Evaluating an existing MR for RT service against the 'IPEM topical report: guidance on the use of MRI for external beam radiotherapy treatment planning'

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Background. The 'IPEM topical report: guidance on the use of MRI for external beam radiotherapy treatment planning'[1] (EBRT) gives comprehensive guidance to MR and RT departments. The existing MR for EBRT service at our Trust, comprising two 1.5 T scanners, was evaluated against the guidance. The aims were to ensure the service is fit for purpose, and to identify and carry out any improvements to the service that were discovered.

Methods. The current MR for EBRT pulse sequence parameters were extracted from sequence pdf's downloaded from the scanner using in-house scripts. The pulse sequence parameters were checked against the IPEM guidance, for example comparing receive bandwidth, distortion correction algorithm and slice gaps against recommended values[1]. A pathway was established for ongoing optimisation of MR for RT pulse sequences, via a multi-disciplinary group of MR and RT clinical scientists and oncologists. Multiple QA tests were completed, including repeat scans of clinical RTP head sequences with the CIRS large field MR image distortion phantom (604-GS).

Results.

Anatomy	Protocol	Sequence	Duration	Orientation	Positioning Mode	Mode	Matrix	PhaseRes	TR	TE	Averages	FOVRead	Bandwidth	Distortion Correction	Mode
Head	Radiotherapy Planning	t1_fl3d_sag_iso	4:29	Sagittal	ISO	3D	256	97	30	5.2	1	260 mm	130 Hz/px	On	3D
Head	Radiotherapy Planning	t1_mprage_sag_p2_iso	5:27	Sagittal	ISO	3D	256	100	2130	3.3	1	256 mm	130 Hz/px	On	3D

Figure 1. Example output of in-house script that was used to check MR for EBRT pulse sequence parameters against IPEM guidance. The highlighted cells do not meet recommendations.

Timeline	Duration	Orientation	Positioning Mode	Mode	Matrix	TR	TE	Averages	Bandwidth	Distortion Correction	Mode	Slice thickness	Slices	Post-processing reconstruction
Before optimisation	11:56	Transversal	ISO	3D	256	6000	348	2	592 Hz/px	On	3D	1.5 mm	96	3mm tra
After optimisation	07:32	Transversal	ISO	3D	256	6000	348	2	592 Hz/px	On	3D	3 mm	60	n/a

Figure 2. Example pulse sequence optimisation (T2 SPACE) using the established pathway.

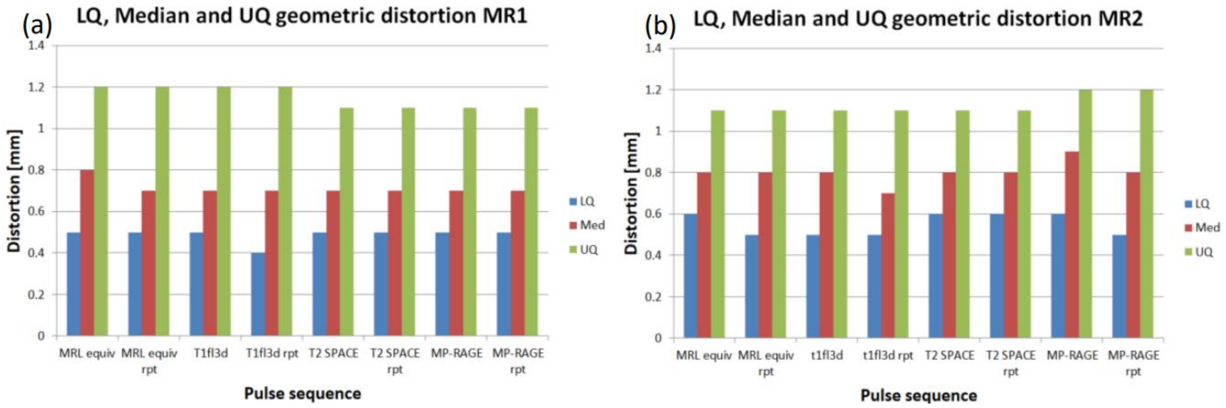

Figure 3. The lower quartile (LQ), median (Med), and upper quartile (UQ) measured geometric distortion of >2000 grid intersections within the 604-GS phantom for four pulse sequences, each with one repeat: three clinical MR for RT sequences minimally adapted to cover the 604-GS and 'MRL equiv' (a QA sequence that covers the whole phantom), on (a) MR1 and (b) MR2.

Discussion. Evaluation of the existing MR for EBRT pulse sequences against the IPEM topical report proved to be valuable. The work highlighted several opportunities for optimisation in the existing protocols, and implementation of those changes has begun. QA testing demonstrated that the geometric distortion of the sequences currently in clinical use are acceptable and stable, including the t1_fl3d_sag_iso sequence with receive bandwidth lower than recommended by IPEM.

Conclusion. An existing MR for RT service was evaluated against the IPEM MR for EBRT guidance and found to be fit for purpose, with some improvements identified and carried out.

