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Findings of the AAPM Ad Hoc committee on magnetic resonance imaging in radiation therapy: Unmet needs, opportunities, and recommendations

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The past decade has seen the increasing integration of magnetic resonance (MR) imaging into radiation therapy (RT). This growth can be contributed to multiple factors, including hardware and software advances that have allowed the acquisition of high-resolution volumetric data of RT patients in their treatment position (also known as MR simulation) and the development of methods to image and quantify tissue function and response to therapy. More recently, the advent of MR-guided radiation therapy (MRgRT) - achieved through the integration of MR imaging systems and linear accelerators - has further accelerated this trend. As MR imaging in RT techniques and technologies, such as MRgRT, gain regulatory approval worldwide, these systems will begin to propagate beyond tertiary care academic medical centers and into more community-based health systems and hospitals, creating new opportunities to provide advanced treatment options to a broader patient population. Accompanying these opportunities are unique challenges related to their adaptation, adoption, and use including modification of hardware and software to meet the unique and distinct demands of MR imaging in RT, the need for standardization of imaging techniques and protocols, education of the broader RT community (particularly in regards to MR safety) as well as the need to continue and support research, and development in this space. In response to this, an ad hoc committee of the American Association of Physicists in Medicine (AAPM) was formed to identify the unmet needs, roadblocks, and opportunities within this space. The purpose of this document is to report on the major findings and recommendations identified. Importantly, the provided recommendations represent the consensus opinions of the committee's membership, which were submitted in the committee's report to the AAPM Board of Directors. In addition, AAPM ad hoc committee reports differ from AAPM task group reports in that ad hoc committee reports are neither reviewed nor ultimately approved by the committee's parent groups, including at the council and executive committee level. Thus, the recommendations given in this summary should not be construed as being endorsed by or official recommendations from the AAPM. [https://doi.org/10.1002/mp.14996]

Key words: biomarker, magnetic resonance, MRgRT, radiation therapy, safety, simulation

1. INTRODUCTION

Interest in the use of MR imaging in RT has been growing rapidly over the past several decades. A search of PubMed (https://www.ncbi.nlm.nih.gov/pubmed) on the term "MRI radiation therapy" from the years 1980 through 2019 listed a total of 30,604 publications, with a per annum increase that demonstrates exponential growth; starting with a single publication in 1980, 2,162 publications were reported for 2019.

Despite both the utility and rapid growth of MR imaging in RT and MRGRT, [1,2] significant challenges and roadblocks to the adaptation, development, and wider dissemination of this technology remain. Because expertise in MR imaging largely falls within Radiology departments, many technologies and clinical practice advances are slow to translate into Radiation Oncology. This is due in part to research and development being performed with a primary focus on diagnosis by research groups closely aligned with Radiology departments. Furthermore, minimal overlap exists between the memberships of relevant professional societies, hindering efforts to disseminate the latest advances in MR imaging - most frequently reported at meetings of the International Society of Magnetic Resonance in Medicine (ISMRM) - to RT medical physicists, whose primary professional home is within the AAPM.

In recognition of the rapid adoption of MR imaging in RT, the AAPM created an ad hoc committee of domain experts tasked with identifying current activities within the AAPM related to MR imaging in RT, assessing unmet needs within the MR imaging in RT field, and providing recommendations on actions needed to address the needs and knowledge gaps identified by the committee. To accomplish this, a variety of data collection methods were used, including stakeholder surveys, literature reviews, content expert interviews, and peer-to-peer communication. The information presented herein summarizes these data and provides those recommendations developed by the committee.

Finally, the rapid integration and growth of MR imaging into RT has created a sense of urgency regarding the need to implement the recommendations developed by the committee. In addition, because implementation will require collaboration across multiple disciplines and specialties, the committee's membership wished to share the major findings and recommendations with the entire community instead of restricting the information to membership of the AAPM only. By sharing this information it is hoped that a broader discussion within the entire community will be initiated and in doing so accelerate solutions to the unmet needs and wants described within.

