IPEM
Institute of Physics and Engineering in Medicine

IPEM Science, Technology and Engineering Forum 2023

Tuesday 28 February - Wednesday 1 March

Book of Abstracts

University of Strathclyde Technology & Innovation Centre, Glasgow

IPEM Science, Technology and Engineering Forum (STEF)

"Tackling Challenges Together"

28th February – 1st March 2023

University of Strathclyde Technology & Innovation Centre

The inaugural Science Technology Engineering Forum showcases some of the most significant developments across medical physics and clinical engineering; identifying and examining the key challenges that lie ahead for physics and engineering in medicine. The key ideas, debates and discussions from the conference will be captured in a forthcoming special issue of IPEM Translation, our open access journal.

This book contains abstracts and summaries for all proffered and invited session talks and posters. Talks and abstracts may be referenced using ISBN 978-1-3999-4663-6.

About IPEM

Physicists, engineers and technologists play vital roles in delivering our healthcare. The Institute of Physics and Engineering in Medicine (IPEM) is the professional organisation that represents this diverse workforce. We are a charity with more than 4,600 members drawn from healthcare, academia and industry. Our mission is to improve health through physics and engineering in medicine. Our members help to ensure that patients are correctly diagnosed and safely treated for illnesses such as cancer and stroke. They also maintain and manage vital medical equipment such as MRI and ultrasound scanners, X-ray machines, drug delivery systems and patient monitors. Their research and innovation leads to new technologies and methods that improve on existing medical treatments. They provide new solutions that enable older people and patients with injuries or long-term conditions to complete everyday tasks.

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Save the date:

• Ultrasound Update	14th March 2023	Leeds
• MR Safety Expert	20-24th March 2023	(online course)
• Clinical Risk Management foundation course	28th March 2023	(online course)
• Environmental sustainability in clinical/rehabilitation engineering	30th March 2023	(online ½ day)
• Clinical Safety in Health IT Systems	24th April 2023	(online 1 hr webinar)
• MRI Protocol Development – Clinical Optimisation and Standardisation	18th May 2023	Bristol
• Quantification in SPECT and PET Update	27th April 2023	Birmingham
• RWA Update and RPA Update	13th-14th June 2023	Birmingham
• Automation in Radiotherapy Treatment Planning	29th June 2023	Sheffield
• Quality Improvement in Radiotherapy	14th September 2023	Manchester
• AGM and Volunteers' Day	29th September 2023	York
• Managing Patient Dose – Utilising Dose Monitoring Software	4th October 2023	Manchester
• MR Safety Update	16th November 2023	London

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Introduction

On behalf of the organising committee it gives me great pleasure to welcome you to Glasgow and to the inaugural IPEM Science, Technology and Engineering Forum (STEF), which incorporates the Biennial Radiotherapy Physics Meeting.

As we emerge from the COVID-19 pandemic and reflect on the profound contribution of the medical physics and clinical engineering community in tackling a global crisis, it is encouraging to see the energy brought to STEF through a diverse range of high-quality invited and proffered works across all career grades.

A primary goal of STEF is to encourage interaction both across MPCE specialisms who traditionally operate separately and between the NHS, academia and industry. The programme is intended to promote debate and discussion around topics of mutual interest, with a number of interactive sessions included alongside traditional scientific presentations.This is an opportunity to reinforce and develop personal networks, catch up with old colleagues and friends and forge relationships with new ones.

In line with the IPEM Science Leadership Strategy, published last year, STEF acts as the cornerstone of an initiative to integrate the various strands of professional and scientific activity within the Institute. Early career presenters will be offered feedback on their presentations to support their development, and a special issue of IPEM Translation is being prepared that will include both papers covering the posters and presentations at the meeting and editorials capturing the opinions shared during the discussions.

Alongside contributions from the IPEM MPCE community I am delighted that the STEF programme is underpinned by keynotes from eminent individuals who support the environment in which MPCE activity operates, including Sir Jonathan Van-Tam MBE, Professor Bas Raaymakers, University of Utrecht and Carol Monaghan, MP for Glasgow North West and a member of the House of Commons Science and Technology Select Committee.