Key references.

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An Evaluation of Cushion and Flat Top Overlay Setups on a 1.5 Tesla MRI Simulator Based on Spine Coil SNR

[1,2]Doran E, [2]Allwood-Spiers S, [2]Brennan D, [1]Glegg M, [2]Foster J, [1]Thomson S, [1]Sankaralingam M
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Background. Magnetic Resonance Imaging (MRI) is increasingly being used in radiotherapy to exploit the superior soft tissue contrast available in the images for the delineation of target volumes and organs-at-risk (OARs) [1]. More precise definitions of these structures will increase the accuracy of highly conformal external beam radiation treatments for certain cancer areas [2].

Dedicated MRI simulators have been developed so that the patient's treatment position can be replicated during pre-treatment imaging [3]. A flat top overlay replaces the standard cushion overlay on the scanner couch. MR Safe positioning or immobilisation devices can be attached to the flat top overlay. The phased array spine receive coil is located underneath the overlays [4]. There is concern that the additional distance the flat top overlay introduces between the receive coils and the patient can be detrimental to the signal-to-noise ratio (SNR) of the acquired images.

The radiotherapy physics department at the Beatson West of Scotland Cancer Centre (BWoSCC) has recently installed a Siemens® 1.5 Tesla MAGNETOM® Sola® (MAGNETOM RT Pro edition). This abstract presents an evaluation of spine coil SNR with respect to the use of the standard cushion overlay, normally used in diagnostic imaging setups versus the use of the flat top overlay which will be used for radiotherapy pre-treatment imaging.

Methods. The effect of the cushion (Siemens®) and flat top (QFix® INSIGHT™) overlays on spine coil SNR was measured using the MagNET spine test object, with images acquired according to the MagNET imaging protocol [5]. The distance from the spine coil to the test object was 1.0 cm and 1.5 cm for cushion and flat top overlays respectively. The spine coil has 8 elements (S1-S8). Six receive element combinations were tested, moving the test object down the scanner couch over the relevant elements before each acquisition. The MagNET normalised SNR analysis was performed on coronal slice 8 of 16 using an in-house Python script (see Figure 1).

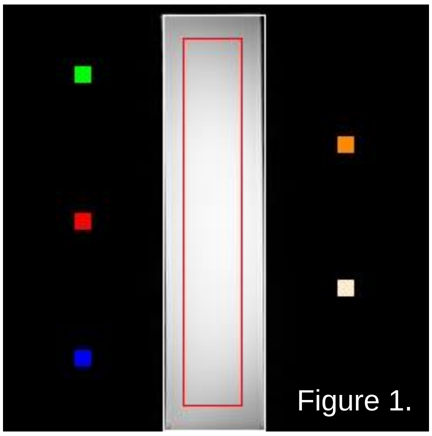

Figure 1.

Results. SNR varied by 2.7% and 4.2% along the spine coil for the cushion and flat top overlays respectively. SNR was 7% lower in images acquired with the flat top overlay compared to SNR in images acquired with the cushion overlay (see Figure 2).

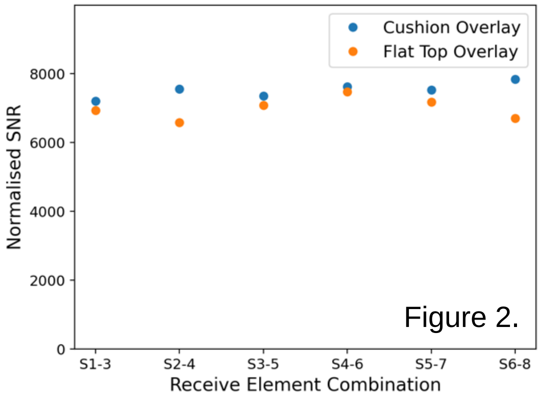

Figure 2.

Discussion and Conclusion. SNR did not vary significantly along the spine coil though more pronounced differences were observed for element combinations S2-4 and S6-8 which correspond to the areas where the respiratory sensors are located on the scanner couch. The performance of the respiratory sensors with the flat top overlay will require further investigation due to the reduced SNR over these areas. The decrease in SNR observed with the flat top overlay was expected due to the additional 0.5 cm between the spine coil and test object and should not affect the image quality of radiotherapy pre-treatment MR images.

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Systematic multi-disciplinary sequence evaluation for integration into the MR-linac workflow – J Chick

Background. Vendor-approved Magnetic Resonance (MR) sequences are provided for MR-linac workflows, however alternative 'off-label' sequences may offer advantages. Prior to clinical use, the safety, accuracy and overall clinical benefit of such sequences should be determined. The aim of this study was to develop a systematic approach for off-label sequence evaluation and demonstrate the application for bladder cancer MR-guided radiotherapy (MRgRT) on Unity[1].