2. DATA COLLECTION METHODS

The findings described in this report were based on data collected by the committee. Data collection methods included a formal AAPM hosted online survey, literature review, and question and answer format email surveys. The online survey was sent to 60 content experts identified by committee members with representation from clinical practice, academic medicine, and industry. Most individuals were located within North America with European representation being the minority. Figure 1 shows the distribution of survey participants based on job description. The survey focused on identifying unmet needs and roadblocks in the MR RT space pertinent to clinical practice, education, professional activities, and research. The purpose of performing a literature review was to identify unmet needs and roadblocks that may not be identified in the online survey, specifically from individuals and organizations working in this space from outside of North America. Email question and answer type surveys were sent to AAPM members and leaders within MR-related professional societies including the ISMRM, RSNA, ASTRO, ESTRO, and the national Swedish consortium (aka Gentle Radiotherapy). MR and MRgRT equipment manufacturers were also surveyed to obtain industry feedback. Surveying professional society members was performed to obtain insight into roadblocks within a society (e.g. AAPM) as well as identifying communication barriers between organizations thereby identifying methods to address them.

3. MAJOR FINDINGS AND RECOMMENDATIONS

3.A. Clinical practice

Technical developments, the marketing of MR imaging systems for RT specific applications, and worldwide regulatory approval of MRgRT systems have given rise to specific needs regarding adaptation and integration of MR imaging in RT into routine clinical practice. Three areas of unmet and/or under-met needs that represent potential roadblocks to further integration and dissemination of these technologies into widespread clinical practice have been identified and are described below.

3.A.1. Improved spatial fidelity of MR imaging data over large (50 cm diameter) fields of view (FOV)

Technical developments, including high-field wide-bore and lower-field open systems, flexible and high density radiofrequency (RF) coils and volumetric imaging sequences, have addressed many technical limitations that have historically impeded the widespread clinical use of MR imaging in RT. However, ensuring high spatial fidelity over a large FOV (50 cm) throughout the entire imaging volume of an MR scanner remains challenging. This is particularly relevant for nonisocentric imaging in which the FOV extends beyond the diameter of spherical volume (DSV). Advanced distortion correction methods that reduce spatial distortion to acceptable tolerances across the entire imaging volume and therefore beyond the volume characterized by the DSV are needed. At a minimum for RT applications spatial fidelity needs to be maintained within ± 2 mm over a DSV of 50 cm centered about the isocenter of the MR scanner and ± 1 mm for stereotactic applications over a DSV of 20 cm which is consistent with the recently published report by the AAPM TG 284 committee[3] and the recommendations provided by AAPM TG 147.[4]

3.A.2. Standardized, vendor-agnostic quality assurance (QA) and quality control (QC) protocols, phantoms, and automated analysis tools

Several phantoms and measurement tools are currently under development or are commercially available (see http://www.cpqr.ca/wp-content/uploads/2020/09/MRI-2020-05-01.

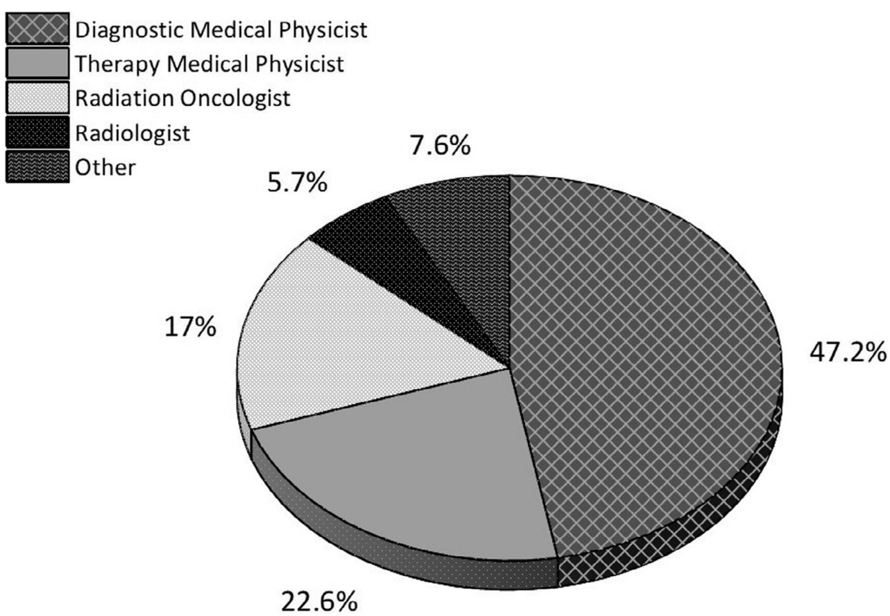

Fig. 1. Distribution of individuals who successfully completed the online stakeholder survey. The survey was sent to 60 individuals of which 53 responded and completed the survey in full.

pdf as an example of guidance on performing MR RT quality control). However, there remains a lack of standardization of phantoms, scanning protocols, and analysis tools to perform QC and QA that are independent of MR scanner manufacturer, model, and field strength. This significantly limits the reproducibility of the MR simulation and MRgRT processes, prevents cross-vendor validation of MR data and the ability to perform multicenter clinical studies. Validation of MR data would include but not limited to assessment of spatial fidelity, accuracy, and reproducibility of quantitative MR parameters and biomarkers, and quantification of the accuracy and reproducibility of 4D and motion tracking techniques and algorithms.

