7 England (data not publically available outside of England) it has been estimated that six
8 percent of patients undergo MRI as part of their EBRT treatment planning which is lower
9 than the 24% of radiotherapy treatment courses in the USA that are planned with MRI as
10 part of their treatment (IMV 2018). Although this is not a direct comparison, it is clear that
11 patients in England are not receiving MRI as routinely as in the USA. Furthermore, a higher
12 figure (32%) has been reported from a Centre in Australia (Liney 2018) with a dedicated MRI
13 scanner for radiotherapy where there had been previously little MRI use.
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19 This survey has revealed a number of issues around the use of MR in EBRT treatment
20 planning that need to be addressed for the benefits of MRI to be widely realised for EBRT
21 patients in the UK. Specifically, these issues relate to the diverse working practises across
22 the UK resulting from a lack of consensus in the literature and no clear guidelines from
23 professional bodies; and, barriers to access and funding.
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27 Highlighting the lack of consensus that exists across the UK, the variety in choice of MRI
28 sequences, commissioning and quality assurance of image registration, or MRI technology is
29 reported. The choice of MR sequences used for treatment planning varied widely between
30 tumour sites and institutions. A number of sites used diagnostic MR scan protocols,
31 suggesting that those sequences may not be optimised for radiotherapy treatment planning.
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35 A combination of spin-echo (SE) and gradient-echo (GE) based sequences were reported
36 between tumour sites and institutions based on specific need e.g. GE sequences for
37 depicting fiducial markers. The choice of 3D versus 2D sequence varied between tumour
38 sites and institutions. The use of 3D sequences was greatest in the brain (>50% of
39 institutions), likely associated with the high isotropic spatial resolution that can be attained
40 to assess fine details and the ability to produce multi-planar reconstructions (Paulson et al
41 2015). Differences in contrast between 2D and 3D sequences could be the reason for some
42 variation in the sequence choice between institutions. Preference for 3D sequences for
43 brain and H&N planning and 2D for prostate and cervix planning has been suggested in a
44 recent consensus paper (Paulson et al 2016).
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50 Contrast agent was most commonly used for brain, H&N and liver MR imaging. However,
51 the number of contrast enhanced scans reported is possibly underestimated as there was
52 no presumption that diagnostic or PACS acquired scans used a contrast agent unless
53 explicitly stated. The use of contrast agent for brain and H&N MR treatment planning has
54 been suggested (Paulson et al 2016) and is recommended for diagnostic MR imaging of the
55 brain in NICE guidance (NICE 2018).
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3 2D and 3D radial acquisition techniques (Feng et al 2014, Pipe 1999) , compressed sensing
4 methodology (Lustig et al 2007) and fast sequences, were mentioned for treatment sites
5 associated with motion, e.g. the liver and lungs. The use of MRI for prostate and
6 gynaecological patients with hip prostheses suggests the inherent benefit of reducing large
7 metallic artefacts over the tumour bed compared to CT when planning in the pelvis (Schmidt
8 et al 2016). The use of DWI was small and varied across centres, with the greatest use being
9 in the prostate (15% of institutions), potentially related to its use in the PI-RADS system
10 (Weinreb et al 2016).
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15 Quality assurance and commissioning of MRI scanners specifically for RT was reported to be
16 variable and was highlighted in this survey by the test frequency variability of QA
17 procedures with only 29% of institutions owning MRI QA test objects that address specific
18 issues within the RT setting. The majority of centres are utilising MRI scans from PACS for
19 use in EBRT planning, only 12% of these centres are performing any QA on the images to
20 ensure their suitability for this purpose.
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25 With regard to a lack of guidance from professional bodies, although various groups have
26 reported their solutions to the use of MRI in EBRT (Liney and Moerland 2014, Paulson et al
27 2015) there is no consensus in the literature or clear guidelines from professional bodies on
28 the topic, or in the case of image registration only beginning to be available. To overcome
29 this, guidance by professional bodies in the literature (either nationally or internationally)
30 would be of benefit to standardise practice. The AAPM TG132 report (Brock et al 2017) is
31 currently the only published guidance on image registration, with no UK-specific equivalent
32 available. Based on the results of this survey, it is clear that the TG132 recommendations on
33 per-patient quantitative tests, or those specifically for deformable registration (Paganelli et
34 al 2018a), have not yet been widely adopted into UK clinical practice.