I would like to thank all those who have laboured tirelessly to structure the programme, develop the sessions and score submissions. I am also extremely grateful to our industry partners for sponsoring the event and being active participants in the sessions.

STEF is the first large-scale in-person meeting for IPEM after the pandemic so I'd also like to thank you, our delegates, for taking the time to participate in the meeting. We couldn't do it without you!

Andrew J Reilly

Chair, IPEM STEF Organising Committee
Scientific Director, Clinical Physics and Bioengineering, NHS Greater Glasgow and Clyde
February 2023

Implementation of CBCT-Based Online Adaptive Radiotherapy: Challenges and Opportunities

Liz Adams

Keywords: adaptive radiotherapy, Varian, ETHOS, CBCT, cone beam

The Radiotherapy team at Royal Surrey have implemented online adaptive radiotherapy using the CBCT-based Varian ETHOS Therapy system, with the first patient treatment in January 2021. To date the team have treated over 800 adaptive fractions to patients with pelvic cancers, with the majority being bladder and cervical cancers. This talk will cover the challenges faced by the team at every stage of the process - from the initial decision to purchase the machine, through commissioning and initial implementation, up to establishing the current radiographer-led service - and discuss how the team worked together to find solutions. It will also demonstrate the patient benefits seen to date, and opportunities to further improve through expanding the range of sites treated and reducing margins.

Quality Assurance of the Varian Ethos Adaptive Radiotherapy System Using Virtually-Deformed Anthropomorphic Phantoms

Joel Burton-Lowe[1], Mathew Jones[1]

Keywords: deformable registration, Varian, Ethos, adaptive radiotherapy, quality assurance

Background: Online adaptive radiotherapy is an emerging field that is becoming widely available, providing a means to modify treatment plans via a patient specific imaging feedback loop [1,2,3,4]. Currently limited guidance regarding commissioning, validation and QA is available for the quality assurance of the Varian ethos and other online adaptive systems [5]. The inability to preform pre-treatment QA whilst maintaining the clinical benefits of the online adaptive workflow [3, 4, 6] in addition to the increased clinical adoption of commercially available adaptive systems highlights the need for immediate and appropriate guidance. Therefore, to quantify the limitations and error propagation through the Varian Ethos adaptive workflow virtually-deformed anthropomorphic phantoms were used, with the aim of developing with the aim of developing a comprehensive quality assurance program for end-to-end testing of the auto-deformable image registration (DIR).

Method: The Ethos adaptive treatment planning system (TPS) was presented with CT images of the CIRS Virtual Human Male Pelvis Phantom 801-P-F with varying degrees of deformation as reference. An initial test with no deformation was performed to evaluate the systems baseline and any errors arising from system limitations such as CBCT resolution, followed by a physical deformation and multiple virtual deformations. Following treatment delivery, the session data was exported, sorted and imported into the Eclipse TPS for analysis. The dice similarity coefficient (DSC), hausdorff distance 95% (HD 95%), change in center of mass (ΔCM), mean distance to agreement (MDA) and change in volume (ΔVol) were calculated between the baseline clinical target volume ($CTV_{Baseline}$), propagated target (CTV_{Prop}) and the cone beam CT influencer (CTV_{CBCT}) as well as the (CTV_{CBCT}), reference target (CTV_{ref}) and the manually drawn synthetic CT (sCT) target (CTV_{HU}).

Results and discussion: The inter-modality variations were the most significant cause of error in the structure guided target propagation. Although the similarity and agreement were found to be high between the $CTV_{Baseline}$ & CTV_{CBCT} for the bladder (DSC>0.9, MDA<2mm) the value decreased as the target became smaller. This was directly reflected in the resulting CTV_{Prop} with the accuracy following the same trend. The comparison of CTV contours used to quantify the effect of the DIR upon the sCT show low similarity (bladder DSC<0.8, SVs DSC<0.5) and agreement (bladder MDA>4mm, SVs MDA>3mm) with little difference from the CTV_{Ref} presented. The method used does not take into account the effect of the DIR in creating the entire sCT nor the resultant deformed Hounsfield units (HU) on the dose distribution.

