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ORIGINAL ARTICLES

Static Future Technologies, Dynamic Professionalism — Co-creating Future Scenarios in Medical Imaging Practices

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Abstract

New magnetic resonance imaging (MRI) techniques that offer faster scanning and potential artificial intelligence-assisted interpretation and diagnosis can significantly impact existing workflows in radiology. In a qualitative study embedded within a responsible research and innovation design, we investigate the development and potential implementation of quantitative MRI. We aim to investigate postdigital MRI futures, covered by scenarios of potential workflows, as well as the resulting implications for professions and related education involved in the MRI process. Furthermore, we examine the related and changing responsibilities, more specifically reflecting on 'forward-looking responsibilities'. Through expert interviews ($n = 20$) and a focus group, stakeholder perspectives on the future of quantitative imaging techniques were explored. During a subsequent co-creation workshop and another focus group, stakeholders reflected on future scenarios in quantitative MRI. Our study shows that a proactive and future-oriented investigation of the influence of emerging technologies on potential workflows and subsequent changes in expertise and roles help in gaining or increasing awareness about the wider impact of a technology developed to contribute to faster and quantitative MRI exams. We argue that anticipating postdigital worlds by reflecting on future responsibilities through the co-creation of imaginaries can help making uncertain futures tangible in other ways.

Keywords Responsible innovation · Imaginaries · Workflows · Postdigital professionalism · Quantitative medical imaging · Forward-looking responsibilities

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Introduction

The field of medical imaging is witnessing numerous technological breakthroughs, including advances in hardware, computing power, and storage capacity, focusing on reducing scanning times and enhancing overall image quality (Harisinghani, O'Shea, and Weissleder 2019). These developments make imaging scans faster and more streamlined, i.e., making it easier for technicians to perform scans. Until now, qualitative MRI has been dominant: identifying anatomical structures based on contrast differences or enhancement patterns. Quantitative MRI strives to measure tissue properties (Gulani and Seiberlich 2020; Seiberlich et al. 2020). They may not necessarily require radiologists to interpret and report qualitative images obtained from the scan immediately. Instead, this innovative approach involves capturing quantitative data that can, if preferred, still be reconstructed into an image, allowing radiologists to interpret the results by assessing the synthetically constructed image. Synthetic contrast-weighted images can be generated from a single fast multi-parametric scan, providing radiologists and other clinicians with a familiar and traditional perspective. This reconstruction process forms an integral part of the acceptance strategy of the new quantitative MRI technology. It allows radiologists to build trust in the innovation and become accustomed to its use by transitioning from qualitatively generated images toward quantitative-based images rather than abruptly jumping to pure numeric output (Kleinloog et al. 2023; Konar et al. 2022; Tanenbaum et al. 2017). The introduction of quantitative MRI scans holds great promise and is gaining momentum. Over time, there is a possibility that quantitative scans may completely replace traditional qualitative scans.

Additionally, quantitative MRI opens up opportunities for rapidly collecting measurement data. If standardised across MRI scanner types, they can be interpreted with artificial intelligence (AI) assistance: AI-model training becomes simpler and increases AI's role in the diagnostic process and beyond (Hagiwari et al. 2020). The application of machine learning facilitates partially automated diagnostic and treatment practices. While the future remains uncertain, the potential for significantly reduced scanning times and AI integration are feasible scenarios.

These advancements in MRI, combined with datafication and integrating AI applications, are expected to reshape the landscape of professionalism in medical imaging, impacting the professional activities and roles of lab technicians and radiologists, among others (Hosny et al. 2018; Wong et al. 2019). Currently, MRI exams in Dutch hospitals are embedded in specific pre-established workflows, involving patients being, on average, twenty to thirty minutes inside the MRI scanner. Additionally, the scans require the expertise of specialists who make on-the-spot adjustments to scanning protocols and navigate through complex technical scans. Clear demarcations between activities characterise this workflow, distinguishing the work of a radiologist, clinical specialist, lab technician, nurse, and other professionals from each other.

As part of our empirical work, we took the notion of 'postdigital' as a starting point, asking participants to reflect on a possible future in which quantitative MRI as digital technology has been adopted and on the implementation process that should precede that. In our case, the starting point envisions MRI scans resulting solely in numeric maps rather than familiar contrast-weighted images. The digitally created data playing a significant role in imaging practices influence the interpretation of professional roles within the process and perception of these roles in education, training, and workflow creation. Taking the adoption of quantitative MRI for granted, we are interested in the possible postdigital socio-technical relations in such a probable but still hypothetical future and what the repercussions are for professional roles, identities, and responsibilities. Therefore, we asked stakeholders to co-create possible future MRI workflow scenarios, considering what would be needed to embed quantitative MRI in daily care practices. Proactively thinking about these implementation issues might help stakeholders to be better prepared and—in line with the responsible research and innovation (RRI) approach—even lead to early-stage changes in the design of the technology.

