Training Therapeutic Radiographers for Cardiac Imaging on an MR-guided Linac

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Background: A training programme was developed to equip therapeutic radiographers (RTTs) with specialised skills for low-field MRI, particularly in cardiac imaging applications using the 0.35 T MRIdian MR Linac. High-field MRI systems, though the gold standard for cardiac imaging, pose logistical and economic challenges that limit their use, prompting a shift towards low-field MRI (Campbell-Washburn et al., 2024). The MRIdian system, primarily operated by RTTs, requires bespoke imaging protocols to adapt standard Cardiac Magnetic Resonance (CMR) sequences for low-field operation. This programme not only enhances professional development and participation in CMR research for RTTs (Joyce et al., 2022), for example comparing low- and high-field CMR, but also addresses the practical challenges of using low-field MRI in clinical practice.

Methods: The training programme and competency framework was designed by an MR imaging specialist and research physicist, focusing on gaining competency with the operation of the MR Linac system within technical and safety standards. Training was scheduled around clinical treatment slots, beginning with a presentation on the MR system, CMR, and the wider research objectives. RTTs trained in pairs for two-hour sessions using volunteers, following the institution's internal policies for technical development. The CMR protocol, designed by a cardiologist from the research team, ensured coverage of essential anatomy as per standard-of-care CMR. Given the MR Linac's lack of a Patient Monitoring Unit (PMU) and lack of ECG gating, the protocol adapted to provide standard cardiac views and real-time imaging at 8 FPS (Klüter, 2019). Feedback on the training was collected from RTTs through internal online surveys to evaluate effectiveness and inform improvements.

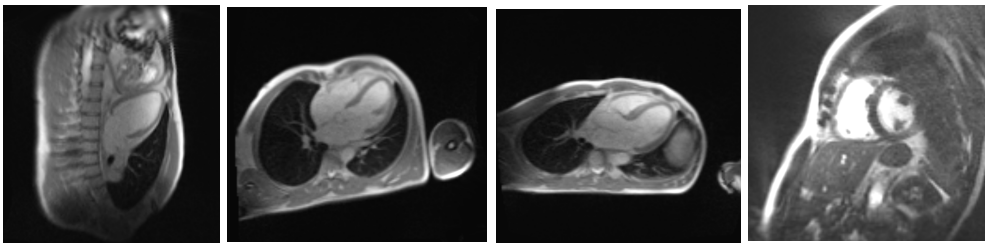

Figure 1: 0.35 T 2D TrueFISP images of the Two Chamber View (2CV), 4CV, 3CV, and real-time cine frame from a mid-ventricular Short Axis (SAX) view.

Results and Discussion: A low-field CMR protocol was successfully developed (Figure 1) and RTTs were trained to implement it via the training programme, allowing them to participate in approved cardiac imaging studies. Feedback collected from RTTs indicated positive responses; they reported increased motivation and confidence in operating the imaging system, as well as enhancing their understanding of the underlying MRI physics and technology. The training programme as implemented has not only positioned RTTs to perform cardiac imaging studies (e.g. comparisons with high-field CMR), but also contributed to professional development and motivation among RTTs.

Conclusion: The training programme effectively prepared RTTs for cardiac imaging on the MR-Linac, showcasing the potential of integrating advanced MR techniques in advanced research activities and clinical practice.

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Keywords: Training, Therapeutic Radiographers, Cardiac Imaging, Low-Field MRI, MR Linac

Implementing enabler technologies for foetal and neonatal congenital cardiac MRI

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Background Congenital heart disease (CHD) occurs in 1.2-17/1000 live births [1] and imaging is an important tool in its clinical management [2,3]. Cardiac magnetic resonance (CMR) imaging is an attractive diagnostic and surveillance tool in CHD due to the lack of ionising radiation, ability to image in any plane or 3D, and the ability to quantify blood flow through the complex vasculature associated with these conditions. However, it is complicated to implement due to the physiological motions (bulk, respiratory and cardiac) that may affect imaging. New technologies can enable the implementation and optimisation of this imaging modality in foetal and neonatal settings, several of which are discussed in this work.

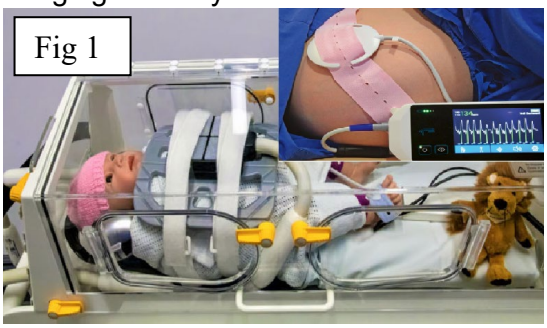
Fig 1

Methods An MR conditional incubator (LMT Medical Systems, Luebeck, Germany) and compatible neonatal RF coils (Noras MRI Products, Hoechburg, Germany) (Fig 1: main) facilitate imaging of neonates while sleeping (fed and wrapped), avoiding the risk and resource demands of general anaesthesia. Cardiac synchronisation cannot be achieved using electrocardiography in foetal imaging, so choice is generally limited to unsynchronised sequences. A Doppler ultrasound (DUS) device (Northh Medical, Hamurg, Germany) (Fig 1: inset.) that detects cardiac wall motion to produce a trigger signal allows acquisition of synchronised data (e.g. cine and flow imaging) in this population for the first time. A prototype compressed sensing (CS) 4D flow research sequence (Siemens Healthcare, Erlangen, Germany) allows time-resolved blood flow quantification across an extended volume, without the time-consuming planning needed for multiple 2D phase contrast (PC) slices. Protocols have been optimised by a multi-disciplinary team comprising clinical, scientific and radiographic staff and through interaction and feedback to technology providers.