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40 There is some guidance on QA frequency for diagnostic radiology purposes (McRobbie and
41 Semple 2017, ACR 2017, Jackson et al 2010); the MRI literature gives fairly detailed guidance
42 to those performing quantitative measurements and rather more flexible approaches in
43 diagnostic examinations (Friedman and Glover 2006, Delakis et al 2004). Paulson et al.
44 proposed an ambitious programme of testing which may be perceived as onerous to most
45 MRI sites working with MR-CT fusion to plan RT (Paulson et al 2015). This issue is the central
46 difficulty in proposing testing schedules – even within a fairly focused group of users of MRI,
47 such as the RT planning users, there are still a range of different needs to be considered. An
48 added complication in the UK is that as the majority of MRI access is provided by radiology
49 and their QA requirements are different to those of RT users (Glide-hurst et al 2016). In
50 addition, time pressures on scanners in clinical use may prevent the development of very
51 detailed QA programmes.
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57 IPEM report 112 (McRobbie and Semple 2017) provides guidance on general MRI QA but
58 lacks detailed guidance for specific RT applications of MRI. Quality assurance of such
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3 applications is explored without giving any substantial detail in IPEM report 81 (2nd edition)
4 (Patel 2018).
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7 Guidance is required to ensure that MRI acquired beyond the control of the RT department
8 is appropriate to use for RT purposes. For images used via PACS taken from MRI scanners
9 not under the control of RT, there is the possibility that acquisition parameters could be
10 changed as is standard practice for MRI acquired for radiology. This may impact the
11 suitability of MRI for RT, such as: orientation of acquisition, any parameters effecting
12 geometric distortion and the application of vendor specific geometric distortion correction.
13 Therefore, for MRI used for RT it is vital that MRI sequences are commissioned for their
14 specific purpose and that checks are made to ensure that relevant acquisition parameters
15 are not changed.
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21 The variability of how centres access MRI and the lack of guidance either in the literature or
22 by professional bodies is also evidenced in the varied interdisciplinary working practices are
23 used to acquire, register, interpret and contour MR images among the 43 centres with
24 access to MRI. Staffing models and training varied significantly for MRI acquisition for EBRT;
25 and it is hypothesised that this is due to both. There is an indication that implementation of
26 MRI for EBRT treatment planning in the UK requires an inter-disciplinary team approach. In
27 terms of physics support, collaboration between radiology and RT is vital with the majority
28 of support coming from radiology. Worryingly, almost one in four centres reported no MRI
29 physics support. This could be addressed via further training, contracting in support,
30 employing an MRI physicist or a mentoring/buddy scheme between hospitals. Although the
31 staff education has been shown to be variable, a full assessment of educational needs and
32 quality of existing programs across all staff groups has yet to be undertaken. This has
33 prompted a response by the Society of Radiographers to provide guidance for Therapeutic
34 Radiographers working in MRI for RT, developed jointly by the RT and MRI advisory groups
35 of the college (Eccles 2018).
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43 In the UK, the MHRA defines two roles with responsibility for MR safety: the MR
44 Responsible Person and the MR Safety Expert (MHRA 2015). Although the MHRA doesn't
45 stipulate the staff groups from which these roles should be filled, this survey demonstrates
46 preferences from the responding centres for the MR Responsible Person to be a diagnostic
47 radiographer (65% of responders who had access to MRI for RT) and for the MR Safety
48 Expert to be an MRI physicist (58%). The choice of a diagnostic radiographer reflects the fact
49 that most centres use diagnostic scanners to acquire MRI for RT purposes.
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53 Although the principles of MRI safety are no different when MRI is used for radiotherapy
54 treatment planning, rather than for diagnostic scanning, most centres apply additional
55 safety measures. We can speculate that the reasons for this include the variety of staff
56 groups involved in scanning and the use of patient positioning equipment. Staff involved in
57 scanning patients for radiotherapy planning are often a mix of staff from radiology and
58 radiotherapy departments. This may require additional policies, procedures and training to
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3 ensure safe working practices. The range of equipment that is required may be perceived as
4 a hazard that requires extra safety measures, such as ferromagnetic detectors and marking
5 to indicate the projectile zone.