In this paper, we reflect on possible futures of an emerging medical technology and implications for (future) professional roles and related responsibilities by reflecting on postdigital scenarios. We draw on a case study conducted at a university hospital in The Netherlands between December 2021 and September 2022. We started our study to explore the different considerations of relevant stakeholders for the emerging medical technology, in this case, the responsible implementation of a novel form of magnetic resonance imaging (MRI) in clinical settings such as hospitals. Additionally, we investigated what introducing the new synthetic and multi-parametric quantitative MRI technology would mean for diagnostics and therapeutic workflows. As professional training and education changes are inevitable, we explicitly focus in this paper on the expected impact of future clinical workflow changes on key professions in that workflow and activities relevant to constructing this profession, particularly training and educational trajectories. We aim to investigate postdigital MRI futures, covered by scenarios of potential workflows, as well as the resulting implications for professions and related education involved in the MRI process.

In the following sections, we further explore notions of postdigital socio-technical relations and forward-looking professional roles, identities, and responsibilities. Subsequently, we outline our qualitative RRI-inspired research design, incorporating a case description, research methods, and data analysis approach. Our qualitative empirical work findings shed light on significant challenges in anticipating future professional roles and associated training and education, considering their deep connection to evolving contexts. Additionally, we reflect on questions from our research, including how to prepare for uncertain and dynamic futures.

Theory

To gain a deeper understanding of the evolving meanings of professionalism in the context of new medical technologies, we draw upon theoretical frameworks from the social sciences and humanities. While our study focuses not solely on the potential implementation of machine learning opportunities via the introduction of quantitative

MRI, we anticipate the increasing role of AI in professional practices. We further explore 'forward-looking responsibilities' as part of possible socio-technical futures (Sand et al. 2022). Before introducing this concept and linking it to literature on shifting professional roles and identities, we will first elaborate on postdigital socio-technical relations.

Postdigital Socio-technical Relations

Our specific focus on and understanding of 'postdigital' as a concept requires some explanation. When we refer to postdigital, we draw on interpretations of postdigital theory previously discussed in this journal, assuming that digital solutions are no longer new yet widely established as standard practice. Studying digital innovation should then go beyond focussing on the impact of introducing these technologies. Rather, relevant questions include how digital technologies become embedded in socio-technical assemblages (Macgilchrist 2021).

In medical contexts, especially clinical MRI settings, human-machine interactions are pivotal due to the prominent presence of machines. Scholars in science and technology studies (e.g., Downey 2008) have long revealed how this human-machine relationship influences technology's actual usage. Some scholars focusing on postdigitalism have recently raised concerns about the potential loss of autonomy and freedom as technological progress is often considered dictating behavior and human activities' modifications (Macgilchrist 2021; Zuboff 2019). We broadly distinguish two messages conveyed by postdigital literature relevant for studying socio-technical relations, specifically professional roles, identities, and responsibilities: education and training, and expectations of 'good care'.

Reflecting on *postdigital education*, Williamson (2019) urges caution regarding the persuasive allure of neuroimages in educational neuroscience. Brain images possess persuasive power, leading to a preference for reductionistic explanations, risking oversimplification and misrepresenting neuroscience study findings (McCabe and Castel 2008: 343). Knox (2019) cautions that routines and repetitions required for the productive introduction and usage of AI may have implications for working conditions and preparational education. He emphasizes the significance of understanding human-technology relationships in the context of teaching. Embracing the postdigital perspective is crucial as it reveals how these relationships are embedded in our practices and systems. Integrating tangible devices and the data they produce into socio-technical systems is part of meaning-making processes.

Medical progress shapes standards and *expectations of 'good' care*, necessitating efforts to establish trust in data representing the real world (cf. Zuboff's reflection on data surveillance, 2019). The capacity to generate data affects broader expectations and implications, such as heightened community awareness and interest in community-based initiatives, leading to valuable knowledge gains (Selwyn and Jandrić 2020: 1003). New imaging developments may raise public awareness, enhance understanding of human body and mind advancements, and trigger social forces and dynamics that foster engagement in accessing the latest techniques (Williamson 2019). These debates in postdigital papers resonate with other social science-based studies, analyzing impact of innovations on professional roles, identities, and relationships.

The rapid and iterative development of digital technologies in medicine raises concerns that require a deliberative and cautious approach (Cohen et al. 2020). Inevitable changes impact professional roles and identities, and preparing for postdigital futures requires reflecting on these roles, identities, and integrated responsibilities anticipation.

