Rapid multi-vendor AAT implementation to increase imaging capacity

Steven Jackson, The Christie NHS Foundation Trust

Background The NHS 2022/23 priorities and operational planning guidance asked Integrated Care Systems to increase diagnostic activity to a minimum of 120% of pre-pandemic levels. In response, NHS England and NHS Improvement Diagnostics invited regions to bid for funding for MRI advanced acceleration technology (AAT). The North West region was awarded funding to install AAT licences on 38 scanners, with the aim to increase capacity in MR by at least 10% using AAT. Christie Medical Physics and Engineering (CMPE) MR physics group hold service level agreements (SLAs) with 11 North West Trusts, where 28 scanners (3 manufacturers) benefitted from AAT installation.

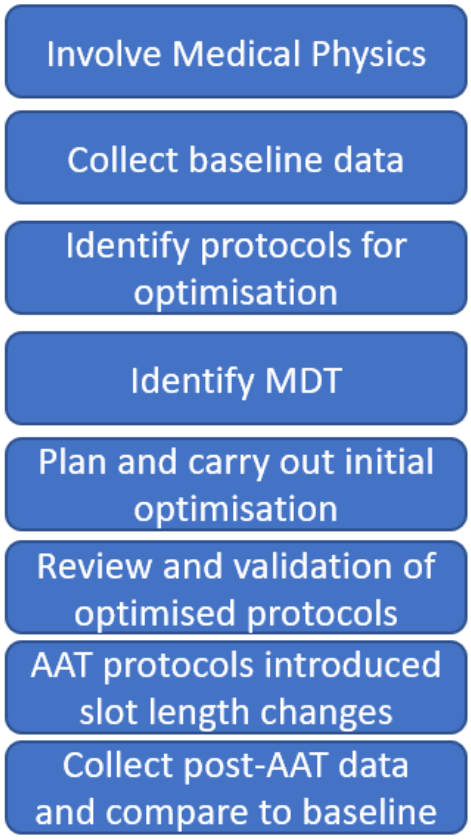

Figure 1 – initial plan for rapid AAT implementation across North West

Method In collaboration with NHS England Improvement North West, CMPE MR physics group devised an implementation plan to optimise commonly used clinical protocols with wide deployment of AAT across the region, see figure 1.

At sites with CMPE SLAs the protocol optimisation involved multiple volunteer scanning sessions, lasting 3-8 hours, with 2 or more MR physicists in attendance. Existing clinical protocols were acquired alongside protocols optimised using appropriate vendor-specific AAT available for each clinical application.

Qualitative comparisons of clinical and AAT sequences were carried out by a radiologist member of an AAT multi-disciplinary team (MDT). Where an AAT sequence was found to robust, quicker and with non-inferior image quality to the existing sequence it was introduced into the clinical protocol. Follow up reviews of patient imaging with AAT were carried out.

To increase patient throughput, clinical slot lengths were reduced wherever the AAT enhanced protocols permitted. After at least 3-months had elapsed since slot lengths were amended, patient throughput data was collected via a CRIS query and compared with baseline information.

Results The project is ongoing, but of the small number of sites who have completed the pathway in figure 1 to date the increase in throughput has been calculated to be greater than 10%, though analysis of CRIS data has proven more complex than anticipated, and the figures vary by available AAT. Improved patient experience and additional inpatient capacity have been regularly reported.

Discussion and Conclusion Patient and MR departments are already seeing the benefit of the approach taken to AAT implementation in the North West. Obtaining accurate throughput figures from CRIS data for comparison was complicated by many factors, including scanner downtime, adjusted referral distributions in multi-scanner departments, variable outsourcing and covid cleaning slot changes. The ability to amend slot lengths was found to be highly dependent on the available AAT for each protocol, and the anatomy and receive coil combination. The aim of the project was found to be achievable, and in some cases the increase in throughput possible via MR AAT is expected to be greater than 10%, though measuring this consistently across multiple sites has proved to be challenging.

Radiographer Perspective – To Tweak or Not To Tweak

Rachel Watt, Jersey General Hospital

Whilst MRI departments are facing increasing pressures with growing waiting lists and staff shortages, it can be difficult to set aside time for protocol development and overcome the associated challenges.
Collaborative working between Radiographers, Radiologists and Clinical Scientists is recommended, using a methodical approach.
The process can lead to improved service provision and outcomes for patients and more rewarding work for staff.

Learning Outcomes:

1) Illustrate rationale for protocol optimisation in MRI
2) Suggest process methods for protocol development in MRI
3) Describe and discuss a radiographer's perspective in terms of workflow and standardisation of protocols

Compressed-Sensing in Clinical Practice- an Audit of Image Quality of Compressed-Sensing SPACE versus Conventional sequence in MRCP

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Introduction

Magnetic resonance cholangiopancreatography (MRCP) plays a vital role diagnosing pancreaticobiliary pathologies. MRCP protocols include respiratory or navigator-triggered three-dimensional (3D) T2-weighted turbo spin echo (TSE) sequences with typical acquisition of 3–9 minutes. Compressed sensing MRCP (CS-MRCP) is a recent advanced acceleration technique that sparsely fills k-space, reducing acquisition time significantly which can limit image degradation from irregular breathing patterns. This study evaluated the performance of respiratory-triggered CS-MRCP.

Purpose

To compare image quality and acquisition time of ST-MRCP with respiratory-triggered CS-MRCP in patients with suspected pancreaticobiliary diseases.

Methods

A prospective study was performed between 1/4/2022 and 10/6/2022 (85 patients). Patients were scanned with standard sequence and CS-MRCP protocol on a Siemens 1.5T Sola or Siemens 3T Vida scanner, using an 18-channel body coil and either a 32-channel or 72-channel spine coil.

The mean acquisition times were noted and qualitative image analysis of the coronal SPACE sequences performed by two experienced Gastrointestinal Radiology consultants using a 5-point Likert scale; grading visualization of the common hepatic duct (CHD), common bile duct (CBD), right hepatic duct (RHD) and the cystic duct(CD). The data was recorded as mean values ± SD and Wilcoxon signed-rank test was used to calculate the p values.

Results

There was no significant difference in the overall image quality between ST-MRCP and CS-MRCP. CS-MRCP was superior to ST- MRCP in the visualisation of the cystic duct ($p < 0.05$) with no significant difference imaging the rest of the biliary tree.
Acquisition time, however, was significantly reduced with CS- MRCP (Mean 1:56 minutes/Range 46 sec - 4:47 mins) compared to ST-MRCP (5:13 minutes/ Range 2:41 - 9:24 mins).

Conclusion

CS-MRCP had comparable image quality and diagnostic performance to ST-MRCP but with significantly reduced image acquisition time. Patients with claustrophobia and irregular breathing patterns may particularly benefit from CS MRCP due to a twofold reduction in acquisition time.

"How are you doing?!"…. "I'm bored."
Experiences in 3D whole-heart MR imaging in paediatrics

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Purpose

Acquiring 3D whole heart images has become routine in our clinical MRI cardiac examinations. In some cases, the data will be used for 3D printing for surgical planning. It is therefore crucial that optimal data is obtained. Prior to the cardiac printing service, we found that the quality of the images were not sufficient and required further optimisation. We discuss our review of images and our experiences to ensure good quality data.

Method

10 paediatric whole heart images, 1 – 18 years, were acquired on either 1.5 T Avanto or Aera Siemens scanner and were reviewed by a radiologist and physicist. 3D trufi navigated fat sat sequences were used with a resolution of 0.5 x 0.5 x 0.5 mm, TR/TE, 3.8/2.46 ms, flip angle 90°, ECG gating and "Gate & follow" respiratory gating, with a total acquisition time of 10 – 15 minutes. No contrast was used. A physicist observed the radiographer's acquisition of these images.

Results

It was found in most cases that the anatomy of the heart was not clearly defined. An example of the worst case is shown in figure 1. The following combination of factors lead to poor quality data:

- Long acquisition times, patient became restless and moved
- Incorrect 'duration window' to image quiescent period
- Not checking the 'acceptance' window for the respiratory navigator

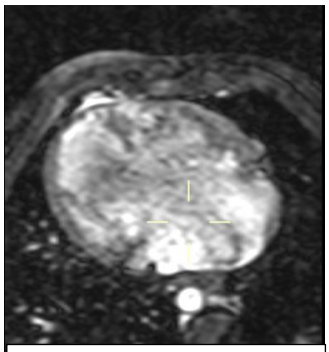

Fig 1. Poor 3D image

Discussion

Identifying whether a patient will comply with a long examination is crucial. From this we were able to decide whether to acquire earlier or later in the protocol. For patients, regardless of age, that did not require 3D printing we lowered the resolution of the scans to 1.5 x 1.5 x 1.5 mm, this shorted the examination to 5 – 7 minutes. The radiographers were asked to

- Use 4 chamber cines to identify quiescent period
- Take the time to check the scout image for respiratory gating
- Patients who required 3D printing – extra care. Using higher resolution sequence and use contrast.
- Ensure a tight shim box is around the heart

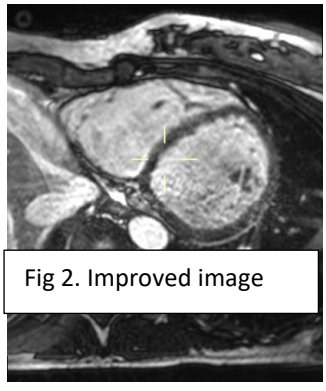

Fig 2. Improved image

Figure 2 shows an improved 3D whole-heart image. Unfortunately, cardiac paediatric imaging is not 'straight-out-the-box' and a lot of thought and planning is required. Patient size, heart condition and ability to lie for a long of period of time will influence the protocol.