3.A.3. Standardization of MR imaging techniques tailored to the needs of RT

MR simulation sessions are complex and can be time consuming, due in part to the need to place patients in often uncomfortable immobilization devices, ensure that they are able to fit within the magnet bore in treatment position, optimize RF coil placement prior to imaging as well as the need to prescribe and optimize various imaging sequences that provide multiple image contrasts and functional information (e.g., T_1 or T_2 diffusion, perfusion etc). Ongoing pulse sequence development was deemed necessary to reduce overall scan time, reduce or eliminate artifacts arising from sources such as metal implants and motion, and accurately estimate electron density. This should be performed in concert with the adaptation of parallel imaging techniques and high coil density RF coils that are either integrated into the patient's immobilization device or are able to be placed adjacent and closely conform to the patient. There was also the need for the development, validation, and standardization of functional MR imaging techniques that provide more accurate delineation of the target volume (gross and clinical) and adjacent organs at risk and more precisely (spatially and temporally) identify response to therapy. In addition, there is a need for the overall simplification of MR imaging systems for RT to facilitate adoption by community-based practices. Examples include a simplified user interface/operator console that limits the number of parameters modifiable by the scanner operator, treatment site specific imaging protocols optimized and standardized for RT applications, intuitive and automated RF coil element selection and optimization, and the development and standardization of automated post processing tools for anatomic and functional MR imaging.

The unique challenges of integrating an MR scanner and linear accelerator into a single MRgRT system result in compromised performance of the imaging system when compared to high end diagnostic MR or MR simulators. This directly impacts performance of RT specific functions such as quantifying and correcting for inter- and intrafractional motion, adaptive planning, and real time motion management and treatment. While MRgRT manufacturers have addressed and /or mitigated the interaction between linear accelerator components and the MR scanner, it is likely that the integration of these advanced treatment techniques such as volume modulated arc therapy (i.e. VMAT) will result in additional interactions between the two systems requiring yet to be developed technical solutions. It is thus recognized that ongoing research and development is required to continue to advance and integrate this technology into routine clinical use.

3.A.4. Workflow and standardization

Improvements in workflow efficiency, as well as standardization of procedures for both MR simulation and MRgRT, were identified as areas of unmet needs. Specific needs include improved/faster localization and tracking of target volumes in MRgRT, standard definitions of the target volume for specific MR imaging sequences, and processes to streamline decision making by physicians present during MRgRT.

Recommendations for clinical practice

1. Foster close collaboration between medical physicists, MR imaging scientists, and physicians to leverage complementary expertise in order to address those unmet needs related to the clinical use of MR imaging in RT.
2. Bring together groups from multiple professional societies to develop consensus statements on topics such as appropriate use criteria for MRgRT, standardized approaches for MR-based segmentation of the target volume and related organs at risk as a function of pulse sequence and contrast, monitoring of the frequency with which patients undergoing adaptive MRgRT are re-planned, standardized techniques and appropriate use criteria for MR-related biomarkers.
3. Develop consensus testing protocols, phantoms, and performance criteria for QA/QC. Participation by members from professional organizations including but not limited to the AAPM, ISMRM, Radiological Society of North America (RSNA), American College of Radiology (ACR), and American Society for Radiation Oncology (ASTRO) was deemed essential. QA/QC programs should be comprehensive and vendor agnostic. Protocols should also be sufficiently automated and simplified to ensure successful use in routine (i.e., nonacademic) practices.
4. Develop medical physics practice guidelines (MPPGs) on MR safety, MR simulation, MR-guided patient setup, MR-guided on-table adaptive planning, and dynamic MR-based gating as it pertains to the unique environments of MR simulation and MRgRT.