Methods & Results. Two T2-weighted Turbo Spin Echo off-label sequences were proposed, denoted 1.1min3mm and 3.4min2mm, indicating both acquisition time and slice thickness. Each sequence was assessed against the vendor-provided 2min1mm sequence. The off-label sequences were acquired on three patients receiving daily bladder cancer MRgRT, and on the ACR phantom for image Quality Assurance (QA)[2].

Table 1: Summary and outcome of sequence assessments

	Summary of Assessment	3.4min2mm	1.1min3mm
Qualitative Review	Workflow suitability for registration and contouring	PASS	PASS
	Image quality	PASS	PASS
Image QA	ACR analysis	PASS	PASS
	Parameter Review	PASS	PASS
Planning Assessment in TPS	Margin growth check	PASS (*)	PASS (*)
	IMRT optimisation	PASS	PASS
	Dosimetric assessment	PASS	PASS
Phantom Workflow	Overall treatment time (compared to 2min1mm)	n/a	- 4min

* Note that the TPS rounds margins to slice below if not integer multiple of the slice thickness

Table 1 summarises the assessments. A qualitative review of image quality and workflow suitability was undertaken independently by doctors and treatment radiographers on the Monaco treatment planning system (TPS)[3]. Image QA included geometric accuracy, image uniformity and ghosting. The planning assessment in the TPS included impact of the larger slice thickness on margin expansions and plan optimisation behaviour. Dosimetric impact was investigated by using existing clinical treatment image data (2min1mm) in VolumeView[4] to reconstruct 2mm and 3mm slice thickness data for plan generation using the same clinical template. Treatment plans were then recalculated on the original 2min1mm sequence, and clinical goals and dose conformity compared. To quantify the potential reduction in overall treatment time for the shorter acquisition of the 1.1min3mm sequence, a phantom treatment workflow was also carried out.

Discussion. Both off-label sequences were shown to be accurate, safe and of non-inferior utility to the 2min1mm sequence, and facilitated clinically acceptable treatment plans. For margins that are not integer multiples of the slice thickness, the effective margin can differ in the TPS, however no dosimetric impact was seen. The workflow time reduction of 4min for the 1.1min3mm sequence can be attributed to both shorter acquisition and reduced dataset size. This could translate into a 14% reduction in MRgRT bladder cancer treatment times at our centre.

Conclusion. A systematic sequence evaluation approach was developed and used to evaluate off-label sequences for use in bladder MRgRT on the Unity MR-Linac. Application of the proposed 1.1mm3mm sequence will enable meaningful reductions in workflow time. This has the potential to minimise intra-fraction target volume changes and permit safe future PTV margin reductions. This approach to evaluating off-label sequences will be applied to other indications and sequences before clinical implementation.

[2.] Acr.org; [1.] Elekta AB, Stockholm; [3.] v5.40.1, Elekta; [4.] v5.3.31, Philips Medical Systems, Best

Dosimetric Evaluation of MR-based Deep Learning Automatic Contouring in the Pelvis

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Background. Manual contouring is an essential component of the radiotherapy workflow but is time-consuming and prone to inter-observer variability[1]. Automatic contouring algorithms could provide significant time-savings and improvements in consistency but to date have not demonstrated sufficient accuracy and reliability for clinical use[2]. Magnetic Resonance (MR) imaging has superb soft-tissue contrast which has demonstrated improvements in manual contouring[3], which may facilitate more accurate automatic contouring. In addition, conventional contouring metrics, such as Dice, do not correlate with clinically relevant dosimetric outcomes[4]. Therefore, the aim of this study was to develop a MR-based Deep Learning (DL) automatic contouring algorithm for pelvic Organs At Risk (OARs) and evaluate it dosimetrically.

Methods. An ensemble of 2D and 3D DL convolutional neural networks were trained on T2-weighted MR images from 88 patients (13 female, 75 male) from a 1.5T (n=49) or 3T (n=39) scanner. Ccontours were generated for bladder, bowel bag, femoral heads, rectum (all patients) and penile bulb, prostate, prostate & Seminal Vesicles (SV) and urethra (male patients) using a separate DL model for each OAR except for the urethra and penile bulb which used a joint model. Manual contours were produced by medical students trained by clinical oncologists.

The algorithm was evaluated on 3T T2-weighted MR images from 20 patients (6 female, 14 male) treated for prostate (n=10), rectal (n=4) and anal (n=6) cancers. A volumetric modulated arc therapy plan was optimised for each patient using the clinical Planning Target Volume (PTV) and the automatic OAR contours to deliver 60 Gy in 20 fractions (prostate), 50.4/45/25 Gy in 28/25/5 fractions (rectal) or 53.2/50.4 Gy in 28 fractions (anal). The doses to the automatic and manual contours were determined and differences at clinically relevant dose constraints calculated. The prostate and prostate & SV contours were excluded from the analysis for the prostate patients and the rectum contours excluded for the ano-rectal patients.

Results. Automatic contours were successfully generated for every organ except urethra (failed for two patients) and penile bulb (one patient). Example image shown in the figure opposite (automatic and manual contours shown as solid and dotted lines respectively).