Conclusions: Contour comparison metrics show good agreement between the physical and virtual deformations for all propagated targets whilst also highlighting site specific limitation and tolerance requirements, suggesting a suitable method of QC. However, the method of contour comparison does not provide sufficient information on the DIR used to create the sCT or the error associated with variation in HU. Investigating the dose distribution difference between the initial and the adapted plan would provide the measurable impact of the errors propagated through the adaptive workflow.

References:

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[1]Royal Surrey NHS Foundation Trust, Guildford, Surrey, GU2 7XX

MR-Only Workflow Validation for Daily Adaptive Radiotherapy for Prostate Cancer Patients on the Unity MR-Linac

[1]Stankiewicz H, [2]McQuaid D, [3]Tree AC, [1]Nill S, [1]Oelfke U, [1]Dunlop A

Keywords: linac, magnetic resonance, workflow validation, adaptive radiotherapy

Background: For daily adaptive radiotherapy on the Unity MR-Linac (MRL, Elekta AB, Stockholm), a reference plan generated on a reference image is adapted online according to the daily MR image acquired with the patient on the treatment couch. Using an MR as the reference image should enable more streamlined online workflows due to the improved volume propagation from the reference to daily MR, and removing the requirement for a pre-treatment planning CT would save time and cost. The lack of the patient-specific electron density (ED) information required for dose calculation and bone ROI generation on a reference MR image are the two main challenges to overcome in MR-only workflows for MRL treatments where dose calculations are facilitated using a bulk density override strategy. The aim of the study was to validate MR-only workflows for 5-fraction SBRT (40/36.25/30Gy) prostate cancer treatments on MRL.

Methods: For MRL treatments for prostate cancer, MR-based dose calculation uses a 3-volume bulk density override strategy where patient-specific electron densities are applied for the external, clinical target volume (CTV), and bone structures. Population average EDs were calculated from 57 prostate cancer patients previously treated on MRL within various clinical trials (PERMIT NCT03727698, PACE-C NCT01584258). Atlases consisting of 20, 30 and 40 patients for a bone region of interest (ROI) on MRL-acquired MR images were created from previously delivered MRL treatments using vendor-provided tools in the RayStation treatment planning system (v.11B, RaySearch Medical Laboratories AB, Stockholm). The bone atlases were evaluated on MR images by visual clinical acceptance of the contour with comparison to the clinically-used bone ROI which is considered a gold-standard for this study. For 10 randomly selected previously MRL treated 5 fraction prostate patients, the clinically-delivered online adapted treatment plan from the first fraction was recalculated using population average ED and auto-generated bone ROI. The plan dose statistics were compared between the clinically-delivered and recalculated doses and the plan clinical goal compliance for each calculation was assessed. Gamma analysis was also performed comparing the two calculations with results evaluated in regions that received at least 20% of the prescription dose.

Results: The calculated mean (SD) population average relative ED values for bone, CTV and external ROIs were 1.183 (0.025), 1.050 (0.013) and 0.983 (0.014), respectively. All tested bone atlases generated acceptable volumes upon visual inspection. Mean time of bone auto segmentation ranged from 4.5min to 8min depending on the number of patients included in the atlas and number of fusions selected for auto-contouring. Although bone ROI generation using the atlas is performed offline and is therefore not time-limited as in the online situation, given that all bone ROIs were clinically acceptable, the most time efficient approach (atlas of 20 patients using 15 fusions) was selected for dosimetric validation. The median (range) CTV V100% (% of CTV volume covered by 100% dose) deviation between the clinically-delivered and recalculated plans was -0.99% (-2.39 to +0.61%). The corresponding median (range) high dose planning target volume (PTV_3625) V100% deviation was -0.51% (-1.33 to +0.92%) and the median (range) low-dose PTV (PTV_3000) V100% difference was 0.00% (-1.36 to +1.33%). Across all comparisons, 9 (out of 160) clinical goals changed from being achieved on the clinically-delivered plan to failing for the recalculated dose. All comparisons achieved 100% gamma <1 for global 3%/3mm gamma criterion and the median (range) gamma <1 for global 2%/2mm was 96.0% (95.1% - 96.8%).