3.B. Education and MR safety

Ongoing technical innovations in MR imaging, their adaptation to RT and the development of MRgRT systems (e.g. MR-linacs) has given rise to the need for education of the RT community. As these innovations and systems mature and propagate into community-based healthcare systems, this need will grow. Educational requirements must therefore be established for all personnel who work either within or in support of the MR imaging in RT space. At the graduate level, it was recognized that current Commission on Accreditation of Medical Physics Education Programs (CAMPEP) guidelines do not provide sufficient depth for non-MR physicists and do not provide course materials that address the specific needs of MR imaging in RT. Establishing MR safety standards that are universal to both Radiology and Radiation Oncology environments and minimum requirements for MR safety training were deemed to be the most urgent needs.

Recommendations for education

1. Develop medical physics graduate and residency programs with greater integration of imaging with RT, including content to address the needs of imaging and therapy medical physicists specific to MR imaging in RT.
2. Create postgraduate, post-residency, and post-certification peer-to-peer educational programs for medical physicists on MR imaging in RT topics.
3. Develop new and support nascent (e.g. American Board of Medical Physics MR RT sub certification program) credentialing mechanisms for medical physicists specific to MR imaging in RT.
4. Create multisociety co-sponsored educational courses on MR imaging in RT for radiologists, radiation oncologists, and MR scientists.
5. Establish cross-disciplinary training and credentialing of MR technologists and radiation therapists, particularly with regards to MRgRT treatment systems.

Recommendations for MR safety

1. Develop consensus standards for MR safety endorsed by professional bodies such as the AAPM, ISMRM, RSNA, and ASTRO that are applicable to *all uses* of MR imaging. This would include minimum training requirements and standardization in terms of content and hours for MR safety training and continuing education.
2. Standardize all MR safety protocols and procedures within a given facility and across multiple facilities that are part of the same healthcare organization.
3. Develop MR materials for institutional leadership and administrators to convey the scope of education and training required. Facilities without prior MR experience, such as free-standing Radiation Oncology centers, will require comprehensive education of all facility personnel. Links to existing safety standards, regulations, security requirements, and accreditation criteria should be included.
4. Develop didactic courses, online tutorials, and peer-to-peer educational sessions to implement universal MR safety standards and protocols for all personnel.
5. Endorse MR safety officer training and credentialing through professional bodies, such as the American Board of Magnetic Resonance Safety (ABMRS), and standardize MR safety practices across all specialties, including practices that use MR imaging in RT.

3.C. Research

A consistent theme that emerged from the data collection process was the critical need for ongoing research and development to address a range of challenges and unmet needs. Specific research areas/themes included: (a) advanced and rapid image acquisition techniques for improved motion management and improved tumor/disease visualization, (b) validation of both conventional MR (anatomic) and MR biomarkers for disease identification (i.e., contouring), biological targeting to identify radiosensitive tissues, and improved monitoring of treatment response or failure, (c) establishment of clinical trials to determine appropriate use criteria for both anatomic and functional MR imaging for MR in RT, and (d) funding by both private and governmental agencies to address the aforementioned unmet needs and to help expedite the long latency from research discovery to clinical translation. The need for validation of research through large scale clinical trials was frequently mentioned for each of these areas, especially given that the use of MR imaging in RT will lead to treatment decisions (planning, dose escalation and targeting, and identification of treatment response or failure) being made based on MR information alone.

Recommendations for research

1. Develop strategies to raise awareness and increase funding for research that will address the unique needs of MR imaging in RT. Such strategies could include outreach to policymakers and both private and governmental funding agencies that is endorsed by stakeholder professional societies and organizations working in the MR in RT space.
2. Establish a data registry for MR biomarker and treatment data to facilitate the collection and validation of large data sets for use in outcomes research to determine efficacy and cost-effectiveness.
3. Promote research into the following key strategic areas:

a. Synthetic CT development and standardized validation for MR-only planning independent of the anatomical/treatment site.
b. Incorporation and validation of imaging biomarkers into online adaptive radiotherapy process.
c. 4D MR imaging planning and delivery tools.

3.D. Medical physicists

Medical physicists are uniquely positioned to advance the field of MR imaging in RT and should, therefore, play a central role in the shaping and growth of this space. Examples of how the medical physics community can advance the field of MR imaging in RT include: (a) Development of hybrid imaging (e.g., MR imaging in RT, theranostics) as a unique subfield/focus within medical physics, (b) Coordination and collaboration of efforts by all physicists in this space, and (c) Training of physicists across traditional lines of demarcation (i.e., therapy vs diagnostic). This last unmet need was noted as the most urgent due to the fact that the skill set of today's medical physicist is quickly evolving, requiring ongoing education and diversity of expertise that cannot be provided by therapy, diagnostic, or nuclear medicine physicists alone. This is being driven in large part by the integration of imaging technologies, such as MR imaging into therapy and the translation of therapy techniques into diagnostic fields such as nuclear medicine (e.g., theranostics).