Conclusion

Cardiac imaging can be very challenging for inexperienced radiographers however through reflection and observation of scans one can determine key areas for improvement. We hope that in the future we will be able to obtain sequences where the acquisition time will be reduced and all cardiac phases can be obtained.

Key words: Cardiac MRI, paediatric MR

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UHNM experience of introducing Siemens Deep Resolve to a busy inpatient department

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Background.
Deep Resolve (DR) is a new software technique which enables accelerated MRI acquisition, whilst maintaining high image quality [1]. This software was installed on three scanners at UHNM in January 2023. An optimisation program was performed which first tested all sequences on volunteers, followed by carefully selected patients. The aim of the optimisation work was to ensure all images maintained or improved image quality with a reduced scan time.

MRI physics collaborated closely with both radiographers and radiologists to ensure all staff received appropriate training on the new software, and all optimised sequences were thoroughly reviewed before implementation.

Methods.
Images were acquired on 2 Siemens Vida 3T and 1 Siemens Sola 1.5T scanners. Two hours per day for 18 days was allocated to volunteer scanning, and a total of 41 volunteers were scanned across the three scanners. A wide range of scans were optimised including head, spine, knee, wrist, shoulder, hips, foot, prostate, rectum, gynae pelvis, breast, and neck. All volunteer images were reviewed by clinical radiologists and the DR Imaging sequences deemed clinically acceptable were subsequently tested on patients, all of which were consented to be scanned with both the standard and DR sequences. For paediatric imaging, no volunteers were scanned, but suitable patients were consented for additional imaging.

A minimum of 5 patients were scanned for each area and sequence using both the standard and DR sequences. Feedback was requested from radiologists using a standardised template with image quality assessed using a Likert scale and free text to feedback any observed artefacts.

Results.
Initial scoring for lumbar spine and shoulder imaging showed that image quality for DR sequences showed equivalent or improved image quality across all sequences. Initial feedback for knee, cervical spine, thoracic spine, breast and prostate was variable depending on the sequence. This enabled sequences which required further optimisation to be identified before clinical implementation.

DR sequence acquisition times typically showed a reduction of at least 50% compared to standard image acquisition times. A standard lumbar spine protocol reduced from 8m 40s to 4m 12s at 1.5T and from 6m 27s to 1m 52s at 3T. Scan time improvements were consistently greater at 3T compared to 1.5T.

Discussion.
In many areas, particularly prostate, MSK and lumbar spine, optimisation using DR was straightforward and image quality was consistently improved for a significantly reduced scan time.

In other areas, such as cervical spine, thoracic spine, head and breast, more work was required to optimise the parameters to allow for consistently high quality imaging free of artefacts. Artefacts that we have seen include flow, wrap, ghosting, and structured noise. The steps that we have taken to overcome these will be discussed. The appearance of these artefacts highlights the importance of optimisation work and appropriate training for both radiographers and radiologists.

A simple standardised scoring template facilitated well-defined and rapid image quality assessment and allowed for targeted sequence optimisation.

Conclusion.
UHNM have successfully optimised DR sequences across a wide range of body parts.

Key references.
1: Deep Resolve – Mobilizing the power of networks. Siemens Whitepaper, available from [Accessed 17/2/23]: https://marketing.webassets.siemens-healthineers.com/cc86f5120c06595c/d13b5f98477c/siemens-healthineers_MR_Deep_Resolve_Whitepaper.pdf

MRI Protocol Optimisation in the Era of Deep Learning Reconstruction

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Background: Since its inception, MRI has revolutionised medical imaging. MRI acquisitions are complex and a trade-off between scan time, resolution, and SNR. Considering also artifacts, image quality optimisation is a challenging task. Many techniques have been developed to improve quality and scan time, by the introduction of high channel density coils and undersampling approaches [1]. Recently, deep learning algorithms redefined MRI reconstruction and showed tremendous potential to significantly speed up exam times and maintain or improve image quality. This work compares a commercially available deep learning (DL) algorithm to conventional reconstruction techniques and discusses the way this may change the way health professionals approach protocol optimisation and overall patient experience and outcome [2,3].

Methods. Thirteen images from a range of anatomical sites were acquired on a GE Signa HDxt + SW 1.5T MRI with conventional reconstruction and AirReconDL algorithm (Table 1) [4]. The same sequences were tested with higher no. of excitations (NEX) and a higher acquisition matrix. The images were qualitatively assessed by visual inspection for overall quality and artifacts, and quantitatively using SNR calculation and two open-source image quality assessment algorithms (NOMRIQA and ENMIQA [5,6]) which have previously been applied on MR images with good correlation to subjective radiologist scores.

Table 1. Revelant MRI acquisition parameters.

	Ankle				Foot						C-Spine				T-Spine				Knee				Brain			
	A1	A2	B1	B2	A1	A2	B1	B2	C1	C2	A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2
Sequence Type	Sag PD FS FSE				Cor PD FS FSE						Sag T2 FSE				Sag T2 FSE				Sag PD FS FSE				Ax T1 FSE			
Acquisition Matrix	384 x 288				384 x 288				512 x 512		416 x 320				512 x 352				384 x 288				352 x 256			
Acceleration Factor	2				2				2.5		2				2				2				2			
NEX	2	4			2	4			4		2	4			1	2			1	2			1	2		
Acquisiton Time	01:52	03:49			01:16	02:27			03:56		02:09	04:10			01:57	03:47			02:36	04:54			02:01	03:55		
AirReconDL Level	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-	M	-

FS: Fat Saturated, FSE: Fast Spin Echo, A/B/C: correspond to different acquisition parameters, 1/2: refers to whether the reconstruction was performed with/without AirRecon DL respectively, M: Medium, which refers to the level of DL applied to the reconstruction. NEX: No. of excitations.

Results: Qualitative evaluation of MR images showed an improvement in overall image quality of all AirReconDL (labelled '1') reconstructions compared to the original images (labelled '2'). Appearance of noise was reduced, making it easier to differentiate contrast in structures (Figure 1). Furthermore, AirReconDL in some occasions removed certain artifacts from the images (e.g. truncation artifacts from brain and spinal cord, Figure 1). Quantitative analysis of the images showed a similar trend; higher SNR and image quality assessment (IQA) scores for AirReconDL reconstructions compared to the original images. In most cases, these metrics were higher for AirReconDL data, even if a higher number of averages were used for the original data (Figure 2).

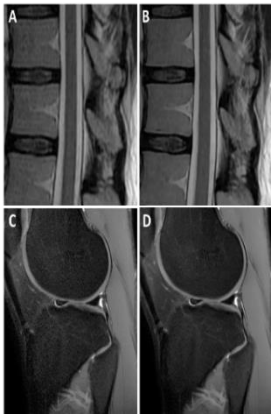

Figure1.(A,B)T-Spine B2 and A1.(C,D) Knee A2 and A1.

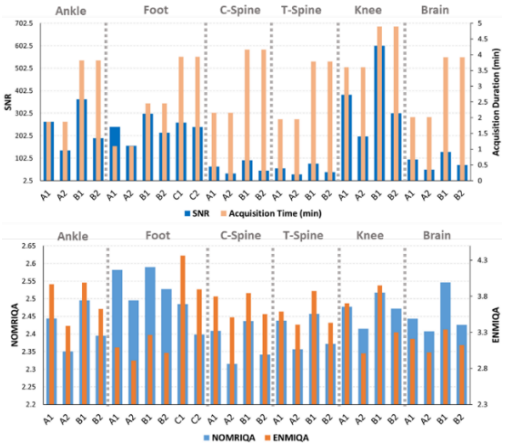

Figure2. Quantitative comparison between AirReconDL and raw images.

Conclusion. This work demonstrates both qualitatively and quantitatively that new reconstruction algorithms utilising deep learning have the potential to change the approach of image and protocol optimisation. Depending on the desired outcome, scan times can be reduced with higher patient throughput and higher successfully completed scans, or overall exam duration may remain unchanged but achieve higher spatial resolution or more sequences for enhanced exam protocols with the aim to improve overall patient care. Continuous improvement in the reconstruction algorithms and availability in a broader range of pulse sequences (e.g., 3D acquisitions) will guide MR imaging to a new era.