For the prostate patients, mean dose differences were ≤ 0.1 Gy for all constraints for the femoral heads, penile bulb and urethra. Mean relative volume differences were ≤ 0.6% for bladder and rectum except the rectum V30 Gy. Mean dose differences for the bowel bag were ≤ 2.0 Gy. For the ano-rectal patients, mean dose differences were ≤ 0.7 Gy for all constraints on all organs except the bowel bag D180 cm^3.

Discussion. The automatic contours appeared accurate for most organs with dose differences < 1% of prescription dose. The larger differences in the rectum V30 Gy were due to differences in the superior extent between manual and automatic contours. Similarly, there were discrepancies about the inferior extent in the bowel bag, which generated large dose differences for the prostate plans because of the steep dose gradient at the superior edge of the PTV.

Conclusion. A MR-based DL algorithm has been developed for a range of pelvic OARs. Small dose or relative volume differences to manual contours for the bladder, femoral heads, prostate and prostate & SV organs were observed. This suggests the model is sufficiently accurate for clinical use for these organs for prostate and ano-rectal radiotherapy plans.

Key references. [1] C Cardenas et al. Seminars in Radiation Oncology 29(3), 2019. [3] A Pathmanathan et al. British Journal of Radiology 92(1096), 2019. [4] D Roach et al. Physics in Medicine and Biology 63(3), 2018. [2] G Sharp et al. Medical Physics 41(5), 2014.

Early experience with radical cervix treatments on the Elekta Unity MR-Linac

[1]Berresford J, [1]Freear L, [1,3]Chuter R, [1]Agnew J, [1]Meara S, [1]Marchant T, [1]Whitehurst P, [1]Budgell G, [2]Nelder C, [2]Benson R, [2]Clough A, Pitt E[2], [2]Barraclough L
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Background. An MR-Linac is ideal for cervical cancer radiotherapy due to excellent imaging of soft tissues and the ability to adapt daily for target variations in bladder, rectal and bowel filling. Four radical cervix patients have now been treated on the Elekta Unity MR-Linac at the Christie. Our early experience with these treatments is presented.

Methods. Patient selection was restricted due to the limited superior-inferior field length (22cm), however four suitable node-negative patients have been identified during our first clinical year since commissioning. The prescription, contours and reference plan were created as per EMBRACE II guidelines. The primary RTP scan was MR with bulk density overrides applied to enable dose calculation. Daily adaptation was carried out using the Adapt-to-Shape (ATS) workflow; deformed structures were reviewed and edited if required prior to a full plan re-optimisation. A prescription of 45Gy in 25# was used to the primary PTV. Planning was with 15 equi-spaced beams. Reference plans were verified prior to first delivery using an MR-Delta4.

Results. All four patients have been successfully treated on the MR-Linac. Challenges included:

- Patient discomfort under the MR headrest, under the back and from the hand grip. This was improved via foam padding under the head and back, and one patient chose to wear gloves.
- Optimising the drinking protocol so the bladder would fill during the planning process and eventually match or slightly exceed the original rigid bladder contour, without significantly affecting the target position. It was found important to ensure the patient was pre-hydrated before the planning scan.
- Initial set-up proved extremely important due to the treatment length only just fitting within the MR-Linac field. Any systematic offsets had to be identified and applied very early in treatments. Following image registration, set-up had to be within 1.0cm superiorly/inferiorly.
- Contouring, which was initially time-consuming, improved with experience, with treatment times of under an hour being achieved. Contours are automatically deformed however discrepancies were noted from the reference plan, for which edits were only made if deemed clinically significant. . Bladder and bowel bag contours were rigidly propagated which aided in reducing contouring time.
- On one patient, shrinkage of tumour was noted and the uterus position changed throughout course of treatment. This was conveniently addressed by selecting previous adapted plans with various different uterus positions, and deforming these contours to the daily plan.
- Long optimisation times were improved by editing plans to make them more robust and changing settings within Monaco to enable faster online optimisation.

Discussion. Despite the limitations of the aperture on the Unity MR-Linac and the complexity of the contouring and planning, it has been possible to create a practical workflow which has been used on four patients who have tolerated the treatments well despite the long treatment times. The treatments require multi-disciplinary co-operation between clinicians, radiographers and physicists.

Conclusion. Radical cervix patients can be successfully treated on an MR-Linac with daily adaptation due to the high quality soft-tissue imaging capabilities.

Feasibility of Measuring Mandibular Perfusion Using Dynamic Contrast Enhanced Magnetic Resonance Imaging (DCE-MRI) to compare with Radiotherapy dose

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Background

Mandibular Osteoradionecrosis (mORN) is a serious side-effect of head and neck (H&N) radiotherapy, affecting 3 – 20 % of patients post treatment[1]. The pathophysiology of mORN is complex, however radiation dose correlates with severity of disease[3]. Changes to mandibular perfusion remain challenging to measure. Dynamic Contrast Enhanced MRI (DCE-MRI) presents a non-invasive opportunity to measure perfusion of the mandible[2]. We present a case-study, demonstrating for the first time DCE-MRI at 1.5T to measure mandibular perfusion.