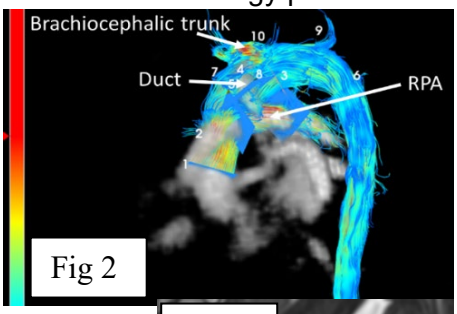

Fig 2

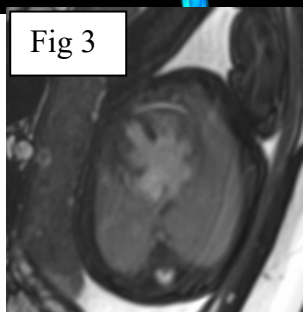
Fig 3

Results. Aided by the above technologies, approximately 25 foetal and 100 neonatal patients have been scanned with protocols including CS 4D flow MRI (Fig 2: neonatal 4D flow. Fig 3: foetal cine). In a neonatal sub-study ([4], also including early patients scanned in an open bassinet rather than the incubator, for which there was a lower success rate) CS 4D Flow MRI gave highly comparable data to 2D PC MRI with very low variability, high internal consistency, and clinical consistency with echocardiography. More recently we have shown 4D flow derived pressure recovery distance to have potential value in early diagnosis of coarctation of the aorta [5]. Foetal work is earlier in development with assessment of early data and protocol ongoing, alongside transition to a wider bore scanner which should further aid compliance and comfort for expectant mothers.

Discussion. By adopting new technologies, we have implemented CMR based comprehensive assessment of complex cardiac anatomy and blood flow in foetal and neonatal patients, allowing the risks of ionising radiation and anaesthesia to be avoid. The data is now being used by clinical teams to aid prognostication and treatment planning, providing valuable information in addition to the more established tool of echocardiography. It is also facilitating ongoing clinical research.

Conclusion. Adoption of new technologies have aided clinical and research applications of CMR in foetal and neonatal CHD, where it was previously extremely challenging or impossible.

Key words. Cardiac MRI (CMR), neonatal, foetal, congenital heart disease, enabling technology

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Measurement of myocardial extracellular volume and cell diameter before and after aortic valve replacement in patients with severe aortic stenosis

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Background: Extra cellular volume (ECV), the fraction of the myocardium occupied by the extracellular matrix, is an independent predictor of mortality [1] and can be measured using contrast enhanced MRI (CE-MRI) [2,3]. Myocardial T1 maps are produced pre- and post-contrast administration and are used to estimate the change in tissue R1 ($\Delta R1_t$) and blood R1 ($\Delta R1_b$). These are used to calculate ECV and subsequently cell and matrix volumes indexed to body surface area [4]. In standard myocardial ECV measurements, $\Delta R1_t$ is assumed to be linear with $\Delta R1_b$ and hence independent of contrast agent concentration. However, at higher concentrations, deviation from linearity, due to the limited rate of exchange of water between cardiomyocytes and the extracellular matrix, becomes significant, leading to underestimates of ECV [5, 6].

The aim of this study was to use a 2-site exchange model (2SXM), that accounts for water exchange, to measure ECV, indexed cell and matrix volumes and water residence times, an indicator of cell diameter [7] in patients with severe aortic stenosis (AS). Measurements were made before and after aortic valve replacement (AVR) and 2SXM values were compared to values from the standard linear model (LM).

Methods: 20 patients (67 ± 7 yrs) with severe AS, referred for AVR, underwent CE-MRI on a 3 T MR system before and 6 months after AVR. T1 measurements were made using mSASHA pre contrast and at 4 minutes after a 0.05 mmol/kg dose of gadobutrol. A further 0.10 mmol/kg gadobutrol was administered and T1 measurements were made 10 and 30 minutes later.

Measurements of left ventricular end diastolic volume (LVEDV), left ventricular ejection fraction (LVEF), myocardial mass (MM) and myocardial wall thickness (MWT) were made. The 2SXM and standard linear models (LM) were both used to estimate ECV and the 2SXM was used to estimate water residence time. The indexed left ventricular volume (LVV) was used to calculate derived indexed cell volume, (LVV x (1-ECV)) and derived indexed matrix volume (LVV x ECV), as previously described [4].

Results: Data were acquired before and 182±24 days after AVR. MM reduced following AVR, from 80.2 g/m^2 (CI: 73.9 – 88.9) to 64.2 g/m^2 (CI: 59.1 – 69.6); p<0.01. ECV estimated using the LM increased from 22% (CI: 21 – 24) to 29% (CI: 27 – 32); p<0.01, but only increased from 28% (CI: 26 – 31) to 33% (CI: 31 – 35); p<0.01, when using the 2SXM. The derived indexed matrix volume did not change significantly following AVR using either model. The derived indexed cell volume calculated from the LM decreased from 59.3 ml/m^2 (CI: 54.5 – 66.1) to 43.5 ml/m^2 (CI: 39.2 – 47.8); p <0.01, and decreased from 55.0 ml/m^2 (CI: 50.1 – 61.6) to 41.0 ml/m^2 (CI: 37.1 – 44.9); p<0.01, according to the 2SXM. Finally, water residence time decreased post-AVR from 0.21 s (CI: 0.16 – 0.26) to 0.12 s (CI: 0.08 – 0.16); p<0.01.

Discussion: Reductions in MM and MWT confirm reversal of myocardial hypertrophy following AVR. Both the 2SXM and LM demonstrate an increase in ECV following AVR, however, the matrix volume remained the same while the cell volume decreased, indicating that at 6 months the reversal of hypertrophy is cellular, as shown previously [4]. Water residence times decreased post AVR, indicating that the reduction in cell volume can be attributed to a reduction in cardiomyocyte diameter.