Discussion: Out of the 9 clinical goals that failed in the recalculation, 7 were failing the PTV_3650 V100% > 95%. The SBRT plans were prescribed so that PTV_3650 V100% = 95%, meaning any degradation in dose for the calculation would result in a failure for this clinical goal. The gamma analysis results validate the use of atlas-based bone ROI, the population average ED and therefore the MR-only workflow approach.

Conclusions: MR-only workflows for 5-fraction SBRT prostate cancer treatments on the MRL are feasible and can generate dosimetrically accurate MR-based plans using population average ED for bulk density assignment

Using ROMEO to Unwrap B0 Maps for Eligibility Assessment of Patients With Implants for Magnetic Resonance Guided Adaptive Radiotherapy (MRgART)

[1]Joan Chick, [2]Rachael Franklin, [1]Yassine Azma, [1]Andreas Wetscherek, [1]Alex Dunlop, [1]Simeon Nill, [1]Uwe Oelfke

Keywords: MR imaging, radiotherapy

Background: The presence of implants can introduce spatial distortion and signal loss into MRI images, due to B0 field perturbation in the vicinity of the implant. The impact of the spatial distortion needs to be considered when using the images for MRgART. B0 maps can be used to assess the field perturbations, however they can be ambiguous in the presence of large implants due to discontinuities for any phase evolutions greater than ±π(3). The aim of this work was to implement a method using ROMEO(1), a fast open-source phase-unwrapping algorithm designed for MRI phase data, to enable the B0 maps to be unwrapped for use in eligibility assessments for MRgART on the MR Linac.

Methods: Volumetric B0 maps were acquired of an abdominal phantom on the Unity MR-Linac(2,4), comprising of 2 gradient echo acquisitions with ΔTE=4.46ms, which produces phase unwrapping artefacts over |Δf|>109Hz. Scanning was repeated with a paperclip to introduce field perturbations. B0 maps were unwrapped using ROMEO, with an image mask based on signal intensity, and evaluated using difference maps, histograms, and visual assessment. The same unwrapping method was applied to clinical B0 maps from patients scanned under the PRIMER trial (NCT02973828) with implants including hip replacement and aortic stents, and image distortion in target volumes was then estimated.

Results: Figure 1 shows an example slice of the original and unwrapped B0 map for the phantom data. All visible wraps were corrected for, bar residual errors in low SNR regions, with the difference images and histograms showing pixel changes by a multiple of 218Hz (2π). Computational times were less than 1minute. Figure 2 shows results from the clinical data, including the ROMEO quality map which can be used to help identify areas of uncertainty in the unwrapping, and the B0 histogram, which is expected to peak around 0Hz for successful unwrapping. The maximum absolute B0 for the bladder target volume for the patient in Figure 2 was 353Hz (with an average B0 of 74Hz). For a typical bandwidth of 500Hz/mm, this is a maximum distortion of 0.7mm. The B0 histogram showed a broader peak for the aortic stent, indicating ambiguity in the B0=0 position after unwrapping, further work needs to be done for validation in these cases.