Method

A 62 yr. old female was scanned on a 1.5 T Siemens Magnetom Sola XA20 (head first supine; radiotherapy immobilisation; Ultra-Flex coil on bridge for patient comfort).
MRI protocol: T2w TSE. Six T1w VIBE sequences at varying flip angles. Following an injection of contrast agent a DCE T1w VIBE sequence with Golden-angle Radial Sparse Parallel (GRASP). Data were post-processed in the Siemens Syngo.Via Platform. Firstly all other data was registered to structural T2w scans, a T1 map was calculated using a variable flip angle (VFA) approach from the T1w VIBE sequences. Perfusion maps of relevant parameters: K^{trans}, V_e, K_{ep}, and V_p were then calculated from DCE data using the extended Tofts Model[4].

Results

DCE-MRI is feasible within a timeframe of 20 minutes. Mandibular perfusion parameters were successfully extracted for the patient, producing quantitative maps of K^{trans}, V_e, K_{ep}, and V_p.

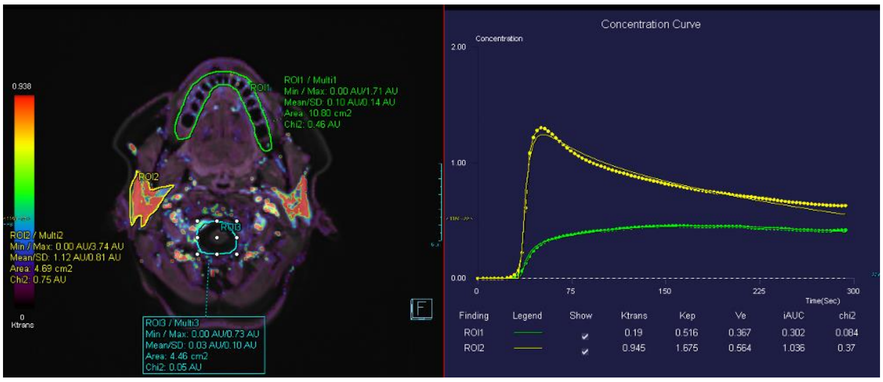

Figure 1: Example perfusion maps of processed data.

A) Perfusion map of perfusion metric K^{trans}

B) Concentration curves of contrast agent over the imaging timeframe, showing derived perfusion metrics (K^{trans} & V_e)

Discussion & Conclusions

We have demonstrated feasibility of implementing DCE-MRI to measure mandibular perfusion. To our knowledge, this is the first study of this kind. We are now performing a study, scanning patients undergoing radiotherapy for bilateral oropharyngeal cancer multiple times over and beyond their treatment to better understand changes to mandibular perfusion as a result of radiation dose delivered.

Key references

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Daily prostate ADC in patients having SABR or conventional prostate radiotherapy on an MR-Linac

Christopher Moore

Background/Aims: The MR-Linac (MRL) allows daily anatomical and functional imaging [1]. Prostate ADC has been shown to act as a biomarker for radiotherapy treatment effectiveness [2]. If ADC can be measured during treatment then it may be possible to predict the effectiveness of treatment and adapt plans based on functional information. This work set out to compare prostate ADC changes in individuals treated with conventional vs stereotactic ablative radiotherapy (SABR) treatment.

Material/Methods: The Elekta MRL Biomarkers working group diffusion-weighted imaging (DWI) sequence [3] was run on five patients undergoing conventional treatment and four patients undergoing SABR treatment under the MOMENTUM trial. The purpose of the DWI imaging was explained to patients who then provided consent to undergo additional imaging for research purposes after daily treatments. At each treatment, patients could opt out of this imaging.. Treatment contours on daily T2w images were rigidly registered and copied to the daily DWI b0 images. ADC maps were generated from b = 150, 500 s/mm^2 images, and median values were extracted from whole prostate ROIs. A 2-sided, paired t-test was used to determine if there were any significant ADC changes between the start and end of treatment for either treatment.

Results: There was no significant change between the start and end of treatment for either the conventional treatment ($p = 0.81$) or the SABR treatment ($p = 0.14$) [fig 1].