Acknowledgments: Funded by the British Heart Foundation (PG/20/10008)

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Implementation of Air Recon DL on clinical real-time protocols for imaging speech.

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[1]MRI Physics, Barts Health NHS Foundation Trust

Background. MRI is becoming more prevalent to study the organs of speech dynamically[1]. Although advanced speech MRI techniques are constantly being developed, their use tend to be limited to research scanners[2], and few clinical protocols tend to be published for clinical use[3,4]. Real-time clinical speech MRI studies tend to have limited temporal resolution and have lower image quality than the more advanced techniques. There has been a recent implementation of clinical AI software on MRI scanners following central government funding[5] to denoise and/or accelerate image acquisition (e.g. Air Recon DL (GE), Deep Resolve (Siemens) and SmartSpeed (Philips)). In this work, AirRecon DL was implemented on a previously optimised clinical real-time speech MRI[4] to look for improvement in image quality at both 1.5 T and 3 T.

Methods. Data was acquired on 6 volunteers on a 1.5 T SIGNA Artist (2/6) and 3.0 T SIGNA Architect (4/6) using the standard head and neck coils at Saint Bartholomew's Hospital using optimised speech protocols[4]. On the 1.5 T, the optimised sequence is FIESTA, with a TE/TR = 1/2.8 ms, and on the 3 T, a SPGR sequence with TE/TR = 0.9/2.6 ms at frame rates of 10 fps. The same acquisition was acquired with no Air Recon DL, and with settings Low, Med and High applied. The frame rate for each acquisition was kept constant. Image quality was assessed using SNR measurements of the soft palate and a visual scoring metric on a scale of 1-5[6] of the soft palate and visibility of velopharyngeal closures.

Results and Discussion. Table 1 shows the average visual scoring grades for each Air Recon DL setting across the six available datasets. It shows that using Air Recon DL has resulted in limited overall increase in helping to identify velopharyngeal closures or removing artefacts which interfere with the boundaries of the velum at low and high level and no at medium. However, there is an improvement in the SNR with the use of Air Recon DL, mainly for the higher settings (Figure 1). The overall image quality has improved, with less noise affecting the overall image. However, it has little effect on artefacts in the soft palate, that are mainly caused by off-resonance effects when the soft palate is elevated (Figure 2). The improved SNR would be more beneficial in other sequences, such as hybrid EPI, were the diagnostic quality is affected by low SNR[7]. This work was limited to GE as Deep Resolve cannot be adopted on all MRI pulse sequences and was not able to be applied to the clinical speech MRI protocol on Siemens.

Table 1. The average visual scoring grades for each Air Recon DL setting averaged across 1.5 T and 3 T datasets.

Air Recon DL Strength	None	Low	Med	High
Average visual score (1-5)	3.5	3.7	3.5	3.7

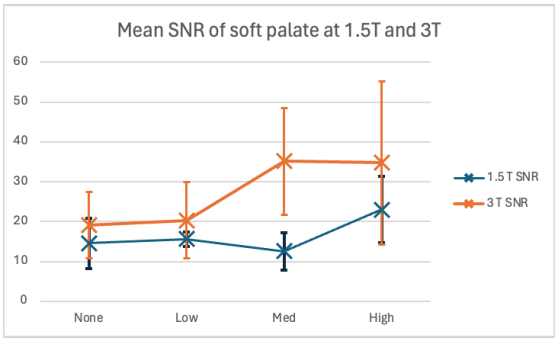

Figure 2. Measured mean SNR of the soft palate during velopharyngeal closure and at rest at each field strength with increasing levels of Air Recon DL applied; None, Low, Med and High.

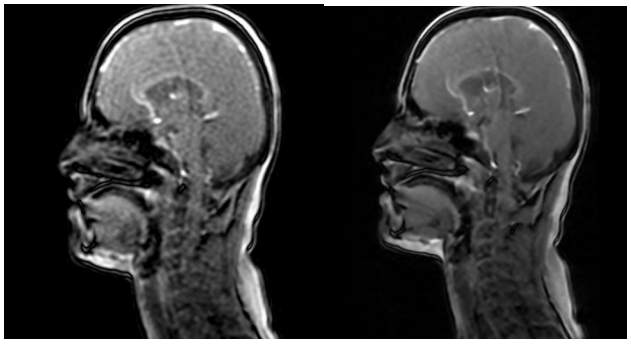

Figure 2. A single frame of a speech MR acquisition without Air Recon DL (left) and with Air Recon DL set to high (right). It shows that artefacts affecting the boundaries of the soft palate aren't improved with Air Recon DL, with the boundary merging into the post pharyngeal wall.

Conclusion. The use of Air Recon DL in this case has improved the overall image quality when applied to dynamic imaging of speech, however, it has limited effect on the visualisation of the boundaries of the soft palate due to the nature of the present artefacts. Future work will look at using the technique to increase the temporal resolution.

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Meaningful Relaxometry Quality Assurance in Clinical Practice

A Goodall, J Lister, L Clayburn, S Powell, A Fry

Background: Relaxometry is increasingly being used in routine clinical practice; from direct measurements for evaluating liver[1] and cardiac[2] iron loading; extra cellular volume (ECV) measurements which are diagnostic for various inflammatory diseases[3,4]; and even in radiotherapy for treatment response monitoring[5]. For these measurements to be clinically relevant there is a need for robust and meaningful relaxometry QA for the associated measurements. The current guidance in the IPEM 112 report[6] was used to develop our own method for relaxometry QA which provides clinicians with assurance that the quantitative values they are seeing are accurate, reliable and reproducible. We report our findings and advice from 2 years of routine relaxometry QA in clinical practice.