Shifting Professional Roles and Identities

Previous research has demonstrated that advancements in medical technologies profoundly impact their utilization and significance within patient journeys and professional workflows. These changes affect the relationships and roles of various professionals, patients, and machines (e.g., De Togni et al. 2021; Shachar 2022; Timmermans 2020; Tyskbo and Sergeeva 2022). Tyskbo and Sergeeva's study (2022) on a novel medical MRI technology (iMRI) illustrates how such innovations can disrupt the coordination of expertise across temporal, interactional, and (professional) role dimensions. They highlight the need for expertise reconfiguration and the potential devaluation of previously considered critical expert knowledge. As boundaries between roles shift, specialists must navigate the complexities of coordinating expertise, considering new technological possibilities and new knowledge and information generation.

For example, in the case of iMRI, surgeons increasingly rely on radiological expertise to effectively utilize the real-time information provided during surgery, enabling them to make more informed decisions. Simultaneously, radiologists require surgeons' input to interpret these new types of images. Consequently, introducing novel technologies can alter the distribution of responsibilities among different experts and stakeholders. Questions arise regarding whose knowledge takes precedence and how rigid role boundaries may hinder coordination (Menchik 2021; O'Donnabhain and Friedman 2018; Tyskbo and Sergeeva 2022) when novel technologies generate new information.

Sand et al. (2022) propose the concept of *forward-looking responsibility* to support reflecting on the notion of responsibility within innovation processes, particularly in medical AI-system contexts and for anticipating implementation of novel technologies. They argue that it is crucial to consider current values, such as transparency, fairness, and explainability, next to future competencies and duties that physicians should possess to use new technologies responsibly. Given new information streams and the increasing engagement of patients, professionals need to be knowledgeable about new technologies and their potential implications. Physicians will get new responsibilities, including effectively communicating uncertainties associated with the latest technologies to patients, being aware of the sensitivity and specificity rates of different techniques, critically assessing the reasonability of new outputs within the broader diagnostic procedure, reflecting on their biases based on experience, possessing knowledge about content and quality of input data, and awareness of how their experiences and skills may change with increased automation of tasks (Sand et al. 2022). Thus, professionals need to consider current and future competencies and duties as they navigate using new technologies.

Jha and Topol (2016) have previously discussed the adaptation to new AI-based 'intelligence' and anticipate new roles for radiologists and pathologists as information specialists. They suggest that professionals focus more on interrelational aspects than solely on interpreting scans. Communication and relational management become crucial in ensuring accountability and the quality of patient interactions. Professional identity in healthcare is thus transforming due to digitalization, automation, and the increasing availability of information. Professionals must adapt to changing patient roles and expectations while embracing the relational aspects of care. The emergence of AI and the growing importance of information require professionals to re-evaluate their roles and emphasize effective communication and relational management as essential components of quality patient care.

In sum, we discussed that postdigitalism uncovers socio-technical relations in contexts like education, working practices and in connection with what is considered 'good care'. We can learn from literature on shifting professional roles and identities by studying the dynamics of these relations in medical practices. In the next section, we will describe how we studied professionals' roles and identities, aiming to understand better how to anticipate postdigital MRI futures.

Research Design

Our study focused on investigating future scenarios and conceptualizations of care and professionalism within the context of quantitative MRI development and implementation. For our study approach, we draw on rich responsible research and innovation (RRI) literature (e.g., Owen et al. 2013). The premise of the RRI approach is to prospectively investigate various stakeholder perspectives from an early stage onward, with the ambition to feedback lessons to the innovation process. Owen et al. (2013:1570) describe responsible innovation as a 'collective stewardship of science and innovation in the present, emphasizing care for the future'. Following the RRI framework, this study brings together viewpoints from various stakeholders through an interactive and transparent process. The underlying idea of this approach is that it contributes to what is considered responsible innovation, which means in development and implementation 'the ethical acceptability, sustainability, and societal desirability of the innovation process and its marketable products', thereby ensuring the 'proper embedding of scientific and technological advances into our society' are reflected on (Von Schomberg 2011: 9).

Case Description

To better comprehend the technique at the center of our study, called MR-STAT, some background information on expected changes and potential value recognized by the development team embedded in the university hospital's computational imaging group is essential. Insider's knowledge [two of the authors of this paper were at the time of the study part of the development team] helps to outline the transition from qualitative MRI to quantitative MRI and its impact on the roles of radiologists and lab technicians.