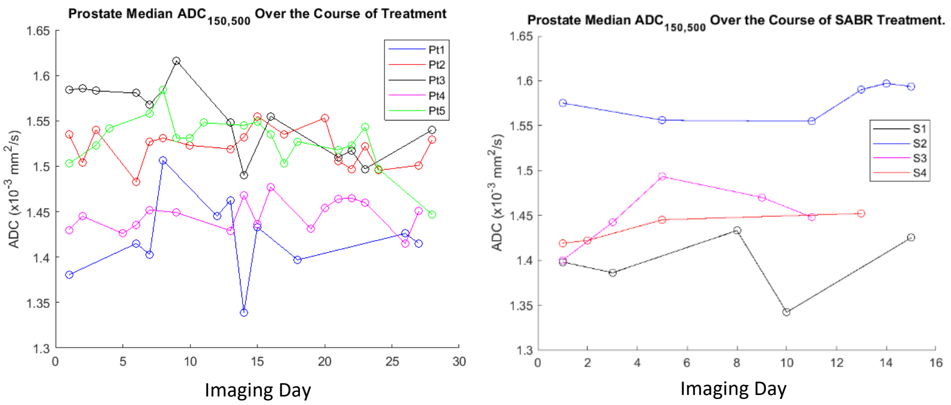

Fig 1: Median prostate ADC measured across the course of treatment on patients undergoing conventional (left) and SABR (right) treatments.

Discussion: Daily DWI measurements on the MRL are feasible and measured ADC values were comparable to literature [2]. Further optimisation of DWI image needed to help distinguish tumour from prostate tissue. There was no significant change in ADC between baseline and end of treatment for either treatment. Limitations include the low numbers of patients; previous treatment with neo-adjuvant hormone therapy [4], and that only the whole prostate, rather than having ROIs for the tumour, was assessed in this preliminary work.

Conclusion: Daily prostate ADC measurements are feasible on the MRL. More work is required to improve image quality and separate tumour and healthy prostate ADC. Additional patients will be recruited to this study

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Experience of online MR-guided adaptive radiotherapy using the Elekta Unity MR-linac.

[1]Dunlop A, [1]Mitchell A, [1]Chick J, [1]Stankiewicz H, [2]Ingle M, [2]Gough J, [3]Alexander S, [3]Bhide S, [3]Aitken K, [3]Tree A, [1]Nill S, [1]Oelfke U

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The Elekta Unity MR-linac [1] has been in clinical use at The Royal Marsden hospital in Sutton since September 2018. The Unity combines a 1.5 T Philips MRI scanner with a 7MV FFF Elekta linac. As well as being able to utilise MRI for image guidance, it also enables online adaptive radiotherapy (ART) where a new treatment plan can be created on an MRI image, acquired with the patient on the treatment couch, enabling radiotherapy to be tailored to the daily anatomy. The Unity has two main treatment planning strategies, and both require a reference plan, generated on a reference image, to be adapted according to the daily MRI. In adapt-to-shape (ATS), a daily treatment plan is generated on the daily MR, using the daily contours, and delivered to the patient. In adapt-to-position (ATP), the treatment field apertures of the reference plan are adjusted according to the rigid, translations-only registration between the daily MRI and the reference image [2]. As such, ATP is akin to daily image guided RT (IGRT)-based corrected treatment on a C-arm linac but with MRI guidance, whereas ATS strategies require recontouring, plan optimisation, and plan checking to all occur within a matter of minutes with the patient on the couch.

Since September 2018 we have treated over 190 patients and 2,100 fractions with > 95% of treatment sessions being delivered using the ATS workflow. We routinely treat a range of clinical indications including prostate, bladder, rectal, gynae, oligometastatic disease, breast, and head and neck. With the ability to create dose distributions according to the shape of the target and OARs visualised on the daily MR, we have the opportunity to assess the feasibility of PTV margin reduction. The exquisite soft tissue contrast means we are able to treat sites that are difficult to visualise on cone beam CT (CBCT) with greater confidence. Furthermore, the improved confidence of delivering dose to the intended target [3] enables ultrahypofractionation schemes to be explored.

In this presentation we will provide an overview of the Unity system and provide details of the workflows we have recently-commissioned at our site. Clinical case examples presented emphasise our change in focus as we move from demonstrating feasibility of existing paradigms towards more novel approaches such as PTV margin reduction and ultrahypofractionation.

In January 2021 the RCR published new guidelines for IGRT for rectal cancer, recommending reducing PTV margins from 10 mm to 5 mm [4]. We have undertaken a study to ensure that such margins could be safely applied to rectal cancer patients treated on our MR-linac and found that PTV margins can be safely reduced to 5 mm for our MR-linac based treatments, caution is advised when reducing the margins for non-adaptive techniques. Margin assessment studies for bladder and oligometastatic treatments are ongoing.

We have recently opened the HERMES trial (CCR5273) to recruitment where we aim to establish the feasibility and safety of treating prostate cancer with ultrahypofractionated radiotherapy, delivered in 2#. In this randomised Phase II single-centre trial, patients are divided into two prescriptions groups: 36.25Gy/5# stereotactic body radiotherapy (SBRT) with boost of 40 Gy to the CTV and 24Gy/2# SBRT with boost of 27 Gy to the dominant lesion GTV. For HERMES we have implemented MRI-based reference planning as standard and implemented a novel online workflow to deliver the 2 fraction treatment arm. We are currently developing a treatment strategy for the treatment of pancreatic cancer SBRT on the MR-linac.