Key references. [1] Hiroyuki et al. 2022, [2] Dana et al 2020, [3] Greenspan et al. 2016, [4] Lebel et al. 2020, [5] Mariusz et al. 2020, [6] Obuchowicz et al. 2020.

Title of Study: Managing MRI protocol creep on multiple clinical systems

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Background. An MRI protocol tree on a clinical system is a large database containing hundreds of protocols and thousands of parameters. MRI protocol variation leads to to increased waste and less than optimal outcomes(1). One of the main causes is protocol creep, where MRI protocols are adapted on a case by case basis, because a standardized protocol catalogue is unavailable or not managed properly(2). Here we present real world evidence of protocol creep in a university hospital setting, using a Python tool (3) to analyse the differences between protocols.

Methods. Neuro MRI protocols from 3 systems were exported as xml files. The differences between the protocols were assessed with a in-house developed Python script, which provides Excel files of differences in naming of Regions, Exams and Programs, as well as detailed differences between sequences that share the same name. In the next step, all sequences were renamed following the convention <contrast>_<sequence_type>_<orientation>_<dimension> using a virtual machine of the scanner console. The script was used again to find differences between sequences that share the same name. This process was repeated until all differences were resolved. In the final step, the cleaned protocols were discussed with the neuroradiology team and lead radiographer to decide which protocols and sequences could be kept.

Results. We found a large number of differences between scanprotocols on the three systems. Out of 84 sequences in the neuro Program, 35 were duplicates and 7 duplicate sequences contained different parameters that needed to be adjusted on the scanner console. When comparing sequences with the same name, 65 duplicate sequences were found. In one example sequence, a coronal T2* TSE from the Head/Neck exam, there was a mismatch of 72 parameters. We also identified sequences that serve the same purpose, but do not share the same sequence parameters, for instance in DWI/DTI exams of the brain. Sample output of the script in the figures below:

Duplicates	Nr. duplicates	
t2_tse_cor_3mm_fs	2	No differences
t2_tse_tra_3mm	16	Differences found!
t1_se_r_cor_3mm	2	Differences found!
mprage_tfl3d_sag_0.9mm	10	Differences found!
dwi-12d_ep2d_diff_tra_no-ipat	2	No differences
t1_se_tra_3mm_fsgd	2	Differences found!
dwi-12d_ep2d_diff_tra_3mm	11	Differences found!
mprage_tfl3d_sag_1mm	4	No differences
localizer	2	Differences found!
t2-flair_tir_tra_3mm	13	Differences found!
tof_fl3d1r_tra_0.5mm_multi-slab	5	No differences
swi_r_tra_2mm	3	No differences
t1_vibe_tra_0.8mm	5	Differences found!
t2_tse_cor_3mm	5	Differences found!
t1_se_sag_3mmgd	3	Differences found!
t1_se_sag_3mm	14	Differences found!
t1_se_r_cor_3mmgd	4	Differences found!
t2_space_spcr_sag_1mm-iso	2	No differences
t2_tser3d_rs_tra_0.5mm-iso	6	Differences found!
t1_se_cor_3mm	2	Differences found!
dwi-trace_haste_diff_tra_3mm	4	Differences found!

Comparing	1672ea70-28ee-4817-9077-b67b424851ad	
\\Aera_UZGENT\Neuro_Hoofd_Hals\Neuro\Craniale zenuwen\t1_se_r_cor_3mm *, TA: 1:59 Voxel size: 0.9×0.9×3.0		
with	4a3224a1-fff1-46e6-9e64-dddfc7eb8f9e	
\\Aera_UZGENT\Neuro_Hoofd_Hals\Neuro\Craniale zenuwen\t1_se_r_cor_3mm *, TA: 3:27 Voxel size: 0.9×0.9×3.0		
Parameter to change	**From**	**To**
Contrast - Common-TD	0.0 ms	
Contrast - Common-TR	525 ms	600 ms
Geometry - AutoAlign-AutoAlign	Head > Brain	Head > IAC
Geometry - Common-Concatenations	2	1
['Geometry - Common-Dist. factor']	10 %	33 %
Geometry - Common-Slices	38	21
Geometry - Common-TR	525 ms	600 ms
['Inline - Composing-Distortion Corr.']	On	Off
Inline - Composing-Mode	2D	
Inline - Composing-Unfiltered images	Off	
Physio - Signal1-Concatenations	2	1
Physio - Signal1-TR	525 ms	600 ms
['Resolution - Filter Image-Distortion Corr.']	On	Off
Resolution - Filter Image-Mode	2D	
Routine-AutoAlign	Head > Brain	Head > IAC
Routine-Concatenations	2	1
['Routine-Dist. factor']	10 %	33 %
Routine-Filter	), Prescan Normalize, Image Filter	Prescan Normalize, Image Filter
Routine-Slices	38	21
Routine-TR	525 ms	600 ms
System - Miscellaneous-AutoAlign	Head > Brain	Head > IAC
System - Miscellaneous-Positioning mode	ISO	REF

Discussion. Protocol creep hampers productivity and efficiency in a clinical radiology department. Once cluttered, it is very time consuming to manually compare all sequences and may not be possible at a busy clinical scanner. The Python tool helps to find differences between sequence parameters, but input on the scanner is still needed to correct errors.

Conclusion. An efficient workflow is created to manage protocol trees, which saves valuable console time at the scanner. A large number of unwanted or hidden discrepancies between protocols was removed, which results in consistent MRI exams.

Key references.1. Boland GW, Duszak R: Protocol Management and Design: Current and Future Best Practices. *J Am Coll Radiology* 2015; 12:833–835.2. Ravi KS, Geethanath S: Autonomous magnetic resonance imaging. *Magn Reson Imaging* 2020; 73:177–185.3. Pullens, Pim, et al: Declutter the protocol tree: managing and comparing sequence parameters of multiple clinical systems using Python tools. In *Proc ISMRM 2020*; :4160.

Neuroradiology MRI Clinical Service Improvement Process at the National Hospital for Neurology and Neurosurgery

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Background. In 2014 a new system was introduced in the Neuroradiology Department at the National Hospital for Neurology and Neurosurgery to effectively manage new service improvement projects with clear responsibilities and set time frames. Prior to this there were well defined processes for research, and clinical audits, but there wasn't a system to systematically manage the introduction of a new protocol that would change the radiographers' and radiologists' clinical practice. We review 22 projects that followed this procedure, to assess pros, cons and identify possible improvements. **Methods.** The process is managed at a departmental level through our multi-disciplinary MRI Management (Mgmt) Group, chaired by the Head of Department, with representation of clinical scientists, radiographers, neuroradiologists, operational management, and admin staff. Any new service improvement proposal (from any staff group) is initially assessed for its feasibility through a Stage 1 form. This includes a brief outline of the proposal and is discussed by the MRI Mgmt Group. Once approved to continue, the proposer submits a more detailed description of the clinical indications (target patient group, estimated nr of examinations per month, predicted clinical benefit), estimated protocol development needs (hardware, software, etc.) with related time frame, and recurring resources needed to deliver the service (acquisition durations, specialist staff attendance, dependence on specific scanner availability). In this detailed Stage 2 form clear responsibility for relevant parts of the projects are assigned to a lead radiologist, a lead clinical scientist and a lead radiographer. Following approval of the Stage 2 form the protocol optimisation is performed, with monthly progress reviewed by the MRI Mgmt group, and an audit, or where appropriate formal service improvement evaluation, is registered to assess the clinical effectiveness of the new protocol and allow an informed decision on whether to implement it as a clinical service or not. **Results**. Out of 22 projects that followed the described procedure, 6 are ongoing, 12 completed, 1 not approved, 3 withdrawn. Of the 12 completed projects there were: 4 protocol implementations (2 new sequences introduced for a specific patient group, 2 established sequences introduced either on new scanner or for new patient group), 3 protocol optimisations (2 reduction of scan time by ~50%, 1 more efficient scan selection), 2 for establishing newly available sequences replacing older sequences in selected protocols, 1 for optimising a reporting pathway using a newly available CE-marked software. Finally, 2 projects were not implemented because the newly available sequence evaluated were found not to be appropriate for the intended use. **Discussion.** The introduced service improvement process has several advantages. It is a formalised process where a multidisciplinary team evaluates and monitors the project and there is a formal decision on the outcome. It encourages sensible project planning for a set nr of patients, outcome measures and time frames. Projects align with the department's priorities; it enables to capture improvement making it more measurable, transparent, open to everyone within the department, visible to the senior members of the department and progress can be monitored. It involves all staff groups in Neuroradiology, each with a clear role, promoting teamwork and it prevents extra spurious scans run on patients. Several service improvement projects involve testing Works-In-Progress sequences with the condition to send feedback back to the sequence developers. In these cases, neuroradiologists' input is valuable in identifying a suitable patient group to test the WIP and set the outcome measures. There are also some drawbacks. It requires all member of staff involved to understand the process and engage with it. There is extra paperwork that needs to be submitted and wait for approval before any service improvement project can start, making it a lengthier process. Extra delays can occur, and although some can be avoided, delays during the Covid period were beyond our control. To further improve the process, it's important to publicise and clarify all the required steps, ensure new members of staff know where to find all the relevant information and explicitly account for any training needs. **Conclusion.** Whilst being imperfect, this framework has enabled us to formalise the process of introducing service improvement in a transparent and visible way, enabling us to capture progress within the department. It helps streamlining service improvement requests and using available resources in an efficient way.