In qualitative imaging, radiologists create scan protocols tailored to diagnostic or treatment needs, encompassing specific machine settings, scanning choices, and—sometimes—the use of contrast agents. However, a notable shift occurs with quantitative imaging, as it enables the visualization of multiple contrasts in a single scan. The innovation that prompted this investigation revolves around the quantification of MRI images, aiming to eliminate the need for 'multiple MRI scans and provide quantitative maps of fundamental MRI parameters' (from the HTSM 2019 grant proposal, MR-STAT: unlocking MRI's full quantification potential). By significantly reducing *scan time* and *producing* standardized and *quantitative information*, this technology promises to support 'future AI-driven workflows and facilitate the discovery of new biomarkers' . In essence, this novel technology aims to expedite and standardize clinical MRI exams, thereby contributing to the advancement of personalized medicine. The urgent need to accelerate and standardize scans arises from the challenges posed by the increasing demand for MRI exams, issues of accessibility, rising costs, and the potential for leveraging new biomarkers and AI-based workflows to enhance the efficiency and effectiveness of radiology departments.

The objective is to eliminate the need for contrast agents, simplifying the workload for lab technicians and nurses and reducing patient burden (Kleinloog et al. 2023). Nevertheless, quantitative imaging generates different outputs—quantitative data—compared to the traditional qualitative images in MRI processes. To aid the transition and facilitate adaptation, researchers aim to reconstruct qualitative-like images rapidly and accurately. Preserving image quality is crucial, as radiologists depend on familiar patterns for accurate diagnoses, with the number of images they have encountered influencing their proficiency. Quantitative MRI is expected to significantly reduce scanning time and preparation while potentially incorporating AI-assisted diagnosis (Kleinloog et al. 2023).

Methods and Analysis

Our approach covered several steps (Fig. 1), which we explain below. Before participating in interviews and workshops, all participants provided signed informed consent. All activities were (video)recorded, detailed notes were taken, and recordings were automatically transcribed verbatim for analysis. We presented our research plan to the Medical Research Ethics Committees of Utrecht Medical Centre. They stated that ethical approval for this research was not required as it falls outside the scope of the 'Dutch Medical Research Involving Human Subjects Act' (in Dutch: WMO), and no actions or interventions were performed that necessitated external assessment.[1]

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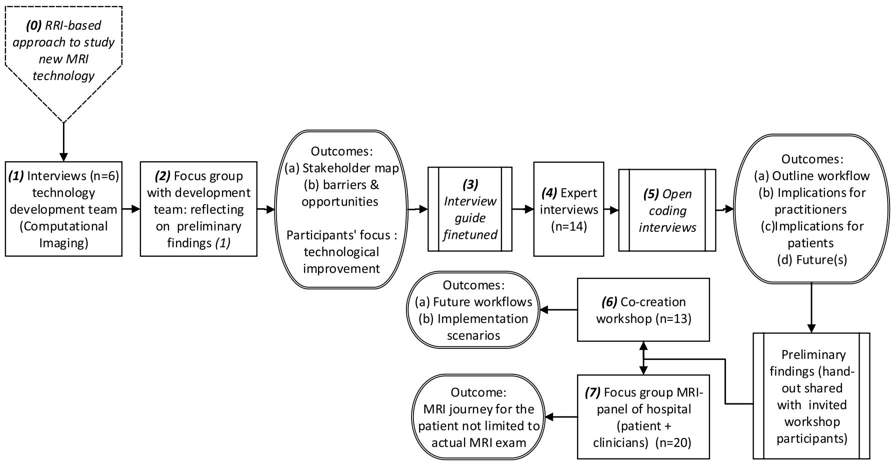

Fig. 1 Schematic overview of iterative data collection

First, we conducted two series of interviews to gain a better understanding of different aspects related to quantitative MRI. These interviews explored potential opportunities and challenges for implementing and further developing quantitative MRI and anticipated future impacts on workflows and expertise. The first series of interviews (1) involved members (n = 6) of the quantitative MRI technology development team, all working in the computational imaging group of the hospital. These first interviews took place from December 2021 to January 2022, with two researchers from our team present during each interview, lasting between 45 and 60 min. Next to mapping relevant stakeholders, interviewees in these interviews illuminated expected opportunities and barriers. The interviewees firmly focused on technological elements, although we asked them to also think about other implications, like ethical and social ones.

As two of the authors are part of the development team, close and ongoing observations were guaranteed. The other two team members are social science researchers who regularly attended (team) meetings. The participation of social researchers enabled the possibility to zoom out. After the series of interviews, we organized a focus group with the technological development team (2), focusing on the barriers and opportunities of the new technology, as well as the questions these experts think are required for responsible further development. During the focus group, preliminary findings were confirmed, and the interview guideline was finetuned (3).

The second series of expert interviews included a broader range of stakeholders (n = 14) (4). For the selection of stakeholders, we had asked the development team of the quantitative MRI project to identify relevant stakeholders, and during interviews, we also asked which additional stakeholders were considered relevant. We used the members of the so-called user committee involved in the project as a starting point. This committee exists for potential innovation users (or their representatives) but also for actors who can highlight relevant perspectives, like that of an ethical expert or a patient. Furthermore, we invited experts identified as also relevant, like a regulator. Interviewed stakeholders thus represent diverse backgrounds, such as healthcare insurers, vendors, radiologists, lab technicians, policymakers, AI-experts, ethical expert patient representatives, and fund managers (involved in the development via the creation of a solid business plan for the innovation, development, and eventual scaling). Some participants held multiple roles, serving as trainers or educators while working as radiologists. Interviews took place from March to July 2022, with two researchers from our team present during each interview, lasting between 45 and 60 min.