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Tracking Organ Motion in the Pelvis for Radiotherapy Planning

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Background. Magnetic Resonance (MR) has demonstrated improvements in contouring accuracy and precision for pelvic radiotherapy planning [1]. MR is a very flexible imaging modality able to produce different images optimised for different tasks, including functional imaging which could enable dose painting strategies [2]. However, this multi-parametric imaging approach requires long acquisition times (≥ 20 minutes), during which organ motion from bladder filling is substantial (bladder volume changing ~ 4% min^{-1}) [3]. Therefore using MR to its full potential for radiotherapy requires a method of tracking and correcting for organ motion in the pelvis. The aim of this study was to develop and evaluate this method in healthy volunteers.

Methods. MR images of 9 healthy volunteers (5 male, 4 female) were acquired following bladder emptying and drinking 400 cm^3 of water. Three high resolution T2w images (6.2 minutes long) were acquired at 15, 30 and 45 minutes after drinking. Immediately before and after each T2w was a low resolution tracker image (1 minute long). Each volunteer underwent three identical imaging sessions on different days. A validated automatic contouring algorithm produced bladder, rectum, femoral heads (all volunteers) and prostate (male volunteers) contours on each T2w image. Contours from T2w 1 and T2w 3 were compared to T2w 2 contours using the mean Distance To Agreement (DTA) metric. Deformable registrations from tracker 2 to tracker 4 (2→4) and tracker 6 to tracker 4 (6→4) were carried out in RayStation. Contours on T2w 1 image were deformed by the 2→4 registration and compared to contours on the T2w 2 image. A similar process was applied to contours on T2w 3 using 6→4.

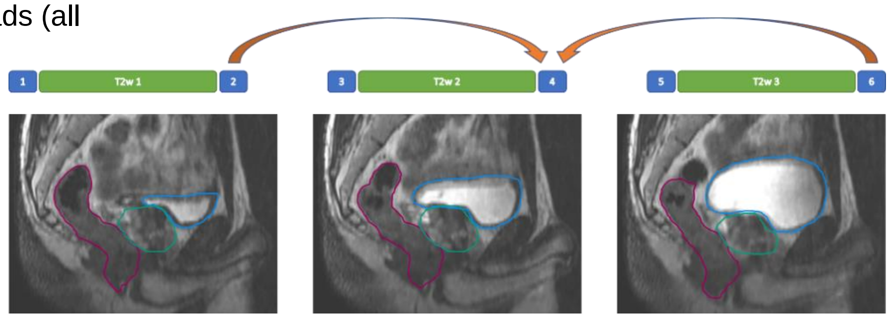

Fig 1 *Top, diagram of imaging protocol showing tracker (blue box), T2w (green box) and 2→4 and 6→4 deformable registrations (orange arrows). Bottom, example T2w images with bladder (blue), prostate (green) and rectum (purple) contours.*

Results. The mean bladder fill rate was 6 ± 2 cm^3 min^{-1}. The tracker deformation substantially improved the mean DTA results for the bladder, with smaller improvements in femoral heads and no change in rectum and prostate (figure 1).

Discussion. The mean DTA results from the validation of the automatic contouring algorithm were 1.1 ± 0.1 mm compared to manual. The 6→4 deformation improved bladder mean DTA results to 1.5 ± 0.1 mm, which was approaching the validation result. The 2→4 deformation results were 2.6 ± 0.3 mm, suggesting the deformation worked better going from larger volumes to smaller. This was a general pattern for all organs studied.

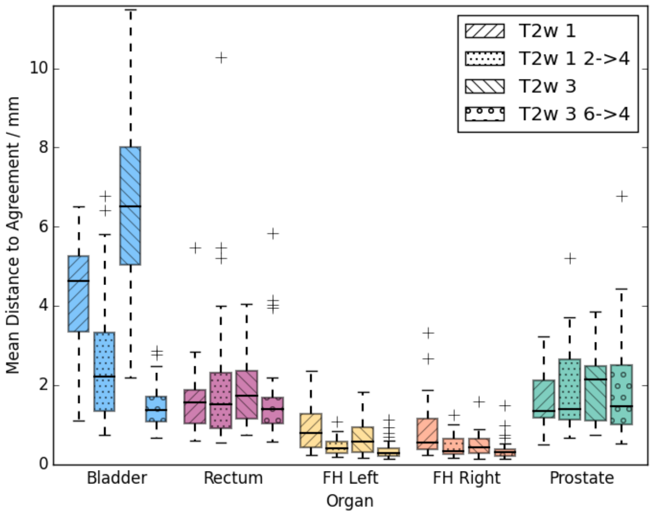

Fig 1 *Boxplots of DTA mean results for each organ showing T2w 1 and T2w 3 compared to T2w 2. Also the corresponding results using deformations 2→4 and 6→4.*

Conclusion. A method for tracking and correcting organ motion in the pelvis has been developed. Initial results are promising but require further development. Use of this method could enable using multiple MR sequences for pelvic radiotherapy planning. It would also provide a patient-specific motion model that could be used for robust planning approaches.