Harmonisation of protocols on Siemens Sola and Vida MRI Scanners: our experience on a process to achieve diagnostic standards.

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Background: The long lifespan of an MRI scanner results in that, when one is replaced, it is generally with a machine of one or two generations further developed. Typically, these newer scanners purport to have more advanced features, allowing improved imaging. However, initially it can often be difficult to even recreate protocols that produce images of comparable diagnostic quality to the previous scanners, before then moving on to use the latest technology and image acquisition and processing techniques to improve imaging. This is more taxing if the department is changing scanner manufacturers or magnet field strength, if there is a significant upgrade in the structure of its operating system, and if you are an early adopter; all of these occurred at our centre. This work reviews the protocol development and harmonisation process and results from the replacement of 2x *Ge Optima 1.5T* and 1x *Siemens Avanto 1.5T* with 2x *Siemens Sola 1.5T* and *1 x Siemens Vida 3T* at a tertiary trauma centre, with focussed case studies on harmonising to national and international diagnostic standards PI-RADS® for prostate[1], *MY-RADS* for myeloma staging[2] and adhering the imaging guidelines for the NHS Breast Screening Programme[3]. This process, akin to a PDSA cycle[4] and visualised in figure 1, began in Summer 2020 and continues to the present.

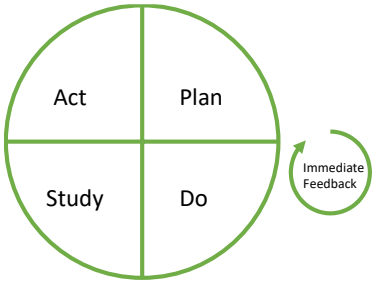

Figure 1: PDSA-like process followed in Protocol Development and Harmonisation at our centre, including a sub-cycle for immediate feedback.

Methods: The process, consciously agreed and signed off by all stakeholders, began with a discussion for the choice of coil and software options between the clinical users (radiologists, referrers, radiographers, physicists) and the manufacturer. We then established a radiology lead for each sub-specialism to be a point of contact, who was tasked with reaching consensus with their colleagues. We created a task list, including prostate, myeloma, breast screening, temporal lobe epilepsy (TLE), multiple sclerosis (MS), fMRI protocols that needed to adhere to their respective guidelines. We were also under pressure to reduce scanning times both for patient comfort and due to Covid-19 related backlogs. We had a three-week period in which manufacturer application specialists would be available, and we created a schedule for volunteers in the morning and patients in the afternoon. Radiologists were ready to give immediate feedback (see Figure 1). Following apps, many protocols, including myeloma and breast screening, spine and paediatric neuro were not optimised to an agreeable standard, based on consensus between the superintendent radiographers and the lead radiologist. Iterative optimisation therefore continued, reaching out to national and international colleagues and guidance bodies for assistance. Latterly, once most of the standard, routine scans were created to an acceptable standard, more specialised, lower volume scans were created. A protocol development 'ticketing' system was devised to help the development of new protocols and support the continuous improvement of current sequences, to help ensure diagnostic image quality is always in keeping with best clinical practice.

***Results*:** Through iteration, robust protocols have been created for the vast majority of routine scans at our centre, including prostate, myeloma, and breast screening. For certain sequences we have had to diverge from guidance due to differences in scanning methods available on this newer generation of scanner, although this was only accepted when a clinically suitable alternative had been developed and with the consent of responsible clinicians. The ticketing system created allows continuous improvement of imaging, whilst ensuring all stakeholders are engaged, requests are prioritised and that the work of radiographers, physicists and radiologists is properly acknowledged. This approach also allowed optimisation of resources, by pairing each clinical application with the best option available. The use of higher field at our centre is now preferred for specific applications where the above process identified the greatest benefit (e.g. MS, TLE, fMRI, pituitary, vessel wall) and, where feasible, avoided if the challenges could not be resolved (e.g. large head-foot FOV or whole spine, due to B1 limitations).

Conclusion: The iterative process we adopted allowed us to take systematics steps towards achieving the desired diagnostic standard and optimal clinical protocols.

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MRI Protocol Development in Proton Beam Therapy, Clinical Optimisation and Standardisation

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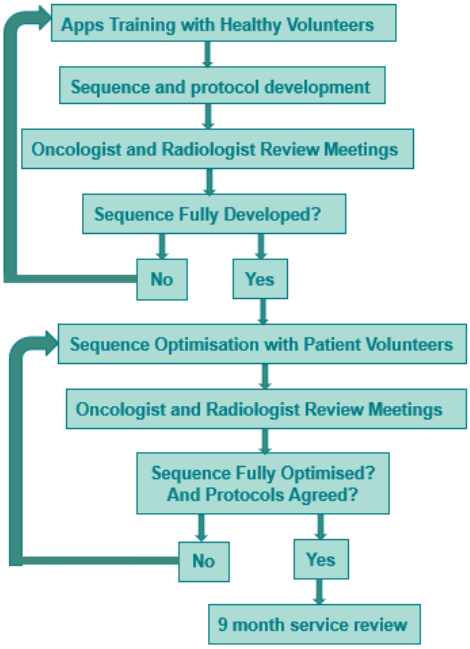
Aims:

The Proton Beam Therapy Department has a dedicated Philips Ingenia Ambition 1.5T MRI that undertakes scans for treatment planning. Patients are scanned in their treatment immobilisation and position which can be a challenge in terms of Signal to Noise Ratio (SNR), resolution and patient comfort. During service development the aim was able to identify and optimise which sequences were useful for planning purposes. Equally to develop protocols that are safe and easy to use for both diagnostic and therapeutic radiographic workforce.

Method:

Planning MRI requires additional considerations such as high resolution isotropic volume imaging with minimal geometric distortion. This enables the Oncologists to contour both pathology and organs at risk with accuracy and in multiple planes. Sequences which are vital for diagnostic reporting for example DWI prove to be less useful in the planning setting due to inherent distortions. MDT style review meetings were held with both Oncologists and Radiologists for image review. Discussions centred around which type of imaging sequences would be useful and these were subsequently evaluated on healthy volunteers. Imaging was reviewed and adaptations made. This process was repeated until the Oncologists approved the quality. The pathway was then repeated with patient volunteers with known pathology. This enabled sequences and protocols to be refined further. Post go live reviews were completed at 9 months and 1 year with the aim to continue the review cycle.

This work has been supported by Philips Applications and Diagnostic MR Physicists.



Results:

Protocols developed, evaluated, and streamlined per pathology and tumour site.

Adult Neuro Sequences		
Standard	**Pathology specific**	**Removed post review**
Ax 3D T2	Non Contrast Angio	Ax 2D DWI
Ax 3D FLAIR	Ax 3D T2 Drive	
Ax T1 Dixon		

Tabulated example of protocol refinement

Conclusion:

Ongoing reiteration of the image review and protocol optimisation process ensures high quality protocols which are site specific and are time sensitive for patient comfort. This review process supports expansion into new imaging sites and research, enhancing service development.

Optimising an Acquisition Protocol and Processing Pipeline for Robust Clinical Quantitative Susceptibility Mapping in the Brain

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Background. Quantitative susceptibility mapping (QSM)[1] has been used to investigate the effect of movement disorders in the brain and may aid early diagnosis but has not been integrated into routine neuroradiology practice. We optimised an acquisition protocol and a robust QSM pipeline for clinical evaluation of movement disorders under the Quantitative Neuroradiology Initiative [2].

Methods. To investigate the trade-off between QSM acquisition time and image resolution/quality, we acquired, seven multi-echo 3D gradient echo (GRE) sequences with different partial k-space approaches (Table 1) in a healthy volunteer on a clinical 3T Siemens Prisma MR system. QSM reconstruction used a preliminary pipeline with iterative Tikhonov[3] susceptibility calculation. Sequence parameters were based on experience and preliminary consensus guidelines[4]: $TE_1/\Delta TE/TE_5$ = 4.92/4.92/24.6 ms; $GRAPPA_{PE1}$ = 3; PE_1 direction R>>L; PE_2 direction F>>H; adaptive coil combination; flip angle = 15°; TR = 30 ms; resolution 1x1x1 mm^3; FOV = 256x192x176 mm^3. After comparing sequences in one healthy volunteer, 11 patients with movement disorders underwent routine clinical scans with sequence #7 appended to the clinical protocol, with informed consent and approval by the local ethics committee. 32 post-processing QSM pipelines, combining different unwrapping, background field removal and susceptibility calculation techniques, were tested to optimise a robust QSM pipeline for clinical use. These pipelines were compared on a numerical phantom[5] and in the 11 patients.