In preparation for the co-creation workshop, transcripts were independently coded by the first two authors using qualitative analysis software NVivo, starting with an open coding approach (5). The coded data were then compared, discussed, and further analyzed until a consensus was reached on key themes: a first impression of future workflows emerged, including implications for professionals—particularly radiologists and lab technicians—and patients—an assumed increased quality of care. The analysis of interviews was compiled into a handout that we shared with participants before a co-creation workshop in September 2022 (entire afternoon) (6). The content discussed during the interviews informed the workshop's design, including insights into participants' knowledge of the technology, their expectations, and perceived opportunities and challenges for future development and implementation. Interviewees and other stakeholders were invited to actively co-create potential future scenarios and discuss how changing workflows could impact the various stakeholders, including patients. The workshop specifically focused on workflows, future scenario development, and the imagined responsible implementation of such a scenario. Participants reflected first on the current MRI workflow and identified pivotal moments within it. Subsequently, participants were prompted to consider how quantitative MRI would impact or alter these workflows. Finally, the workshop facilitated discussions on potential challenges, opportunities, and implementation pathways for future workflows resulting from the innovation. Visualizing workflows and future scenarios stimulated conversations about professional roles and expected workflow changes. To further discuss patient perspectives, we organized one additional focus group a week after this workshop, with the 'Klankbordgroep MRI' (a panel of MRI stakeholders organized by the hospital), where we shared preliminary findings of the workshops and asked participants for additional input with a focus on the patient perspective (7).

The analysis of the interviews feeding into the workshops and the subsequent workshop data led to the identification of emerging themes in relation to potential implementation issues of qualitative MRI. For this paper, we honed in on those themes related to the impact on professional roles and identities of stakeholders involved in quantitative MRI futures and what is expected to be important when preparing for these professional roles, for instance, in training and education.

In sum, we followed a qualitative research design to study the innovation process and the co-creation of imagined implementation scenarios for this innovation. This means we assumed a postdigital perspective where quantitative MRI would have become part of daily practices, asking stakeholders to imagine being part of such a future and to look back at the pathway that led to that point. Alternatively, if they considered this not plausible, what barriers do they recognize being in the way of such a postdigital future? Thus, we explored diverse perspectives and co-creation of future scenarios in the form of imaginaries (cf. Jasanoff 2015).

Findings

In this section we share findings following an iteration of interviews, focus groups, and a stakeholder co-creation workshop (see Fig. 1). Our data shows changes in professional roles and professionals' training and education, as being anticipated for imagined MRI futures. Our data (stages 4 and 6) shows how professionals working with MRI scans are not only raised and moulded by their training and the medical practices in which they act but also by the nature of the field, which is inherently dynamic and continuously evolving.

We focus here on postdigital futures as imagined during the workshop, but substantiated with findings from the interviews. Before the workshop we shared a handout including preliminary findings based on the interview cycles. These resulted in the identification of relevant stages in the workflow, including—among other things—education and training, request of an MRI exam, diagnosis, and financing. Key elements in anticipating postdigital scenarios of MRI futures, including implications for professional roles and preparation for these roles, are current workflows, preparing through education and training, expected future professional roles, and implementation issues.

Current Workflows

To enable workshop participants to imagine future scenarios, we asked them to come to a shared understanding of current practices. During the workshop, we asked workshop participants to reflect on these practices and explore and visualize current workflows. They started with the request for an MRI exam and then discussed the different steps and disciplines involved.

Although there are variations, most of the requests for MRI exams are filed by *medical specialists*, like neurologists, who need a diagnosis. A *radiologist* will create a scanning protocol based on the request, after which the actual MRI exam is conducted by *a lab technician* with the help of one or two *assistants*. Such a protocol may entail the expected need to use a contrast agent, for example, that requires preparation via an infuse. The images are then interpreted by the *radiologist* and returned for final diagnosis to the *medical specialist*, who may decide on immediate treatment or involvement of different disciplines (e.g., oncology).

The issues that emerged as themes in relation to the workflows were technical barriers and opportunities, differences between academic and peripheral hospitals, education and training, knowledge diffusion, workflows, expertise, patient impact/implication, decision-making, and regulation. Our focus here lies on education and training.