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8 Barriers including a lack of MRI access and funding are severely limiting, the responses
9 reported in free text comments within the survey suggests many centres recognise the
10 benefit of MRI for a wide range of patient treatment sites, but these issues limit the number
11 of patients that centres are able to scan. In the NHS, there is no specific tariff or
12 reimbursement for MRI examinations performed for RT planning. Radiotherapy for brain
13 cancers are the exception: this is the most commonly acquired patient group with 91% of
14 patients benefitting from MRI as part of their treatment planning, yet 46% of institutions
15 acquire MRI for fewer than five patients per month. The higher uptake of MRI for EBRT
16 planning in the brain is likely due to the common approach of utilising diagnostic scans
17 where good image registration with planning CTs can be achieved using the skull for rigid
18 alignment.
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24 The main reported barriers to utilising MRI for EBRT in the UK are financial, specifically, a
25 lack of MRI access and no tariff. It was reported in this survey that there was a severe
26 shortage of available MRI scanners in many hospitals across the UK; and that a lack of tariff
27 or reimbursement for MRI scans in RT makes building a business case for supporting the
28 required capital and revenue costs challenging. This is in line with the Independent Cancer
29 Taskforce findings in 2015 (Cancer Research UK 2015), which reported that it is becoming
30 increasingly inefficient to use MRI facilities for both radiology and RT. Securing tariffs for
31 MRI scans, as well as the proposed national capital fund proposed by the Taskforce to
32 support the capital costs of MRI scanners for RT, is crucial to enable RT patients across the
33 NHS to benefit from MRI guidance in their treatment plans. It would be of interest to
34 compare the provision of MRI for EBRT in the UK to other healthcare settings with other
35 funding models. Although this is beyond the scope of the survey presented here the authors
36 have started this work by initiating the same survey in other countries with the aim of
37 publishing this data in the future.
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45 Based on the responses to this survey and the growing body of literature on MRI guided RT
46 (Schmidt and Payne 2015), there is evidence of a trend towards including MRI in the EBRT
47 planning pathway over the next five years in the UK. The greatest interest appears to be in
48 dedicated MRI scanners for RT and functional MRI. To a lesser extent, there is interest in
49 MRI-only RT planning and MRI-linacs, generally from more research active centres.
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52 To address some of the issues highlighted in this survey, it is the intention of the IPEM
53 working group who have authored this work to provide guidance. A further point to note is
54 that whilst 39% of responders are planning for a new MRI scanner dedicated to RT, guidance
55 for these centres on how to setup such a dedicated scanner would be useful, 48% of centres
56 are not planning to purchase a new MRI scanner for RT. Therefore, to meet the needs of this
57 48% it is the intention of the IPEM working party to provide guidelines to also offer
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3 pragmatic advice on how to make best use out of the sessions that centres already have on
4 a current MRI scanner.
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6 7 **Conclusion**

8
9 The UK MRI in EBRT landscape has been comprehensively surveyed in 2018. Access to
10 dedicated MRI for EBRT is limited and lower than reported in other countries, with only two
11 dedicated MRI scanners for RT. It is also estimated that only six percent of all EBRT patients
12 in England are benefiting from MRI in their RT planning which is lower than international
13 figures where these data are available. Despite the evidence for reduced toxicity when
14 utilising MRI during planning for prostate patients, only an estimated nine percent of those
15 radiotherapy patients in England benefit from MRI-aided delineation. The main reasons
16 given for the lack of MRI for EBRT treatment planning are financial: lack of access to MRI
17 scanners and lack of tariff making business cases for MRI scanners dedicated for RT
18 challenging. This survey has highlighted that collaboration between RT and Radiology
19 departments is important throughout the UK as it was found that Radiology departments
20 support RT in terms of both equipment and staff. Many aspects of MRI in EBRT have been
21 implemented heterogeneously in part due to the range of access to MRI scanners but
22 largely due to the lack of consensus in the literature or explicit guidance from professional
23 bodies. Despite being covered in the literature, the following have been identified as
24 knowledge gaps in RT: staffing models/training; QA of both MRI scanners and image
25 registration; sequences and the complimentary use of anatomical and functional
26 information. It is the intention of the IPEM working group to attempt to fill these knowledge
27 gaps in a future report specifically offering guidance not only for those who intend to setup
28 a new MRI for RT service on a dedicated MRI scanner, but also for centres to get the most
29 out of limited access on current MRI scanners.
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39 40 41 **Acknowledgment**

42
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44 survey. We would also like to thank all respondents to the survey, without the hard work
45 from these centres the survey would not have been possible.
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50 part of the care and support of cancer patients. The data is collated, maintained and quality
51 assured by the National Cancer Registration and Analysis Service, which is part of Public
52 Health England (PHE).
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9 **Supplementary material Appendix 1 - SEE PDF DOCUMENT**
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