Results. Sequence #7 was used for QSM pipeline selection due to its high contrast in the brain stem and clear boundaries between ROIs such as the subthalamic nuclei and substantia nigra (Figure 1). Partial Fourier in both PE directions resulted in poorer visible separation between brain stem ROIs. The most robust QSM pipeline in the patient cohort included Laplacian phase unwrapping[6] and projection onto dipole fields (PDF)[7] background field removal.

Sequence No.	Partial Fourier	Elliptical Shutter On/Off	Acquisition Time
1	6/8 PE_1 6/8 PE_2	Off	4:42
2	6/8 PE_1	Off	6:16
3	6/8 PE_2	Off	5:53
4	None.	On	6:29
5	6/8 PE_1	On	5:31
6	6/8 PE_2	On	5:10
7	7/8 PE_1 7/8 PE_2	On	5:38

Table 1 *Multi-echo GRE protocols compared for clinical QSM acquisition. The effect of partial Fourier in each and both PE directions was investigated, together with an elliptical k-space shutter. Sequence #7 was found to be best.*

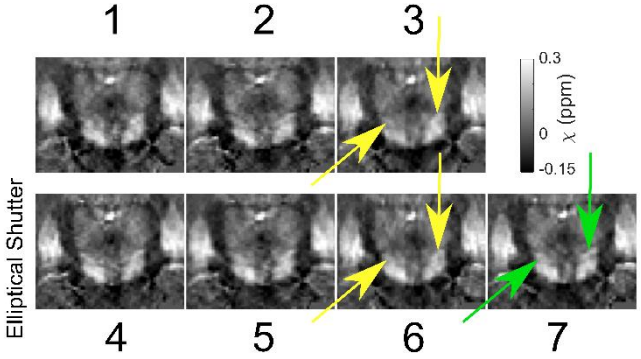

Figure 1 *Coronal views of basal ganglia regions for all sequences tested. Green arrows indicate where sequence #7, taken forward to preliminary clinical use, had high contrast and good delineation of the subthalamic nucleus, compared to other sequences. Partial Fourier in the slice-direction (sequences 3&6) blurred the separation between smaller brain stem structures (yellow arrows).*

Discussion & Conclusion. Evaluating QSM pipelines solely using simulated data was insufficient to predict clinical robustness. A 3D-GRE protocol with partial k-space and an elliptical shutter gave high-quality QSM in 5 min 38 s. In future work, neuroradiologists will score susceptibility maps to select an optimal susceptibility calculation method and finalise a robust QSM pipeline to facilitate translation of QSM into routine clinical MRI in movement disorders.

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An MR Core Lab to support the clinical translation of quantitative MR imaging biomarkers

[1]*Markus J., [2]*Keaveney S., [3]Birchall J., [4]Gallagher E., [3]Gill A.B., [5]Young, J.D., [6]Berks, M., [1]Caselton L., [2]Doran S.J., [7]Aboagye, E.O. and [6]Hubbard Cristinacce P.L., on behalf of the NCITA QA/QC Unit+
[1]University College London, [2]The Royal Marsden Hospital & The Institute of Cancer Research, [3]University of Cambridge, [4]University of Oxford, [5]King's College London, [6]The University of Manchester, [7]Imperial College London. *Joint first authors/presenters +https://ncita.org.uk/

Background: Recent developments in quantitative MRI biomarkers (qMRIBs) have not transferred into widespread clinical practice, with few qMRIBs influencing clinical decision-making. Successful translation requires qMRIBs to be technically and clinically validated[1], which includes an evaluation of multi-centre reproducibility, ideally according to metrological principles[2]. This is hampered by the variability in quality assurance (QA) and quality control (QC) practices across the UK[3], both in terms of image acquisition and analysis. There is a pressing need for standardised quality management in multi-centre imaging studies to support qMRIBs towards clinical adoption.

Methods: The National Cancer Imaging Translational Accelerator (NCITA)[4] was established in 2019 with the primary aim of providing third party support, guidance and infrastructure to develop qMRIBs from ill-defined lab based metrics into reproducible, quality assured imaging toolkits ready for UK-wide clinical use. Specifically, NCITA provides practical support for qMRIBs through the MR Core Lab (MRCL)[5]. The MRCL staff demographics include academic and clinical physicists, radiographers and technicians with a background in research and clinical scanning, and professionals with quality management experience. In consultation with nine NCITA partners, the MRI community and other NCITA units, the MRCL continuously develops and reviews pathways to benefit qMRIB translation, as well as working with study teams to offer bespoke services.

Results: The MRCL provides the personnel and expertise to work with research teams throughout the entire lifecycle of a study, as summarised in Figure 1. The MRCL evaluates imaging protocols to ensure all sites are capable of delivering the study, whilst providing flexible support that maintains data integrity. Harmonised imaging protocols are created at each site through a process of technical imaging review (TIR), which ensures technical performance, data workflow, and staff capabilities are sufficient to provide good quality imaging data.

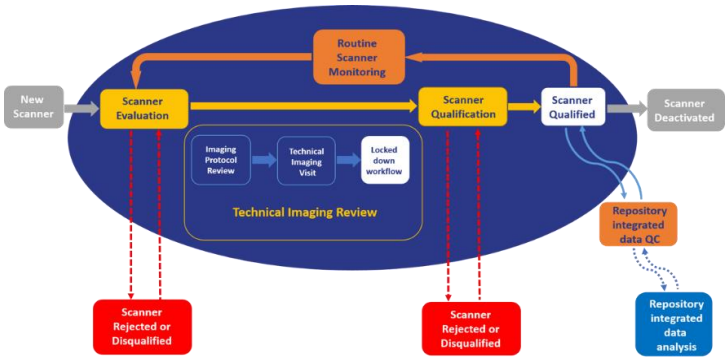

Figure 1 – Overview of the MR Core Lab processes for end-to-end quality management.

A quality management system is used to monitor sites, equipment and processes throughout the study, with on-going QC to ensure standards are maintained. Anonymised imaging data are uploaded to the XNAT image repository[6], where the MRCL provides a combined manual and automated assessment of imaging data quality. This is comprised of a tool to monitor compliance with the imaging protocol and visual inspection of quality metrics, allowing deviations to be identified early and reported to site teams to quickly rectify problems. Where desired, the MRCL can also provide or establish containerised analysis packages that run entirely through the XNAT repository. This delivers a standardised auditable pipeline for study data, improving reproducibility and increasing the impact of the study outputs.

Discussion: The MR Core Lab provides academic and clinical research teams with end-to-end quality management to support study set-up, image acquisition and image analysis. We propose that this service can provide the critical link between academic research and the NHS that will facilitate the translation of validated qMRIBs into clinical practice.

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An Optimized High-Resolution Acquisition for QSM in the Prostate

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Keywords: Quantitative susceptibility mapping, Gradient echo sequence, Prostate

Background Quantitative Susceptibility Mapping (QSM) has shown potential to measure disease-related changes in tissue composition. However, prostate QSM is challenging due to large background fields induced by tissue-rectal gas interfaces[1] and fat-water phase artifacts[2]. Previous prostate QSM studies[1,3,4] have mostly used single-echo sequences, anisotropic voxels and slice thicknesses ≥ 1.7 mm. Here, we aimed to optimize multi-echo acquisition for high-resolution scans in under 10 minutes, for clinical research in subjects being screened for prostate cancer.

	Subject 1		Subject 2		
Sequence	R3_IP	R2_IP_1p25	R3	R3_IP	R2_ME3_IP
Isotropic resolution (mm)	1	1.25	1	1	1
TE1 (ms)	4.6	4.6	3	4.6	4.6
ΔTE (ms)	6.9	6.9	5.4	6.9	6.9
Echoes	5	5	5	5	3
TR	37	34	28	37	23
SENSE (RL orientation)	3	2	3	3	2
Total acqⁿ time	8 min 26 s	7 min 21 s	6 min 26 s	8 min 26 s	7 min 57 s
Sequence explanation	In-phase acquisition with 1mm isotropic resolution	In-phase acquisition with 1.25mm isotropic resolution and lower SENSE factor	Minimum TE acquisition	In-phase acquisition with 1mm isotropic resolution	In-phase acquisition with three echoes and lower SENSE factor

Figure 1: Parameters optimized include in-phase v. minimum TE, number of echoes, SENSE acceleration factor and isotropic resolution. The optimized sequence is highlighted in green.