Preparing for the Future Through Education and Training

In our expert interviews preceding the workshops, expertise and skills were highlighted already by stakeholders as playing a crucial role in the MRI process, which is subject to continuous changes for which they need to be prepared through training and experience. Interview respondents emphasized the necessity of training; a radiologist stated: 'Well, if there's a new technique, the first priority is to ensure that the quality is comparable and that you can still perform diagnostics just as well with the new technique, if not better, compared to the old technique. And if the technicians need to be trained in the acquisition' (RM09). And, if attention of radiologists is required: 'then it would be useful to provide them with training as well' (RM09). In general, respondents regard educational programs to reflect current practice, whereas for new developments that build on things that already have a place in practice 'people usually go to conferences …, as this is considered the way of learning something new in the first place' (RM10).

In their curriculum, students can opt for an internship in radiology: 'Overall, within the medical curriculum, students learn about various imaging techniques, including MRI, while simultaneously gaining practical experience and exposure to the images produced by such techniques' (RM10). Nevertheless, they are less confronted with recent developments: 'Indeed, the curriculum is more based on things that already have a certain place in practice, rather than anticipating what is to come. Individuals would attend conferences and shorter training sessions for future developments for further education. The curriculum's focus is to provide a solid foundation of knowledge and skills based on current practices in the field of radiology' (RM10).

Expected Future Professional Roles

During the co-creation workshop, participants explored future scenarios with quantitative MRI as the focal innovation. In preceding interviews participants emphasized the inherent innovativeness of the field: 'The innovative nature of imaging, implying that innovation is part of the field, is also supposed to resonate with the characteristics and preferences of professionals working there' (RM10). However, some also expressed concerns about the slow pace of change: 'Things are incredibly slow in healthcare' (RM06). Together with the participants, we reflected on the potential role of innovation, exploring potential barriers, opportunities, and the necessity of implementing quantitative MRI. One of the critical discussions revolved around the prospected change in demand for MRI exams. With the prospect of faster and more accessible scanning, professionals predicted increased MRI exam requests. This, in turn, led to discussions about the development of new workflows and the emergence of a new generation of lab technicians, radiologists, and physician assistants in response to these changes.

An example of an anticipated change is that the role of lab technicians may become more repetitive due to faster scanning and less complex actions, as rather than working with more challenging preparation of contrast agents, scans may be started with a 'push on the button.' A lab technician imagines they may become case managers instead, coordinating: 'two or three nurses or maybe some other trained staff, who start the acquisition' (RM03).

Anticipating such changes, workshop participants co-created a scenario for the responsible implementation of fast scan technology during the workshop. These included some anticipated challenges of the discussed MRI innovation for medical professionals involved in the MRI exam, that relate to professionals' expertise: 'To find a "balance" between perfectionism (scan everything to avoid missing something, reluctance to decide without scanning) and confidence in own judgment (avoid unnecessary scans).' And: 'Learning curve needed: to be able to learn from changes' (summary report of the multi-stakeholder workshop held in September, 2022).

Implementation Issues

Discussions of plausible implementation pathways based on imagined futures in the co-creation workshop revolved around the potential of quantitative MRI scans, concerning a very incrementally additional input to decision-making, to becoming an almost entirely independent service providing answers with one push of a button. A range of scenarios were discussed, in some of which AI plays a role. In those scenarios, AI could handle more straightforward interpretations, while more complex exams would require human expertise. The workshop participants—especially the radiologists among them—welcomed the shift of leaving interpretation of more straightforward cases to machines, as they are primarily interested in complicated cases. However, participants highlighted that this change could also create a higher mental burden: radiologists may be exposed principally to complex or challenging cases, potentially leading to increased stress or dissatisfaction. Workflow changes will likely impact job satisfaction, some may leave their current role in time due to changing responsibilities and the need for new expertise, while others may decide to acquire new skills and transition to a different profession, opt for eventual retirement, or explore opportunities in other organizations.

Increased scanning capacity, coming with faster scanning opportunities, would, according to stakeholders, be (partially) offset by a rise in demand due to ageing populations. According to some, time saved due to faster MRI scanning should be invested in focusing more on information provision and communication as part of the 'patient journey,' an issue raised during the focus group with a panel of MRI stakeholders and in some interviews with professionals and a patient representative. Considering the entire patient journey and not exclusively the time in the MRI scanner, the extra time available is an opportunity to improve patient comfort, not only physically but also in terms of how the entire process is experienced (based on notes of discussion focus group hospital panel of MRI stakeholders, September 2022). Next to a chance to have 'More time to discuss patients' (RM8), there is also more time for communication between specialists involved in diagnostics and treatment. In this case, according to respondents, time becomes an opportunity for more expertise, coordination, and collaboration, yet it also requires a more communicatively skilled professional.