Methods: Measurements were taken for T1, T2 and T2* mapping sequences, as well as two in house liver-iron assessment protocols. At least two 'gold-standard' measurements were used to bookend five copies of these clinical sequences. "Gold-standard sequences" for T1 (spin echo inversion recovery) and T2 (spin echo multi echo) were based on those from the IPEM 112 report. A gold-standard T2* sequence (gradient echo multi echo) was set up such that short T2* values could be adequately sampled before decay, with several very short initial echoes. The TE then elongates quasi-geometrically to allow a fuller sample of the decay for longer T2* values. T1 and T2 measurements were taken on the Euro-Spin TO5 phantom with gels that covered the clinical range and that offer a broad spread of values. T2* measurements were made on a custom phantom[7] made of iron oxide-doped agar gel to simulate a range of T2* values from 1-20ms. Both phantoms had an LCD thermometer on the surface and temperature was recorded before and after scanning. Phantoms were left in the scan room at least 12 hours prior to acquisition to allow temperature equalisation. QA was originally performed quarterly for 1 year to provide baseline data, and then run 6 monthly alongside routine scanner QA.

Results: Analysis of these sequences was performed using a custom ImageJ macro. This allows for comparison of the measured value over time, linearity vs the gold standard, and Bland-Altman plots to judge the accuracy of the clinical sequences against the gold standard values. Results were populated into an excel spreadsheet where pivot tables were used to automatically generate the report. Once set up this was achievable to do in less than an hour.

Discussion: The QA procedure documented here is an improvement on the one suggested by IPEM 112, the results provided are more meaningful allowing for direct comparison to the clinical sequences and so ensuring that diagnoses based on these sequences are accurate. By setting action levels for the gradient of the clinical vs gold-standard plot and the bias of the Bland-Altman plot there can be continuity of QA if gel vials break or if newer phantoms are used with different gel-values. Such analysis also allows for the use of in-house phantoms to be used whose ground truth may not be known but can be measured at each session if a suitable phantom with traceability is used as a comparison, and for the analysis of T2* measurements which are dependent on magnetic field homogeneity.

Conclusion: Relaxometry QA is vital for the use of quantitative MRI. QA images can be easily acquired in 45 minutes and analysed with an open-source software in approximately 5 minutes per sequence. For QA to be meaningful it must be routinely performed with actual clinical sequences which are periodically compared to a reliable ground-truth. Confounders such as temperature must also be accounted for. The use of regular "gold-standard" measurements for relaxometry QA mitigates complications such as the gel values changing over time (as water escapes from the vials) and allows for uncertainty estimates for clinical sequences.

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"Is it Real?" Patient and Public views on AI in MR Image Reconstruction

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Background. The UK has the sixth lowest number of MRI scanners/person in the OECD [1]. MRI services have been under increasing pressure due to backlogs, increasing demand and staff shortages. To increase capacity on current scanners by reducing exam times, NHS England has centrally funded AI software for MR Image Reconstruction in 2023 [2]. However, manufacturers have given few details of their implementations (exact algorithms, training data) raising questions of efficacy and the potential for inequality within the MRI community. In the meantime, there is both enthusiasm and concern in the public and the press regarding the exponential rise of AI in all corners of society. While opening unexplored potentials, the use of AI in medicine is of particular concern. As part of a drive to engage all stakeholders in MRI, we developed a Patient and Public Involvement & Engagement (PPIE) project to engage with our health care community, to hear their views on AI in MRI, with the aim of using it to shape our future research in this area, as well as aid our implementation of manufacturer software.

Methods. A questionnaire comprising of 26 questions and some basic explanations/introduction for each question was created jointly by the MRI physics and Trust PPIE teams, and approved by the Communications Team, to gather the views of patients and the general public on the use of AI in MRI. E-mails were sent to people who have previously expressed interest in such studies and posters were also placed throughout our MRI departments to try to create representative sample of our healthcare community. Once the questionnaire was filled the responders were asked if they would like to help further by attending an online Focus Group session. The focus group included lay explanations of AI intercalated with polls and discussions on topics ranging from practicalities and purpose of AI in MRI to ethical issues.

Results. To date, 36 responses to the questionnaire have been received and 1 focus group session with 10 attendees has occurred, with an additional session organised for later this month. The questionnaire is currently still open (closing 01/05/2024) and will be fully analysed once closed. Preliminary analysis demonstrates a range of views on AI in medicine, but the majority was keen to see it used from booking to diagnosis, however, they do not want the AI to take decisions instead of humans and have considerable ethical concerns on its use.

Figure 1: Perceived positives (left) and negatives (right) of AI in MRI offered by the attendees of our focus group. The larger the word, the more attendees raised this point.

In the first focus group session, the perceived benefits of AI were that is faster, to scan and to access scanning, and offers increased clarity. The primary negative was potential bias and resulting healthcare inequality (*see figure 1*). There was a strong desire that human interaction is always maintained, and that decision on treatment and patient pathway stayed with" compassionate" human. When asked, the group stated better image quality (80%) was more important than faster scanning, including shorter waiting time (20%).

In the discussion on the ethics of AI in MRI reconstruction, the main concerns raised by the focus group attendees were embedding healthcare inequalities and the unknown quality and variety of training data in the manufacturer software currently clinically used at our Trust. When initially asked, a majority of participants declare it important that patients know when AI is used, and have the option to decline, however after further discussion the overriding majority stated that it should ultimately be the medical professionals' decision, and half of these stated they did not think patients needed to be consulted; to quote "*We don't ask a surgeon what instruments they are going to use."*

When asked to rank ethical concerns, the two most prominent were "accuracy of imaging" and "lack of transparency of the training data". When asked what would increase their confidence in AI being used in MR Reconstruction, the two most common themes were "further clinical validation" and "prior information" being given to the patients. At the end of the session, following the discussions, 90% were happy for AI to be used in their diagnostic imaging.