Methods Two subjects were recruited as part of the Histo-MRI clinical study[5] and scanned on a 3T Philips Ingenia using an anterior 4x4 channel receive array and a 4x4 array in the table. All subjects were given Buscopan to reduce rectal gas and bowel motion. To optimize the SENSE factor, resolution and number of echoes, transverse multi-echo 3D-GRE images with a 420 x 320 x 128 mm field of view centered on the prostate were acquired in both subjects with the parameters in Figure 1. To optimize fat-water phase artifact removal, in-phase acquisitions[6] were compared with minimum-TE acquisition with and without fat correction using a three-point Dixon (3PD) technique[7,8]. To select the optimal acquisition parameters, we made visual comparisons of susceptibility maps calculated using an optimized QSM pipeline similar to that in Karsa et al.[6].

Results and Discussion Susceptibility maps (Figure 2) show that 3PD correction resulted in greater noise in the prostate and some water-fat swaps relative to the in-phase acquisition which had no significant fat-water phase artifacts. The 3-echo map was noisier within the prostate than the 5-echo map despite the lower acceleration factor (R2 v. R3), probably because of the lower maximum TE resulting in a lower contrast-to-noise ratio (CNR) in the susceptibility map[9]. The susceptibility maps with 1 mm isotropic resolution were sharper and seemed to have greater CNR.

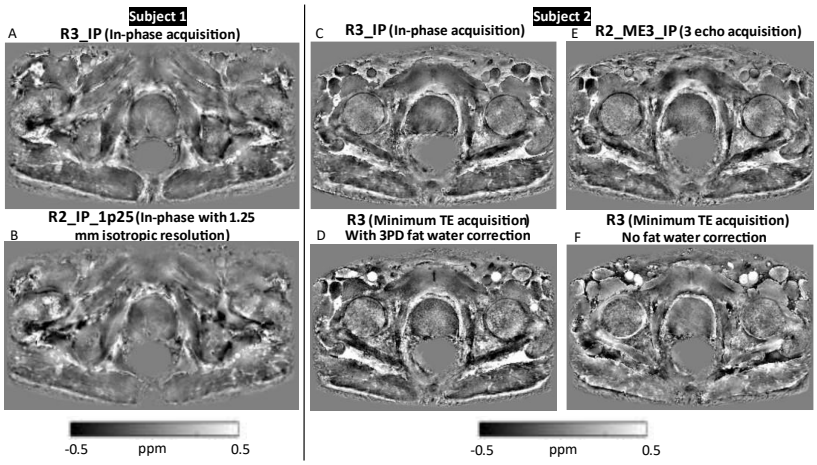

Figure 2: Optimization of resolution and parallel acceleration factor is illustrated in Subject 1 (A and B). Comparison of the in-phase and 3PD fat-corrected susceptibility maps is illustrated in Subject 2 (C and D). The effect of the number of echoes on the susceptibility maps is illustrated in Subject 2 (C and E).

Conclusion We optimized acquisition parameters (and a QSM processing pipeline – not shown here) for high (1mm isotropic) resolution prostate susceptibility maps acquired in < 8.5 minutes. In-phase acquisition with 5 echoes and 3-fold SENSE acceleration provided high quality susceptibility maps in six subjects. This optimized protocol and pipeline will allow incorporation of QSM into clinical research studies in the prostate.

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Title of Study: Reduction of image acquisition times in musculoskeletal imaging through the use of simultaneous multislice acquisitions

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Background

MRI waiting times have increased significantly since the Covid-19 pandemic with 25.7% of patients referred for MRI waiting over 6 weeks in December 2022[1]. Despite this, the number of MRI examinations requested continues to increase[1].

One way to increase patient throughput is to decrease MRI examination times. Numerous technologies exist to reduce MRI scan times, such as parallel imaging, however many of these have a detrimental effect on image quality and signal-to-noise ratio (SNR). A technique that shows potential for decreasing scan times without a reduction in SNR is simultaneous multi-slice acquisitions (SMS). In SMS, data is acquired from multiple 2D slices at the same time. As the data is fully sampled, images do not suffer from an SNR penalty[2], however the technique is only applicable to 2D imaging, requires high coil element density and can lead to high RF power deposition. This technique has shown potential for shortening scan times across several anatomical areas[3].

Methods.

Imaging sequences used for musculoskeletal (MSK) imaging of the knee, elbow, ankle, and scaphoid were optimised predominantly using SMS on a 1.5 T Siemens Magnetom Sola scanner in Leeds. Once SMS was applied, time savings were realised by reducing the repetition time (TR) and number of concatenations.

During the optimisation phase, a multi-disciplinary team acquired images on the same subject using both routine sequences and sequences optimised for the use of SMS. Radiologist feedback was sought on each imaging sequence to ensure image quality was maintained. Acquisition times and imaging parameter changes for each sequence were recorded. Sequences that reduced imaging time and had no deterioration in image quality were adopted into the protocol, replacing existing sequences.

An audit of total examination time of knees and ankles was carried out 3 months after the optimisation work was completed and compared to examination times over a 3 month period prior to the optimisation.

Results.

Several turbo spin echo (TSE) sequences were shortened in all the anatomies investigated due to the application of SMS. Overall examination times in all anatomies were shortened between 5 to 6 minutes in each anatomical area. The audit of imaging times showed a reduction of over 25% in the total examination times of both anatomies.

Discussion.

The application of SMS had a significant time reduction on MR imaging acquisition times without deterioration of image quality. As a result of this optimisation work and realising other efficiencies, appointment times were shortened by 10 minutes across different exams, saving 910 minutes (approx. 15 hours) of scanner time per month, equating to over 30 more patients being scanned.

Conclusion.

Applying SMS and optimising sequences accordingly can lead to significant reductions in scan time and an increase in patient throughput in MSK imaging.

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Real-time MRI of speech: translation between scanner manufacturers and sequence optimisation for clinical speech assessments

A. Peplinski, M-V. Papoutsaki, M. Ruthven, M.E. Miquel. Clinical Physics, Barts Health NHS Trust.

Background. Dynamic real-time MRI of speech and associated organs are an active and progressing field of research with increasing clinical applications [1-2]. For clinical studies assessing soft palate motion and closure, real-time imaging of approximately 10 frames-per-second (fps) is recommended [2]. However, research MRI sequences, and offline or iterative advanced reconstruction techniques are not accessible on standard clinical MRI scanners. Consequently, it can be challenging to achieve the recommended spatio-temporal resolution. Despite Scott et al [3] work on Phillips scanners, most clinical studies do not achieve the recommended temporal resolution [4-5]. Therefore, this study focusses on developing clinical speech sequences on GE MRI scanners operated at 1.5 T and 3 T.

Methods. Work was carried out on two GE Healthcare scanners: 1.5 T SIGNA Artist and 3.0 T SIGNA Architect using the standard head and neck coil. Scanning was carried out on three healthy volunteers who were scanned across 7 scanning sessions, some of them multiple times. Initial scanning sessions were to determine the best sequence for each field strength; balanced steady state free precession (FIESTA) or spoiled gradient echo (Fast SPGR)**.** The following image parameters were then optimised in the subsequent sessions: echo time (TE), repetition time (TR), acquisition matrix, acceleration factor, type of shim and choice of coil element combinations. Image quality was evaluated by two readers using the methodology described by Scott et al. [3].

Results. Example images of each tested imaging types at each field strength can be found in Figure 1. At 1.5 T, the average visual score rating for FIESTA was 3, whereas it was 2.3 for SPGR. For the optimised FIESTA sequence, the acquired spatial resolution was $1.9\times2.3\times10$ mm^3 with an acceleration factor of 3, TE/TR = 0.8/2.6 ms and acquired at 10.6. At 3 T, the average visual score rating for FIESTA was 2, whereas it was 2.6 for SPGR. For the optimised SPGR sequence, the acquired spatial resolution was $1.9\times2.3\times10$ mm^3 with acceleration factor = 3, TE/TR = 0.8/2.6 ms and acquired 10.6 fps.

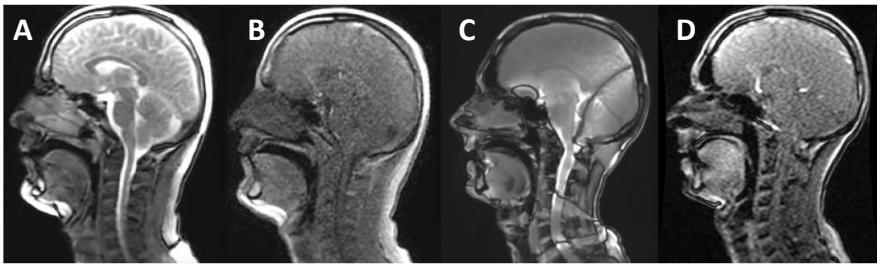

Figure 1. Example images of for real-time MRI of the vocal tract during speech. A. FIESTA- 1.5 T, B. SPGR - 1.5 T. C. FIESTA - 3 T. D. SPGR -3 T. B was discounted due to low SNR and C due to excessive artefacts.