Recommendations for medical physicists

1. Identify existing societal groups (e.g., groups in the AAPM, ABMRS, ACR, ISMRM, RSNA) where medical physics plays, or can play, an important role in the MR imaging in RT space and coordinate an effort to determine areas of overlap, and in doing so eliminate fracturing/duplication of effort.
2. Propose new models that actively engage medical physicists from multiple disciplines and organizations. This will harness expertise across multiple subdisciplines to address the hybridization and evolution of MR imaging in RT.
3. Create a multidisciplinary coalition group to serve as a home for MR imaging in RT akin to Image Gently, which serves as a central resource for the development and dissemination of information that assists practitioners in managing image quality and radiation doses in children.

3.E. Reimbursement

The ultimate success of MR imaging in RT lies in the efficacy of collaborative efforts across multiple disciplines. However, given economic pressures due to declining reimbursements and fundamental and ongoing restructuring of the US healthcare system as a whole, including the recent announcement by the Centers for Medicare and Medicaid Services (CMS) of the evaluation of a new episode-based (i.e., bundled) payment system for RT services (for further details see https://innovation.cms.gov/initiatives/radiation-oncology-model/), it is unlikely that multidisciplinary collaboration will occur unless financial incentives exist, particularly for nonradiation oncology personnel (e.g., radiologists, diagnostic medical physicists, etc.). Alternatively, increased reimbursement paid to radiation oncology departments for MR simulation and MRgRT billing codes could be sought with some form of revenue sharing between radiation oncology and nonradiation oncology personnel thereby offsetting increased costs related to the hiring and support of those incremental nonradiation oncology personnel. This underserved/unmet need requires close collaboration between professional societies, such as the AAPM, ACR, ASTRO, and RSNA, with other healthcare professional organizations to investigate reimbursement models that offer financial incentives and sharing of revenues.

Recommendations for reimbursement

1. Establish professional coalitions and working groups to develop reimbursement models that would support improved access to Radiologists by Radiation Oncology.
2. Develop a working group(s) to investigate appropriate use of CPT codes for MR simulation and other related procedures, such as online adaptive treatments using MRgRT.

3.F. Intersociety communication and relationships

Throughout the data collection process, the committee identified that advances in the field of MR imaging in RT can be more easily implemented through improved communication and cooperation amongst professional societies and bodies. Representatives from several RT related societies indicated that there is a need for improved communication between societies in order to identify areas of common interest and critical needs. Existing intersociety communication includes professional liaisons, scientific symposia, annual meetings, and other ad-hoc communications. However, these efforts are not coordinated in terms of identifying and prioritizing problems and efforts. Greater synergy could be realized by coordinated collaborative efforts between societies to address a single or prioritized set of problems/issues. In this regard, industry representatives identified the need for closer integration and involvement of manufacturers in the communication process, especially at the societal level. Industry representatives noted that it is important to actively engage industry representatives in collaborative efforts due to the highly technical nature of this space and recognition of their role in developing solutions to complex problems. Given the significant cost associated with validation through clinical trials, the committee noted that no single organization or funding agency either governmental or private foundation has the resources and budget to support the clinical trials necessary to demonstrate the clinical efficacy of technologies related to MR in RT. Finally, it was noted that the MR imaging community, especially membership within the ISMRM, remain unaware of the unique needs and requirements of MR in RT.

Recommendations for intersociety communication and relationships

1. Promote and encourage intersociety collaborative efforts (e.g., AAPM, ISMRM, RSNA, ASTRO, ESTRO) to increase enrollment and participation in clinical trials.

An example of one such effort is the recent formation of the COVID-19 medical imaging and data resource center by the ACR, RSNA, and AAPM.

2. Establish intersociety user groups and/or consortia of motivated stakeholders including industry representatives in the MR imaging in RT space.