Conclusion The session highlighted that patients and the public have concerns about the use of AI in MRI and believe that they should be informed of its use. Following detailed lay explanations of how AI in MRI works and the associated ethical issues, they felt that using AI was beneficial but would like to see further clinical validation and standards created.

In general, the preliminary results indicate that while the public is supportive of AI in MRI, they have understandable concerns regarding its efficacy and the ethics surrounding its use. Our second focus group and questionnaire will give us further insights from a larger cohort of our healthcare community.

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Implementation of MRI in the Liver SABR Patient Pathway

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Introduction. Hepatocellular carcinoma (HCC) ranks as the sixth most prevalent cancer type, contributing to approximately 9.2% of all fatalities, making it the third leading cause of cancer-related deaths [1]. One treatment option for patients with localised disease is the use of stereotactic ablative radiotherapy (SABR) [2]. SABR treatments rely on advanced image guidance to enable precise localisation of disease. This, coupled with the steep dose gradients that are characteristic of this technique, allow the delivery of ablatively high doses per fraction over fewer fractions. It also aims to minimise radiation exposure to adjacent vital structures, protecting nearby normal tissues from potential radiation-induced harm [3]. The creation of the SABR treatment plan is informed by an immobilised planning CT, which is used to delineate the lesion and identify organs at risk. MRI is strongly recommended for liver sites, as it provides higher lesion-to-liver contrast and allows superior lesion detection and characterisation [4]. This results in better tumour delineation and therefore, better local control.

The aim of this work was to produce an MRI radiotherapy planning protocol that can as closely as possibly replicate the planning CT in terms of immobilisation, respiratory gating and resolution to improve registration and contouring for patients undergoing liver SABR treatment. In particular, the creation of a gated-DWI for patients was desirable as an MR contrast with proven sensitivity and specificity in the detection and characterisation of hepatic lesions [4].

Methods. Three patients and four healthy volunteers were set up reproducing the immobilisation used in their planning CT. This included an MR Conditional flat top bed and vacuum bag and in-house manufactured MR Safe short bar thoracic board and coil bridge. In-house equipment was tested to ensure it had no significant impact on image quality. The protocol comprised of a fat saturated axial T2 HASTE, axial T2+T2 HASTE, respiratory-triggered (with a 10% acceptance window) fat saturated axial T2 BLADE, respiratory-triggered DWI, breath-hold multi-arterial phase Dixons (pre-contrast, arterial, venous, delayed and 90 second delayed) and a post-contrast coronal T1 Dixon. Variations of the protocol were created for patients being treated in both end exhale breath hold (EEBH) and deep inspiration breath hold (DIBH) positions. The DWI could be triggered using either navigator echoes or thoracic bellows. The resolution was matched to the reconstruction CT with a FOV of 65x65cm to ensure a resolution of 1.2x1.2x2.5mm for each acquisition.

Results. The immobilisation equipment aided in the reproducible patient set up. Image quality tests showed comparable uniformity and SNR measurements with and without the equipment in place. With the addition of triggered and bellow techniques the liver was immobilised to a replicable position for treatment planning. Improved registration between the CT and MRI datasets was found. In addition, Figure 1, shows an example from one patient where additional nodules were observed on the DWI triggered sequence that were not visible on the other imaging techniques including CT.

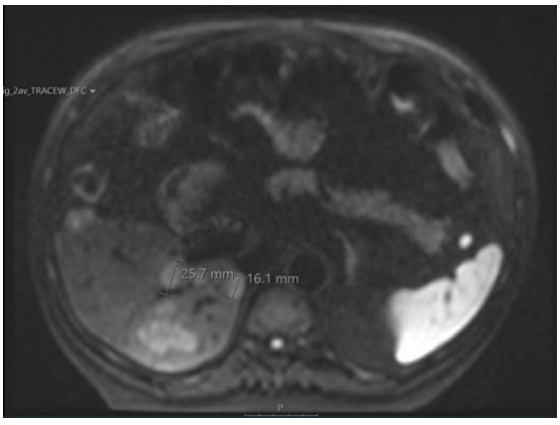

Figure 1. DWI imaging of the liver captured during patient exhale. Additional satellite nodules are indicated by the measurement bars.

Conclusion. MRI is a crucial tool in the liver SABR pathway. With the correct implementation of radiotherapy and MRI techniques, we can better define and treat cancerous nodules that otherwise would not have been included in the treatment plan. It allows for better registration of the two datasets and the ability to optimise the treatment plan based on the liver contour.

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An agile approach to MRI protocol optimisation in Neuroradiology