Discussion. The choice of sequence type at both field strengths is in agreement with Scott et al.'s work [3]. For Siemens, steady state precession sequence also performed worse than half-Fourier acquired single turbo-spin-echo sequence at 3T [4]. The recommended spatial resolution of $1.9\times1.9\times10$ mm^3 [3] was not achieved on GE scanners. This is because Philips scanners use an external SENSE calibration and consequently a higher spatial resolution can be achieved at the same frame rate. However, the acquisition parameters meet the spatio-temporal parameters recommended for clinical assessment of velopharyngeal sufficiency [2]. We had reached the same difficulties on Siemens in previous work [6], where it was challenging to match Scott et al. spatio-temporal [3] while being in the range specified by Lingala et al. [2].

Conclusion. Although it is challenging to match the same quality with identical spatio-temporal resolution as Scott et al. [3], we successfully optimised protocol at 1.5 T and 3 T that still match spatio-temporal recommendations for velopharyngeal closure assessment [2].

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Phantom-based assessment of a deep-learning MR image reconstruction pipeline to inform optimisation of clinical protocols

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Background: A 3T GE MRI scanner with deep-learning image reconstruction capability (AIR Recon DL) was recently installed at our institution. AIR Recon DL is a deep learning-based convolutional neural network for reconstructing MR images on 3T systems. The neural network model is applied to remove image noise and Gibbs ringing truncation artefacts prior to the final image formation, without requiring additional scan time. In removing the conventional trade-off required when optimising clinical protocols, where resolution, time and SNR are intrinsically linked, deep-learning methods such as AIR Recon DL represent a significant step change in MRI technology [1-3]. However, there is a "black box" element to selecting the extent of deep-learning reconstruction applied. The user can select 'Off', 'Low', 'Medium' and 'High', with the chosen setting affecting signal-to-noise ratio (SNR), sharpness and extent of truncation artefact. The aim of this work was to perform a phantom-based assessment of AIR Recon DL to improve understanding of AIR Recon DL and to inform subsequent optimisation of clinical protocols.

Methods: A T2-weighted fast spin echo sequence was used to assess AIR Recon DL performance (TR/TE = 3000/122 ms, ETL=21, slice thickness = 5mm). A spherical water phantom was scanned for SNR analysis. Pairs of images were acquired at each AIR Recon DL setting. Mean signal was calculated from the first image and noise was calculated from the standard deviation of noise in the pair subtraction image (first image minus second image).The large American College of Radiology (ACR) MRI phantom was then scanned at each AIR Recon DL setting and varying voxel dimensions in order to assess image sharpness and extent of Gibb's ringing artefact. Modulation transfer function (MTF) analysis was performed on a low-to-high signal interface on module 1 of the ACR phantom.

Results: SNR increased by a factor of 1.36, 2.04 and 4.35 when AIR Recon DL was turned from Off to Low, Medium and High, respectively. Visual inspection of the ACR images and qualitative assessment of edge spread function (ESF) curves at a high-to-low signal boundary revealed that AIR Recon DL effectively eliminated Gibbs ringing artefact and images were visibly sharper as a result. Quantitative MTF analysis revealed no significant change in the MTF50 for varying AIR Recon DL setting and voxel size (ANOVA test used to compare means for each AIR Recon DL setting, $p<0.05$ for all comparisons).

Discussion: The results of this study suggest that while inherent image resolution is not altered by AIR Recon DL, perceived image sharpness is enhanced through a combination of boosted SNR and suppressed Gibbs ringing artefact. Consequently, these phantom study findings suggest that a lower in-plane matrix setting can be used with AIR Recon DL to obtain equivalent spatial resolution and image sharpness to a conventionally reconstructed image, independent of the SNR improvement.

Conclusion: The results of this phantom study will be combined with ongoing image quality assessment of clinical images acquired using AIR Recon DL to (a) improve local understanding of this new image reconstruction technique and (b) inform optimisation of clinical protocols. In addition, the SNR and MTF tests described here will be used to assess consistency of AIR Recon DL performance as part of the overall scanner quality assurance protocol.

Key references: [1] Kaniewska M, et al. Application of deep learning-based image reconstruction in MRimaging of the shoulder joint to improve image quality and reduce scan time. Eur Radiol(2022); Epub ahead of print. **[2]** Lebel R. Performance characterization of a novel deep learning-based MR imagereconstruction pipeline. GE Healthcare publication, 2020. **[3]** Peters RD, et al. The Clinical Benefits of AIR™ Recon DL for MR image reconstruction. GEHealthcare publication, 2020.

Optimising Clinical MRI Protocols on Volunteers Using Deep Resolve

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Background. Deep learning has many applications in MRI [1,2] Deep resolve is an AI based image reconstruction toolbox by Siemens Healthineers [3], based on [4,5]. We demonstrate the application of Deep Resolve to clinical sequences at STH.

Methods. Volunteers were scanned with clinical protocols, which were adapted to reduce the acquisition time (by reducing base resolution or No. of averages for example). Deep resolve sharp (DRS) was used in combination with boost (DRB) or gain (DRG) to improve image quality. An iterative process has been followed using Radiologist feedback to reach the optimal balance between reducing acquisition time and maintaining image quality. Longer protocols including brain, spine and prostate, were prioritised.

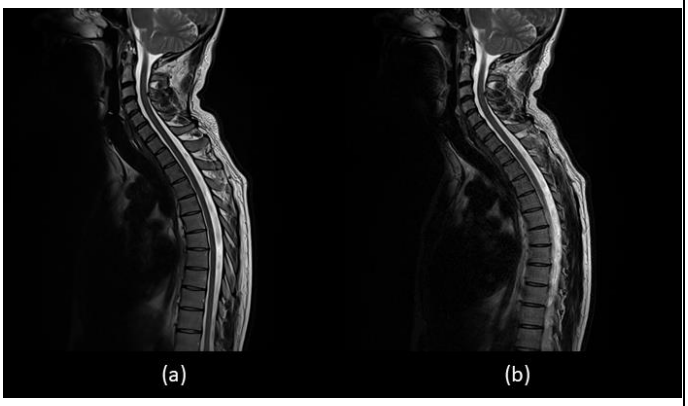

Figure 2: T2 TSE sagittal image (a) before and (b) after optimisation.

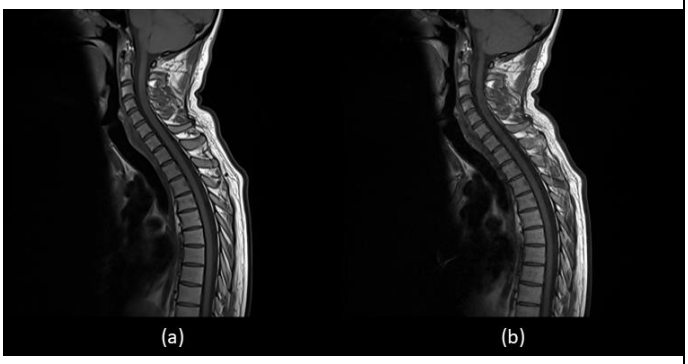

Figure 2: T1 TSE sagittal image (a) before and (b) after optimisation.

Results. Figures 1 and 2 show example T2 and T1 images, whilst Table 1 shows representative protocol changes. For these examples, acquisition time was reduced by x% and x%. Following this process across whole clinical protocols has resulted in time savings of up to 15 mins (% out of 40).

Discussion. Image acceleration software and the resulting reduced protocol lengths has several advantages. This increases patient throughput and can also increase patient comfort (due to reduced time in the scanner). It is also possible to gain improved image quality whilst still reducing acquisition times. The optimisation trade-off between quality and speed requires significant time for testing and close multi-disciplinary co-operation.

Conclusion. Deep Resolve is a very promising technique for reducing the acquisition time of clinical sequences, while maintaining image quality. Further work is needed to further optimise the protocols and to apply it to other clinical sequences.

Key references. [1] G. Zhu, et al. "Applications of deep learning to neuro-imaging techniques." Frontiers in neurology 10 (2019); [2] Argentiero, Adriana, et al. "The applications of artificial intelligence in cardiovascular magnetic resonance—a comprehensive review." Journal of Clinical Medicine 11.10 (2022); [3] N. Behl, "Deep resolve—mobilizing the power of networks." MAGNETOM Flash (78) 1 (2021); [4] J. Herrmann et al., “Feasibility and implementation of a deep learning mr reconstruction for tse sequences in musculoskeletal imaging,” Diagnostics, vol. 11, no. 8, 2021; [5] K. Hammernik et al."Deep Learning for Parallel MRI Reconstruction: Overview, Challenges, and Opportunities." MAGNETOM Flash 4 (2019).

Sequence	Deep Resolve Settings	Other Changes	Original Acquisition Time	New Acquisition Time
T2 TSE	DRG: Strength: 8, Enhancement: 2 DRS: on	Base resolution: 432 Phase resolution: 80 No. averages: 1 TR: 3400	02:44	01:03
T1 TSE	DRB: on DRS: on	Base resolution: 448 No. averages: 1	03:05	00:39

Table 1: A summary of the changes made to each protocol and the change in the acquisition time.