4. CONCLUSIONS

Ever since the clinical introduction of MR imaging, there has been considerable interest in utilizing the superior soft-tissue contrast provided by this modality for radiation therapy treatment planning.[5] Unfortunately, with the focus on its use primarily as a diagnostic imaging device, widespread adoption of MR imaging into routine RT clinical practice has been slow. More recently, major technical advances, albeit originally designed to address challenges within Diagnostic Radiology, have enabled high quality and reproducible MR imaging for RT. Coupled with regulatory approval both within the United States and Europe of MRgRT, there is a significant interest in the clinical adoption of MR imaging and MRgRT. As a result, and in recognition of the need to respond to both the new opportunities as well as new challenges that the translation of this technology into RT brings, the AAPM formed an ad-hoc committee to identify challenges and unmet needs, and to provide recommendations regarding how to address the identified needs and advance the field of MR in RT. This report summarizes the major findings of this committee and offers broad recommendations on how best to address them.

A major theme that emerged during the committee's work is that traditional organizational structures have been designed to identify and differentiate between subspecialties and as a result are not well-equipped to best address and solve urgent needs and problems faced in the MR imaging in RT space. What is needed is a union of forces across multiple disciplines – diagnostic and therapeutic medical physics, MR research, diagnostic radiology, and radiation oncology – if solutions are to be found given existing constraints of time, effort, and resources. In addition, physicists across all disciplines will need to be educated (and reeducated) to provide the diverse skillset needed to meet the needs of this field and continue to advance it. To achieve this, even greater integration and collaboration are required in each of the areas (Section 3) identified in the report. As an example, while many MR researchers and MR related societies, such as the ISMRM, are eager to solve complex and challenging problems related to MR, many in these communities have expressed a lack of knowledge of the problems unique to the field of MR in RT, and more broadly, the field as a whole.

Several of the findings and recommendations detailed in this report may be construed as being specific to either MR simulation or MRgRT. However, unless specifically identified, they are equally applicable to both. In addition, a greater emphasis on MR simulation when compared to MRgRT reflects the relative maturity of MR simulation compared to MRgRT. MR simulation technology is more widely disseminated throughout the RT community and has been commercially available as an FDA approved product compared to MRgRT resulting in more researchers and research efforts being undertaken in the former compared to latter. This was also noted in the stakeholder survey findings (see appendix) which reflect the fact that, while unmet needs in MRgRT are prevalent and urgently need to be addressed, the awareness of them is less when compared to those related to MR simulation.

A limitation of the stakeholder survey results reported herein is that it was distributed to 60 participants generating 53 respondents. While 60 is a relatively low number, it does reflect the nascent nature of the subspecialty within RT. To offset this, participants were identified as content experts from both North America and Europe by task group members as opposed to sending the survey to a broad distribution list. The results of the survey are also augmented by the literature review which was performed to identify areas that may have been overlooked because of the limitations imposed by the relatively small sample size of the survey. Taken together, the committee believe that the data reported represents an accurate survey of the unmet needs and roadblocks for advancing the use of MR imaging in RT at the time of publication. It is also interesting to note that two surveys undertaken first in the United Kingdom in 2018[6] and later expanded to 10 European countries and Australia in 2018/2019[7] identified similar limitations and challenges. Although these surveys primarily focused on identifying patterns of use, they did also identify gaps in the field which included; a lack of access to MR imaging, a lack of reimbursement, the need for consistent QC protocols, and limited to no access to MR imaging physics support, all of which are themes identified in this report.

It is the authors' hope that this report serves as a rallying cry for all professionals and professional organizations working within the diagnostic and MR imaging in RT spaces, to work collaboratively towards solutions to the challenges identified herein. While much expertise exists within the AAPM, particularly in RT, critical knowledge exists and can be leveraged through collaboration with other experts, particularly members of the ISMRM. Finally, it is important to note that the ultimate success of efforts in this regard should be gauged by the ability to translate these developments into routine clinical practice. To that end, innovations and solutions need to be simplified, streamlined and made fail-proof to the level that general practitioners (i.e., community-based clinical medical physicists, dosimetrists, and technologists) can easily and effectively integrate them into their standard of care. Without such efforts, MR imaging in RT and its related technologies will remain concentrated and confined to relatively few major centers of excellence.

DEDICATION

This work is dedicated to the memory of our good friend, colleague, mentor, and fellow committee member Ed Jackson Ph.D, who is deeply missed but not forgotten.

CONFLICT OF INTEREST

The authors have no conflicts to disclose.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary(appendix) material of this article.