When we zoom in on what kind of underlying professional responsibilities emerged from the workshop and expert interviews, we find that participants stressed the importance of not forgetting practicalities amid the potential offered by emerging technologies. New, re-designed, or shifting tasks in and between professions create a first change in responsibilities. Essential values, like safety procedures and data quality, are of utmost importance in the process and are increasingly essential and part of professionals' responsibilities. An increased number of shorter MRI exams may, for example, lead to the risk of missing out on specific 'data artifacts.'

Guaranteeing safety is currently an essential part of the responsibilities of lab technicians. However, their remit might be widened to checking image quality during and right after the scanning procedure, to 'Prevent that you have to recall patients' (RM2) for an additional MRI exam or check. This would also mean that lab technicians should acquire skills to interpret whether an exam is good enough for diagnosis and become responsible in other ways. A second change comes from the question: 'where is the professional autonomy?' (RM01), which relates to the fact that quantitative MRI generated data need new expertise and skills to be interpreted. The related future responsibility is to deal with this shared autonomy between human (e.g., radiologist) and technology (quantitative MRI).

Discussion

Our analysis of postdigital futures for medical MRI professionals, their roles, and identities has revealed two key impacts on a process level. First, introducing new MRI technology will inevitably lead to new professional processes and roles. Actions regarding preparation, practical execution, and interpretation of the scan are subject to change due to increased demand and complexity. These changes necessitate a different set of skills and expertise. It is important to identify who possesses these specific skills and expertise and how they can be integrated into different professional roles or potentially reshape existing roles. The scenarios developed, and reflections shared by participants in our study highlight the changing nature of professions. Second, changes in MRI processes and roles will impact the human-machine relation, where technology in quantitative MRI may take over human tasks, changing the balance between humans and machines and influencing human autonomy (cf. Macgilchrist et al. 2021). Also the type and number of actors being aware of and wanting to be involved in the MRI process might increase due to easier access and higher demand (see about this awareness: Williamson 2019; Selwyn and Jandrić 2020). These changes will impact future responsibilities and how these are constructed, asking to anticipate futures and consider forward-looking responsibilities (cf. Sand et al. 2022).

Forward-Looking Responsibilities

Several distinct perspectives emerged in the workshop through reflections on interview outputs shared before the workshop in a hand-out. They were visualized in the form of co-created scenarios, highlighting future challenges and changes. These scenarios encompassed expectations of revolutionary changes that call for professionals with an innovation-oriented mindset. Anticipated improvements in the quality and quantity of scans were discussed, which would require different skills and expertise, ultimately leading to enhanced diagnostics and an increased number of scans. Faster scanning creates additional time; the workshop participants held different opinions on how this time could be effectively utilized. Suggestions included allocating more time for research, improving communication practices, or conducting a higher volume of scans.

Next to a cognitive dimension, requiring specific knowledge to prepare and process MRI exams, professionals in the anticipated workflow need to proactively reflect on and learn about their responsibilities. The changes unfolding in the scenarios highlight corresponding shifts in values and responsibilities, like ideas on who is accountable for decisions or the balance between benefits of additional or more comprehensive MRI scans and the patient comfort and quality of care. The notion of *forward-looking responsibilities* as introduced by Sand et al. (2022) could be helpful in this sense, provoking reflections on future responsibilities, roles, and inherent dynamics and thereby helping anticipating postdigital futures and education preparing for these future roles and expectations of 'good care.' For instance, communication with and about patients is expected to play a more pivotal role in the future. It is considered important that awareness, information, and communication are improved about technologies and their embedding, as well as continuous reflection on training and education to maintain expertise and coordinate expertise when roles change (cf., Tyskbo and Sergeeva 2022).

As training of professionals in MRI—at least currently—follows rather than precedes innovations, professionals might be left with feelings of unnecessary insecurities and an experienced lack of expertise (O'Donnabhain and Friedman 2018). Dealing with emerging digital technology thus also requires dealing with an 'educational void': after graduation professionals need to continue learning about novel technologies whose impact on workflows is inherently uncertain and subject to molding.

Simultaneously, professionals need to relate to technology and reflect on new constructions of among others their expertise, authority, accountability, and autonomy. In applying the notion of forward-looking responsibilities when imagining future scenarios, it is crucial to consider the dynamics of those futures and the dynamics required from the professionals involved. Futuring, as applied in our study, is an often-used concept or technique for anticipating changes needed for further development and implementation of innovation.

Endless Opportunities or the Limits of Our Imagination

We encountered many medical professionals in interviews and the workshop who approached future technological developments such as quantitative MRI and AI with an open-minded attitude rather than fearing disruption. Despite this non-hostile approach, in principle open toward innovation, they were also hesitant and critical because they found it difficult to assess the implications of these developments for their roles. This perception can be described as ‘ignorantly interested’. Relatedly, discussions on the opportunities and barriers of AI applications remained relatively abstract, with proponents trusting machines and sceptics expressing concerns about potential errors.