Key references. [1] L Beaton et al., Br J Cancer, 120, 2019. [3] H Lotz et al., Med. Phys. 32(8), 2005. [2] D Thorwarth, Br J Radiol, 88(1051), 2015.

Evidence supporting anal and rectal cancer MR-only radiotherapy planning clinical implementation

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Background: Magnetic resonance (MR)-only radiotherapy planning has been implemented in specialist centres, starting with prostate treatments. However, a barrier to the wide-spread clinical implementation of MR-only planning for other pelvic sites is their limited assessment in the literature demonstrating their technical achievability and benefit.

The *Mr-only treAtment plaNning for anal and recTAl cancer RadiotherApY* (MANTA-RAY) study is a non-interventional study investigating the use of MR-only planning for anal and rectal cancer treatments. It aimed to validate synthetic-CT model generation (sCT) accuracy, show the viability of CBCT patient positioning using sCT and MR data as a reference image and demonstrate the clinical benefit of MR-only vs. CT-only to patient treatments for anal and rectal cancer sites.

Methods: The MANTA-RAY study recruited 46 patients with anal and rectal cancers who received CT and T2-SPACE MR simulation in the radiotherapy treatment position after informed consent. A deep learning sCT model was trained and validated in terms of hounsfield unit and dosimetric calculation accuracy on variable input data (paired CT-MR data for 44 patients) from two centres. Differences in CBCT patient position registration accuracy was assessed for 32 patients and 216 CBCTs (110 anus, 116 rectum) when using sCT and MR data as reference images compared to CT. A planning study assessed differences between MR-only and CT-only planned treatments for 17 anal and 29 rectal cancer patients. Target volumes were delineated and treatment plans were produced independently for each modality, differences in target volumes and treatment plan doses to organs at risk (OARs) were compared.

Results: The sCT model was validated with a systematic dose differences to PTV D95%, D50% and D2% of 0.1% between sCT and CT. T2-SPACE MR and sCT data was successfully used as reference images for XVI-based CBCT position verification. Although challenges remain to clinically enable alternative modalities, the systematic differences to CT in all translational and rotational dimensions were <1 mm and <0.5 °. MR-only target volume delineations reduced GTV and primary PTV volumes by 13 cc and 98 cc (anus) and 44 cc and 109 cc (rectum) respectively (example shown in figure 1) and MR-only based treatment plans resulted in statistically significant dose reductions to OARs compared with CT-only plans (table 2).

Conclusions: Our findings provide evidence that supports the wider clinical implementation of MR-only planning for anal and rectal cancers.T2 MR sequences (which are optimal for anal and rectal cancer target delineation) can also accurately be used for sCT generation for anal and rectal cancer sites. Changing reference image modality has minimal impact on registration accuracy. OAR dose reduction, due to the use of MR, could lead to improved patient outcomes if OAR dose reductions translate into less treatment related toxicity.

Standard Plans	Dose level	Anus		Rectum	
		Patient Numbers	Vx effect size (95% confidence intervals) (%)	Patient Numbers	Vx effect size (95% confidence intervals) (%)
Bladder	V70%	17	**-3.8 (-6.4 to -1.2)**	28	**-5.2 (-8.2 to -2.3)**
Uterus	V95%	2	-	13	**-15.9 (-24.4 to -7.4)**
Penile Bulb	V95%	9	**-11.2 (19.9 to -2.5)**	6	-7.3 (-27.2 to 12.5)
Genitalia	V70%	11	**-4.0 (-7.5 to -0.5)**		
	V60%	17	**-3.5 (-5.7 to -1.3)**		

Table 1. Selected MR dosimetric differences to OARs in standard plans for anal and rectal cancer treatments, where volume effect size is the systematic difference in volume of each organ receiving x Gy of dose on MR vs. CT (a negative value indicated a lower dose on MR compared to CT). Bold effect size values indicate statistically significant confidence intervals. "Number of patients" is the number of patients whose DVH statistics were >1% on both CT and MR and therefore included in the analysis.

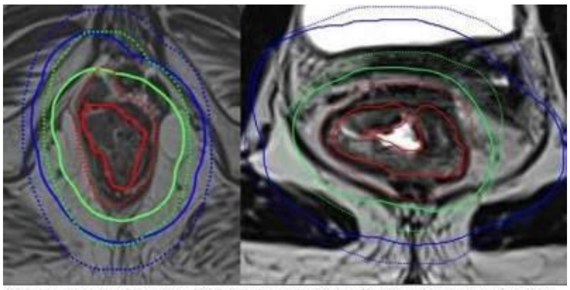

Figure 1. Example of the GTV (red), CTV (green) and PTV (blue) target volume reductions when delineated on CT-only (dotted line) and MRI-only (solid line) for a single anal (left) and rectal (right) cancer patient