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Background. Advanced acceleration methods as Compressed Sensing (CS) and Deep Resolve (DR) on Siemens MRI scanners promise shorter acquisition times whilst maintaining or improving image quality. These have great potential for expediting workflow, but optimisation is a complex process. In addition to the large number of parameters involved, multiple stakeholders need to be engaged, the aims of the optimisation (e.g. improved image quality, reduced acquisition times) may vary depending on clinical indications, and the desire to leverage new features may be tempered by the need to standardise across different model scanners and software versions. Furthermore, to assess diagnostic quality, images from modified sequences and from the current standard sequence must be acquired in combination during the trial period, thus total scan time will be increased before a potentially shorter scan time can be implemented. This adds to existing service pressures and, in the context of increased demand for scanning and a drive to reduce waiting times, a more traditional, longer-term approach to sequence development can become detrimental to the service and tiresome for staff. We here present our approach to managing this process. **Methods.** We established a multidisciplinary working group with clearly defined roles (Table 1) and devised an iterative process, analogous to the agile software development approach. The steps are: (i) use of departmental analytics to identify the most common and longest sequences to be prioritised for optimisation (ii) identification of requirements/optimisation goals, (iii) implementation, (iv) application in (usually) 3 patient examinations, (v) prompt feedback. These steps are repeated until an optimum protocol is identified. Accurate up-to-date documentation is maintained with details of deployed sequences exported in .xml format for ongoing monitoring of sequence use and parameter settings as part of our departmental analytics. Where possible, we leveraged existing experience within the hospital, guidance from the manufacturer and shared knowledge from IPEM meetings. To ensure buy-in from all stakeholders, the plan was championed by the head of department with physicists explaining the process at a departmental meeting and key staff members allowed dedicated time for the project. **Results**. Table 2 shows examples of successful optimisation. We also encountered challenges: in intracranial Time of Flight (TOF) angiography, CS made smaller vessels disappear; and cervical spine sequences using DR introduced artefacts in the cord that could be misinterpreted as pathology. For the sagittal Constructive Interference in Steady State (CISS) the process uncovered that neuroradiologists were already dissatisfied with the quality of our routine sequence. **Discussions & Conclusions.** Protocol optimisation whilst maintaining existing services is a challenge. A multidisciplinary approach is vital for the success of such a complex process, as is engagement and proactiveness of all stakeholders. Regular and effective communication to show success, get feedback from clinicians, and monitor progress is essential. Developing a documentation and monitoring strategy in consensus so that all stakeholders are confident in using it; continuously monitoring progress; breaking up the big process into little more manageable sub-projects; all of these help address the challenge of maintaining motivation, engagement and focus. Since MRI scanners and sequences are continuously improved, this process will require regular repetition. Our current experience will hopefully make the process more efficient in future when we will need to repeat the exercise and could be helpful for other departments facing the same challenges.

Table 1. Staff groups and roles in the multidisciplinary group.

Staff group	Role
Neuroradiologists	prioritise sequences and indications, identify clinical indications and suitable patients, evaluate image quality
Physicists	leverage previously experiences, set-up sequences, scan volunteers, log all scans and documentation of sequence parameter changes
Radiographers	identify suitable patients, scan these with routine and new protocols, add instructions to electronic patient record system (Epic) for which sequences to run and additional acquisition times (to optimise appointment duration), use Epic to share information amongst radiographers

Table 2 Examples of successful optimisations

Series/Protocol	Acceleration method	Initial TA	New TA	% change in TA	Image Quality
SWI	CAIPIRINHA	4:01	2:50	- 29	Improved
T2 FLAIR SPACE	CS[$]	4:28	3:12	- 28	Improved
Lumbar Spine*	Deep Resolve	6:19	3:32	- 44	Similar
Carotid TOF	CS	8:17	4:46	- 42	Improved
CISS Spine	GRAPPA	5:10	5:51	+ 13	Improved

*Lumbar Spine protocol = T1 Sag, T2 Sag, T2 Tra. [$]CS = Compressed Sensing. TA = acquisition time

Practical experience of clinical T2 mapping techniques.

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Background. We present implementations and comparisons of clinical T2 mapping methods. Quantitative T2 mapping offers improved objectivity versus conventional T2-weighted scans. Multi-Echo Spin-Echo (MESE) methods are often used to sample the T2 signal decay curve at multiple echo times (TEs) and derive T2 from exponential fits. Optimal TE range depends on the target T2: short initial TEs allow short T2 estimates but long TEs are needed to capture long T2 decay. MESE uses TEs in increments of TE1, with TE1 often omitted from T2 fitting to reduce the effect of imperfect refocusing[1]. Using multiple TEs can make scans too long for clinical use but reducing TE range compromises accuracy and precision. Dual-Echo Turbo-Spin-Echo (DE-TSE) prioritises short scan time by using only 2 TEs, constrained by other parameters (e.g. Turbo Factor (TF) and Echo Spacing (ES)). Parallel imaging (e.g. GRAPPA[2]) can accelerate both methods. GRAPPATINI[3] increases MESE acceleration by combining GRAPPA with Model-based Accelerated RelaxomeTry by Iterative Nonlinear Inversion (MARTINI)[4] Acceleration Factor (AF), allowing time for more TEs, where the number of TEs must be ≥ 1+3AF and image matrix size in the phase direction must be divisible by AF. **Methods.** We implemented DE-TSE, MESE, and GRAPPATINI T2 mapping on a 3T PrismaFit scanner (Siemens Healthineers), centred on ISMRM/NIST system phantom[1] T2 vials: voxel size 0.4x0.4x3.0mm; phase resolution 60%; GRAPPA 2. DE-TSE: 44 slices; Acquisition Time (TA) 3min57s (5.4s/slice), ES 14.9ms; TF 5; TE1/TE2 30ms/119ms[5]. MESE: 20 slices; TA 8min42s (26.1s/slice); 7 TEs(min:incr:max)24:24:168ms[1]. GRAPPATINI: AF 5; 44 slices; TA 3min46s (5.1s/slice) 16 TEs(min:incr:max)10.9:10.9:174.4ms. DE-TSE and MESE T2s were derived offline from image ratios[5] and ARLO fitting[1], respectively. GRAPPATINI gave online T2 maps[6]. T2s measured from 6 vials were corrected to 22℃ using phantom temperature and a linear model derived from manufacturer T2s for 16℃-26℃. **Results.** Figure 1 shows relative T2 deviation from manufacturer T2s, for DE-TSE, MESE, and GRAPPATINI. Bland-Altman mean and 95% limits of agreement: DE-TSE 30%, 24%-36%; MESE -1%, -8%-6%; GRAPPATINI -1%, -13%-11%. **Discussion.** T2 temperature dependence was observed and corrected. GRAPPATINI and MESE showed good accuracy and precision overall, with greatest bias and spread in the regime T2>>TE. DE-TSE and GRAPPATINI were ~5x faster than MESE per slice but DE-TSE considerably overestimated T2. **Conclusion.** T2 accuracy and precision depends on the protocol and method. Model-based acceleration shows promise for rapid T2 mapping but measurement bias and variation must be evaluated before clinical use. **Key Words.** Quantitative MRI, T2 mapping. **Key references.** [1]Statton *et al MRM* 2022 10.1002/mrm.29065. [2]Griswold *et al. MRM* 2002 10.1002/mrm.10171. [3]Hilbert *et al. JMRI* 2018 10.1002/jmri.25972. [4]Sumpf *et al. JMRI* 2011 10.1002/jmri.22634. [5]Winston *et al. Epilepsia* 2017 10.1111/epi.13843. [6]Gruenebach *et al. Heliyon* 2023 10.1016/j.heliyon.2023.e15064. **Acknowledgements.** This study was supported by researchers at the National Institute for Health and Care Research University College London Hospitals Biomedical Research Centre. Siemens Healthineers provided support and GRAPPATINI, through a research agreement and collaboration with Iulius Dragonu and Tom Hilbert.