Optimisation of faster MP2RAGE acquisition at 3T

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Background. The MP2RAGE[1] sequence provides improved grey/white matter (GM/WM) contrast over standard T_1-weighted MPRAGE and allows generation of T_1-maps. Cortical malformations such as blurred GM/WM matter junctions which are associated with refractory focal epilepsy[2] are difficult to visualize with routine MRI, but MP2RAGE has demonstrated better delineation of epileptic lesions at 7T[3] and has the potential to improve detectability at 3T. However, the standard MP2RAGE 1mm isotropic protocol at 3T has an acquisition time of 8 min with GRAPPA=3 acceleration factor, making it challenging for clinical populations. Here, we optimize the contrast to provide a faster MP2RAGE acquisition at 3T to be used as part of our epilepsy pre-surgical assessment protocol.

Methods. The signal evolution of the MP2RAGE sequence was simulated using code written in python3. The MP2RAGE image signal (complex ratio combination of the INV1, INV2 acquisitions at TI_1 and TI_2) was estimated for WM/GM/CSF tissue assuming proton density and T_1 values of 0.71/0.83/1 and 0.85/1.35/2.5s[1] respectively. TI_1 and TI_2 parameters were optimised to maximize GM/WM contrast at TR ($TR_{MP2RAGE}$) of 4s and 3.5s to accelerate the standard acquisition (TR=5s). In order to validate the simulation results and assess the effect of reducing TR in generated T_1 maps, the T_1-calibrated Eurospin T05 phantom was scanned on a 3T Siemens Skyra system. A healthy volunteer was then scanned using the optimal MP2RAGE parameters.

Results. Simulations showed that shorter TI_2 times can compensate for the loss of contrast when using shorter TR times (Fig 1A, left). Optimal GM/WM contrast for TR=3.5s, (TI_2=1800ms) was obtained at TI_1= 600ms , however slightly longer TI_1 (650ms) yielded 98.6% of the optimal GM/WM contrast while increasing GM/CSF contrast significantly (Fig 1A, right). Data acquired with the optimal parameters (Table 1) shows similar contrast to that of the standard acquisition (Fig1B). Estimated T_1 values were only marginally shorter for acquisitions with shorter TR (Fig.1C), consistent with the trend seen in phantom data.

TR	TI_1	TI_2	α_1/α_2	n_z	TR_{GRE}	iPAT	resolution	TA
5s	0.7s	2.5s	4/5°	176	7.1ms	3	1mm³	8:22s
4s	0.7s	1.8s	4/5°	160	5.8ms	3	1mm³	6:42s
3.5s	0.65s	1.8s	4/5°	160	5.8ms	3	1mm³	5:52s

Table 1: Details of parameters for the standard and optimized MP2RAGE protocols.

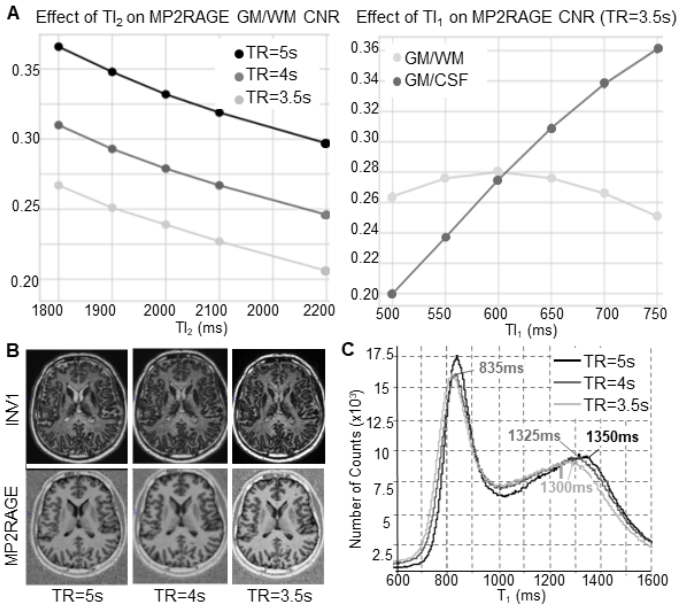

Figure 1: (A) *Simulations of MP2RAGE GM/WM contrast across TI_2 (left) and GM/WM and GM/CSF contrast across TI_1 (right). (B) Example images acquired at TI_1 (INV1) and corresponding MP2RAGE image for standard (TR=5s) and optimal (TR: 3.5s ,4s) acquisitions. (C) T_1 histograms measured in human brain for each MP2RAGE acquisition.*

Discussion. Given that MP2RAGE is based on signal from two acquisitions, it is more challenging to optimise the image contrast than for standard MPRAGE. Using simulations provided a useful guide for the parameter choices to test using phantom and volunteer scanning, hence minimising the use of valuable scanner time. This approach led to effective optimisation of the MP2RAGE contrast in the brain while reducing acquisition time by 20-30% to a more clinically viable duration. Future work will evaluate the clinical implementation of the optimised protocol and investigate optimisation for specific clinical populations where brain T_1 values may vary.

Conclusion. MP2RAGE parameter optimisation through simulations validated by phantom and volunteer scans maintained high contrast in a reduced, clinically applicable scan time.

Key references: [1] Marques et al. NI. 2010,49:1271-1281. [2] Blumcke et al., Epilepsia, 2011, 52, 158-174. [3] Pittau et al. JON. 2018,0:1-5.

A low SAR/B1+rms optimisation strategy for Deep Brain Stimulators

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Background. Requests for MRI scans of patients with Deep Brain Stimulators (DBS) are increasingly encountered in routine clinical MRI. The number of implants per year is rising steadily, and the clinical targets of DBS therapy are expanding to other diseases as phase III clinical trials end [1]. Combined with this has been the welcome developments by implant manufacturers of MR Conditional DBS devices, opening up MRI for another cohort of patients.

These devices present a number of challenges for MRI units including logistics, availability of expert staff (Specialist nurse/clinicians), equipment (for interrogating or reprogramming devices), coil availability (e.g. transmit/receive coils), patient movement (DBS usually treats tremor symptoms) and, crucially, very restrictive scanning conditions. This can results in scans only being undertaken at specialist centres.

We present a typical strategy for optimising MRI protocols to reduce heating risks, showing the results of this strategy in a low SAR/B1+rms protocol for brain and spine scans of DBS patients.

Methods. Firstly, the optimisation strategy was identified, prioritising low SAR sequences whilst acknowledging the tension between scan time, image quality and RF-induced heating.
A selection of low SAR strategies were employed including (1) RF mode – using the Low SAR RF mode should be the first choice. This has no effect on the scan time and only minimal impact on SNR. (2) Flip angle – the SAR is proportional to the square of the flip angle so a small reduction in flip angle can lead to a large reduction in SAR. Will reduce SNR slightly and can affect contrast. Consider both initial flip angle and refocusing angle. This also means the highest SAR sequences contain the most 180° flips per time period i.e. Fast Spin Echo. Therefore (3) consider sequence type - avoid FSE and inversion recovery sequences if possible. Use gradient echo sequences instead (being aware of those with very short TRs (e.g. bSSFP). (4) Consider sequence ordering, interleaving higher and lower SAR sequences. (5) Reduce k-space steps by reducing phase FOV and/or resolution. (6) Reduce number of slices. (7) Take off an average if there is sufficient signal. (8) Increase TR (increases time, may affect contrast). (9) decrease TSE factor – reduces RF duty cycle but increases time.

Results. Following this strategy resulted in a Brain/Spine protocol where all sequences have B1+rms ≤2 μT while maintaining adequate image quality.

The method presented is generalisable to all implants and protocols where a lower SAR/B1+rms is desired. The presented techniques equip the MR Operator with practical optimisation strategies to follow in real world clinical practice.

Discussion. A key skill of the MR Physicist is to support and enable the scanning of complex or unusual implants, to increase patient access to diagnostics and reduce healthcare inequalities. Having these strategies within your mental toolkit are foundational in this work and enable either the *a priori* optimisation of protocols, or *ad hoc* optimisation on a per patient basis.

In addition, the wider clinical context and patient considerations are important to ensuring success with these complex devices. This includes pre-scan engagement with implanting surgeons and clinical teams, manufacturer technical specialists, support from clinicians/nurse specialists in device interrogations and understanding the patient's specific movement challenges. This is supported by clear policies and procedures for the efficient management of such requests.

Conclusion. With a thorough understanding of the physical factors affecting SAR and the corresponding strategies to reduce those components, clinical protocols can be effectively optimised for use with highly restrictive device such as Deep Brain Stimulators as described here.

Key references.
[1] Lozano, Andres M., et al. "Deep brain stimulation: current challenges and future directions." Nature Reviews Neurology 15.3 (2019); [2] Boutet, Alexandre, et al. "Improving safety of MRI in patients with deep brain stimulation devices." Radiology 296.2 (2020);