APPENDIX

INTRODUCTION

To identify the unmet needs of MR imaging in RT, seven questions were developed and distributed to stakeholders across both Europe and North America. The questions and the highest-ranking result for each question are described below. The survey was sent to a total of 60 individuals identified by members of the committee who are considered radiation therapy content experts (e.g. radiation therapy physicists, radiation oncologists) or have MR imaging expertise and experience in the field of MR imaging for radiation therapy (e.g. diagnostic medical physicists, radiologists). Of these, 53 (88%) successfully completed the survey with no incomplete survey submissions.

Question 1: *Within the MR RT space, what is your primary role?*

Survey Result:

Medical physicist (primarily therapy)	25	47.17%
Medical physicist (primarily diagnostic)	12	22.64%
Radiation oncologist	9	16.98%
Radiologist	3	5.66%
Other (please specify)	4	7.55%

Question 2: *How long (in years) have you worked with MR imaging and applications?*

Survey Result:

Average	14
Min	0
Max	27

Question 3: *Rank the following in terms of significance of roadblocks to the widespread development and adoption of MR applications in RT. (1 = most important)*

Survey Result:

Category	Rank (1 = highest, 12 = lowest)
Education and training (for therapy and imaging personnel, including techs, physicists, and physicians)	3.98
Clinical implementation and workflows for MRsim and MR-IGRT	4.06
MR RT-specific protocols and their optimization	4.7
Purchase and operating expenses associated with MR simulation and MR-linacs	5.89
Staffing (tech, physicist, and Radiology support)	6.04
Siloing of resources and expertise between Radiology and Radiation Oncology	6.15
Hardware needs, e.g., RF coils, accommodation, and/or integration of immobilization devices	6.42
Development of fast and robust online segmentation, deformation, and plan optimization	6.81
MR safety challenges and/or training	7.23
Vendor support and collaboration	8.57
Need for RT-related imaging biomarker validation	8.79
Professional issues, i.e., credentialing, continuing education	9.38

Question 4: *Clinical - Importance as areas of unmet need related to the integration, development and advancement of MR in RT. (1 = most important)*

Survey Result:

Category	Rank (1 = highest, 9 = lowest)
Quality assurance standards/recommendations for MR-RT and MR-IGRT	2.87
Collaboration between MR and RT physicists during initial sitting/planning	4.21
Hardware (RF coils, accommodation and/or integration of immobilization devices)	4.32
Staffing	4.68
Fast and robust online segmentation and deformable registration tools	5.17
Benchmarking phantoms	5.28
Real-time tracking and dose accumulation for MR-guided RT	5.66
Comparison datasets	5.87
Vendor support	6.94

Question 5: *Educational: Importance as areas of unmet need related to the integration, development, and advancement of MR in RT. (1 = most important)*

Survey Result:

Category	Rank (1 = highest, 5 = lowest)
Peer-to-peer training	2.68
Need for modified curriculum for graduate students and residents (both imaging and therapy) in CAMPEP-accredited programs	2.94
Improved society collaborations (AAPM with ISMRM, ASTRO, ACR, and/or RSNA)	2.96
Dedicated workshop or summer school	3.06
Certificate program and CE symposium	3.36

Question 6: *Professional - Rank the following with regard to importance as areas of unmet need related to the integration, development, and advancement of MR in RT. (1 = most important)*

Survey Result:

Category	Rank (1 = highest, 5 = lowest)
Therapy physicist credentialing (level of education and training in MR)	2.17
Establishment of staffing guidelines for administrators	2.45
Radonc credentialing (level of education and training in MR)	2.72
MR physicist credentialing (level of education and training in therapy)	3.38
Radiology credentialing (level of education and training in therapy)	4.28

Question 7: *Research - Rank the following with regard to importance as areas of unmet need related to the integration, development, and advancement of MR in RT. (1 = most important)*

Survey Result:

Category	Rank (1 = highest, 5 = lowest)
Improved translation of key research efforts from MR space to therapy	2.36
Motion management, including 4DMRI, real-time tracking	2.49
Development of quantitative MR imaging biomarker measures for earlier detection of malignant diseases, response to therapy, and normal tissue toxicity	2.94
RT-specific RF coil development	3.32
MLC tracking for MR-guided RT	3.89

Question 8: *Are you aware of any other group(s), i.e. other scientific or professional society task groups or working groups outside of this ad hoc committee, that is(are) working on other projects related to MR in RT?*

Survey Result:

Answer	Count	Percent
Yes	19	36.54%
No	33	63.46%

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