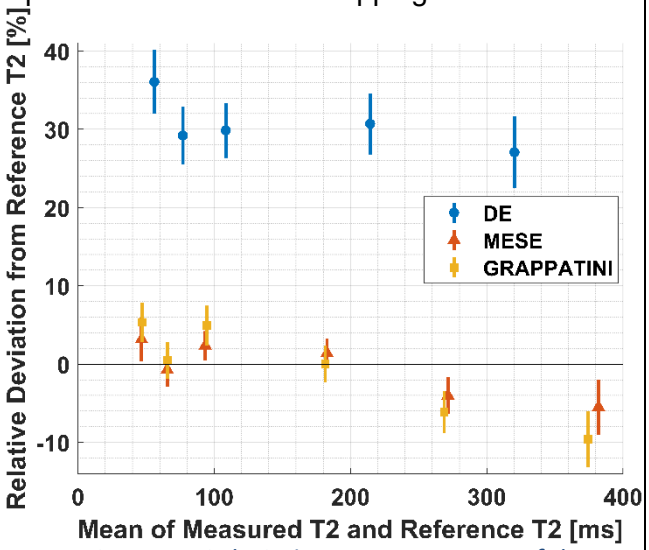

Figure 1. T2 deviation as a percentage of the mean of the measured and reference T2s. DE-TSE shows the largest bias and spread.

Hazen: An Open-Source MRI Quality Assurance Toolbox

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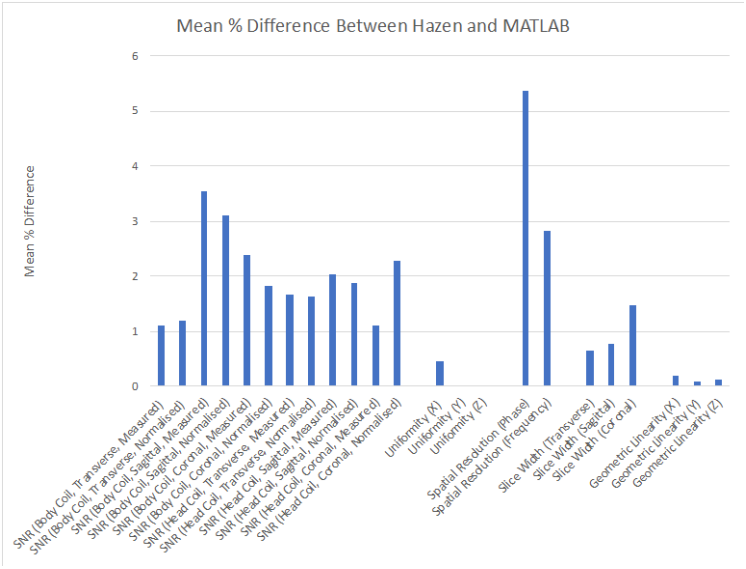
Key Words: QA, Software, Automation

Intro: Quality assurance (QA) in MRI ensures acceptable equipment performance and diagnostic image quality. However, manual analysis of imaging data is time-consuming and may be subject to user variation. This prompted the development of Hazen [1], an open source Python software package which automates MRI QA image analysis tasks. Hazen has been utilised locally since 2018, resulting in a reduction of analysis times down to a few minutes. The aim of this work was to compare results between analysis in Hazen and the previously established manual analysis pipeline as well as providing a general update on recent developments with Hazen.

Methods: Image data acquired using MagNET test objects and acquisition protocols [2] from 5 scanners (Siemens and Philips) at various sites around the UK were analysed for a variety of QA meaurements (SNR, Uniformity, Ghosting, Spatial Resolution, Slice Width, Geometric Linearity, Geometric Distortion and Slice position) using both Hazen and the previous analysis pipeline in MATLAB. The outputs from these two analysis pipelines were compared.

Results: Differences between Hazen and Matlab analyses (figure) were within a few percent for QA measurements with a value of 1.0 or greater. QA measurements with values less than 1.0 had larger percentage changes as a result of limited measurement resolution, but absolute differences were small and did not affect the success of the image test.



Discussion & Conclusion: The results from the automated Hazen analysis match well with those from the previous manual pipeline using Matlab.

Recently, Hazen has moved to github [3] and utilises more deployment features and automated testing. Units test cover 75% of the software, providing ongoing validation for any software updates. Importantly, Hazen now includes functionality to assess images acquired from the ACR phantom [4]. The open-source model provides scope for the MRI community to expand functionality to meet further requirements, such as supporting other phantoms, generating reports with results collated from all analyses, or collating results from various sites and scanners to inform acceptance testing baselines. Finally, a webapp is under development where image data are uploaded and Hazen tasks are executed via a graphical interface, eliminating the need for software installation.