Drawing (visualizing) of crucial steps or actions in healthcare workflows can help in co-defining a guideline for the distribution and coordination of expertise. While the emphasis could be put on the role and tasks required at a specific moment, rather than solely on the profession that should be involved. Such a guideline allows for different interpretations of roles within disciplines, such as radiology, and requires coordination and collaboration within multidisciplinary teams. It also opens opportunities for new professionals, although clear and transparent communication and patient information are essential. In addition to preparing professionals for changing futures, it is crucial to consider the fundamental elements that contribute to sufficient quality of care.

Our approach attempted to circumvent potential deficits of futuring techniques highlighted by previous studies. Macgilchrist et al. (2023), for example, remind us of how design and technology are always future oriented, yet often focusing on what is currently missing or considered messy, thereby not paying attention to whether this current problem would remain in a future scenario when not being taken care of, nor to potentially challenges in futures that not yet exist. Markham (2021) emphasizes that imagining the future challenges our imaginative capabilities, meaning that our imagination can only reach a certain level at a time. Therefore, we followed Markham’s suggestion of a more iterative approach, stretching the boundaries of imagination and asking not only for far away futures, but also about plausible, nearer futures.

Our data show a tendency among stakeholders to focus on what is easily imaginable based on current situations and experiences, relating these to the shorter-term futures. In line with Markham’s (2021) suggestion, we deliberately adopted an iterative approach, beginning with conceivable futures in the workshop and gradually expanding it to encompass presumed-inevitable longer-term scenarios. Stakeholders experience the field of medical imaging as continuously changing, attracting mainly innovation-minded professionals. Despite the fact that radiology is considered a dynamic and innovative field, imagining futures in the realm of imaging technologies still appears static to some extent, being bound to specific expectations or visions attached to the potential of the technology, rather than anticipating the further developments that innovations may enable. By envisioning a predetermined future where technology is the determining factor, there is a risk of overlooking a wider set of factors and dynamics. It is crucial to embrace the field’s ongoing dynamics and create futures responsive to evolving needs and circumstances and remain attentive to these ongoing changes.

Our study thus confirms how awareness among professional experts and patients of possibilities and limitations of available and emerging technologies and their impact on their responsibilities is critical (Cohen et al. 2020; Sand et al. 2022).

Conclusion

Our aim was to investigate postdigital MRI futures, through imagined future workflows and their anticipated implications for diverse professionals in the MRI process and their training. The introduction of quantitative imaging in radiology will change care practices: faster scanning capabilities of MRI are expected to enhance accessibility but also impact existing workflows since the work required of each involved professional (e.g,. radiologist, lab technician, specialist) and the time in the scanner changes. Some tasks may become more routine or repetitions, while others become more demanding. Workloads, especially for radiologists in terms of interpretation, are anticipated to increase significantly due to an increasing demand. As practices and expertise shift, responsibilities and related values, such as professional autonomy, will also change. The dynamics between human and machine will change, prompting discussions on relevant skills, expertise, training, and education requirements.

The participants in this study highlighted the ever-evolving and dynamic nature of radiology and medical imaging, emphasizing the need for professionals to dynamically adjust and envision future scenarios and the requirements to achieve them. However, it remains challenging to capture these ongoing dynamics when discussing the embedding of innovations in (postdigital) futures. Our study shows that a proactive and future-oriented investigation of the influence of emerging technologies on potential workflows and subsequent changes in expertise and roles helps in gaining or increasing awareness about the wider impact of a technology developed to contribute to faster and quantitative MRI exams.

In the current education and training of professionals involved in MRI processes, the focus primarily lies on current techniques and possibilities. While knowledge of novel techniques and innovations can be acquired through conferences and workshops, professional education's core focus remains relatively traditional and does not explicitly prepare new professionals for the forthcoming changes. Upon reflection, it becomes apparent that distinguishing the various factors contributing to future roles, whether technological or otherwise, can be challenging and perhaps impossible, especially when considering 1) what is needed in education and training when aiming to prepare for these uncertain futures, and 2) the 'educational void' in which professionals after graduation and during their working life need to continue learning about novel, yet often unproven and uncertain technologies.

Expected changes related to further development will impact responsibilities coming with the profession. Being responsible for (guaranteeing) safety or data quality, for example, impacts the construction of a profession. Balancing responsibilities and attributing more agency to a machine in this human-machine relations requires a renegotiation of what autonomy means in postdigital futures and how to prepare for this. We argue that anticipating postdigital worlds by reflecting on future responsibilities through the co-creation of imaginaries can help making uncertain futures tangible in other ways.

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Data Availability Data available on request due to privacy/ethical restrictions. The data that support the findings of this study are available on request from the corresponding author, [SH]. The data are not publicly available due to data containing information that could compromise the privacy of research participants.

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