References: [1] Shuaib et al (2021). Hazen: A free, open-source library for MRI QA analysis. QA in MRI IPEM meeting; [2] MagNET Group. (2007). MagNET Test Objects Instructions for Use (Version 5); [3] https://github.com/GSTT-CSC/hazen. [4] ACR. (2022). Large and Medium Phantom Test Guidance for the ACR MRI Accreditation Program;

Visualisation and Analysis of Scanner Utilisation Data to aid Patient Experience

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Keywords: Software development, scanner utilisation, patient throughput, data analysis.

Introduction:

MRI scanner utilisation within a radiology department is a key area of research. The need to make data-driven decisions and to provide meaningful information to stakeholders is paramount. Investment to increase productivity and activity in imaging services has been substantial since the publication of the Sir Mike Richard's report [1]. One key investment was Advanced Acceleration Technology, with the clear aim to increase patient throughput. At a national level, DM01 and activity levels were used to measure the success of the investment. However, this data is granular and can be affected by several other contributors. We have developed an MR Utilisation dashboard, a part of a framework to monitor the true efficiency of our systems, measure the success or failures of any interventions made, and create large databases of queryable data to easily develop techniques and algorithms to help us address these problems.

Methods:

There is data-rich information stored in the MRI scanner log files, which goes beyond what is available from DICOM headers alone. By utilising Powershell scripts, we have mapped our scanners to a secure shared network and multiple log files are dynamically copied as they are modified (Fig 1). The files contain a plethora of information which we have made easily queryable and accessible via a novel, open source C++ codebase that parses, analyses and saves specific data. Our databases update with every scanner event, and then the data is displayed on a dashboard created using JavaScript and React. This sits on the IP address of a local network port. Currently we are displaying clinically required data such as cycle time, defined as the % of time scanning during a day, the average length of each protocol we use (Fig 2) and a map of the daily scanner usage including break time, dead time and preparation scans (Fig 3). The dashboard has been constructed in such a way where adding new data visualisations is trivial due to the queryable nature of the database.

Results:

The dashboard currently works on Siemens MRI scanners on the XA platform. We have our generic dashboard page displaying the cycle time, the current temperature and humidity and the predicted SAR of the day's exams. Fig 2 shows the granular analysis of exactly how our scanners are being utilised on a given day for given patients. Fig 3 shows the accumulated average times of protocols for different types of protocols that we scan.

Discussion:

We have successfully been able to monitor our activity levels in detail and precision, finding the percentage of time we are scanning and the number of breaks as well as dead time for each patient. We also now have a growing and queryable database that can be used for more in-depth analysis and precision predictions for many future projects using data-driven techniques to improve patient experience, as well as throughput. We are working on extending the analysis to Philips and GE systems such that other trusts can use the dashboard for their own analysis. In our next steps we would like to address these issues and marry our database up to Electronic Healthcare Record systems such that we can support more informed methods for patient bookings.

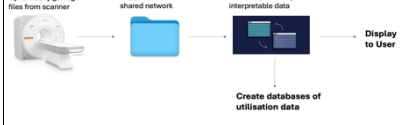

Fig 1: Diagram showing the network structure.

Fig 2: Break down of scan timings.

Fig3: Average time for each protocol.

[1] Diagnostics: Recovery and Renewal - Report of the Independent Review of Diagnostic Services for NHS England, December 2022

Developing a safety framework for portable MRI

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Background. The MIRACLES research study intends to evaluate the potential value of an ultra-low field *Swoop® Portable MR Imaging®* system (Hyperfine, Inc., USA) in patients with suspected or proven acute stroke. The study looks to perform point-of-care MRI scans in the Queen Elizabeth University Hospital (QEUH) Emergency Department in Glasgow. The Hyperfine Swoop scanner is not currently approved for clinical use so all images will be reviewed retrospectively.

Compared with the clinical MRI scanners in NHS GG&C, this scanner is unique for its ultra-low field strength (0.064T, although with a fringe field reaching 0.2T), vertical field orientation, head only scanner and portability. In addition to this, the scanner will not be routinely operated by MRI radiographers. This work outlines the safety framework that was developed for this novel scanner and additional challenges encountered with the development of this project.

Methods. Local rules, SOPs and bespoke MRI safety training for the research team were developed to maintain patient safety. In addition, as very few implants or equipment have been tested using this system, off-label risk assessments were required.

The *Swoop* system required a custom acceptance test, due to the fact that none of the test objects used for standard acceptance testing fit into the head coil. A routine QA program was developed specific to this system.

Results. The *Swoop* system acceptance testing was completed in September 2023 and the study commenced in November 2023. The MRI Physics team are continuing to monitor the scanner performance, including image uniformity, through routine QA.

Discussion. A risk assessment deemed that if a passive implant is safe to scan on a 1.5T scanner then it is safe to scan on the Hyperfine Swoop scanner[1]. Patients with active implants are excluded from the study but will require further investigation when these systems are able to be used clinically. To allow patients to continue being monitored during their portable MRI scan, the risk of using patient monitoring equipment that has not been tested in the MR Environment was assessed[1].

Conclusion. The *Swoop* system is a novel MRI scanner that has the potential to have a major impact on MRI delivery. Once the system is approved for clinical use, this technology is likely to be deployed in more settings. The work performed in this project should provide a framework to deploy these scanners more widely whilst maintaining patient and staff safety.

Key references.

1. NHS GG&C MR Physics website, https://www.mriphysics.scot.nhs.uk/mri-risk-assessments/