Conclusions: As the field of MRgART develops, it is essential that the impact of implants on the treatment localisation is understood, and mitigated where possible. The work presented here will enable individual patient specific assessments, ensuring not only accurate treatments but also reducing potential barriers for all patients benefitting from MRgART treatment. The

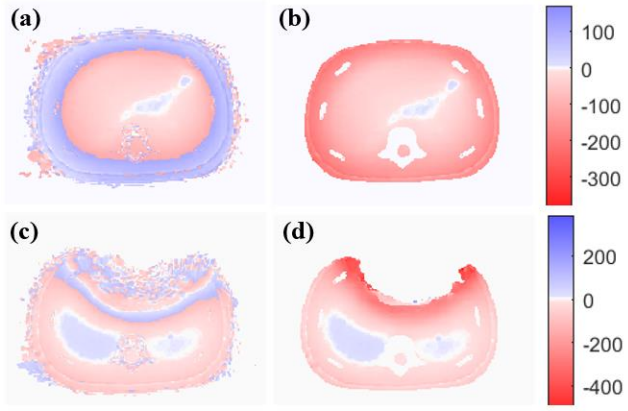

Fig 1: Phantom B0 maps, (a) original (b) unwrapped. Phantom with paperclip present (c) original (d) unwrapped

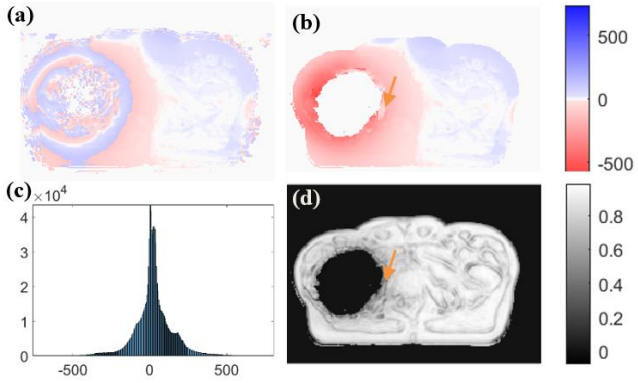

Fig 2: (a) B0 map for patient with L hip replacement. (b) unwrapped B0 map. (c) histogram of unwrapped B0 values. (d) Quality map output of ROMEO. Orange arrow indicates where unwrapping fails and quality map approaches 0.

[1]The Joint Department of Physics at The Institute of Cancer Research & The Royal Marsden NHS Foundation Trust, London, UK [2]Guy's and St Thomas' NHS Foundation Trust, London, UK

unwrapped B0 maps could also be used to investigate optimal shim strategies in the presence of implants, and potentially used to produce distortion corrected images online.

References:

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Conflicts of interest: ICR/RMH is a member of Elekta MR-linac Research Consortium.

Adaptive Radiotherapy for the Oropharynx: A Dose Escalation Journey

Ronan Valentine[1], Laura Grocutt[1], Lisa Hay[2], Anna Cowell[2], Claire Paterson[2]

Keywords: adaptive radiotherapy, dose escalation, oropharynx, RapidPlan®, multi-criteria optimisation

Background: Head and Neck (H&N) cancers are the 6th most common cancer worldwide. A significant proportion of patients with intermediate and high risk squamous cell cancer of the oropharynx (OPSCC) continue to relapse locoregionally despite radical (chemo)radiotherapy ((C)RT). The toxicity of the current regimen limits further uniform intensification. A landmark study by Ang et al., showed patients with high-risk features including heavy smoking history and HPV-negative disease had a 3-year overall survival of only 46.2%. If a predictive biomarker for disease control can be identified during treatment then individualised and adaptive treatment strategies may be employed. The aim of this study is to assess the feasibility of adaptive dose escalated RT to the gross tumour volume (GTV) without increasing surrounding planning target volume (PTV) doses and maintaining clinically acceptable organs at risk (OARs) doses.

Methods: Twenty representative patients with poor prognosis locally advanced OPSCC who were known to have relapsed post RT, were re-planned retrospectively using Eclipse™ TPS v15.5, RapidPlan® (RP) and multi-criteria optimisation (MCO). In our centre, PTV65 is treated with 65 Gy in 30 fractions while areas at risk of containing microscopic disease (PTV54) are treated synchronously to 54 Gy in 30 fractions. The original clinical plans were re-optimised to act as controls (Group I). These plans were split into two plans of 15 fractions each, with the latter 15 fractions used to escalate the dose to the GTV to 73 Gy (Group II) and 82 Gy (Group III). Plan sums were created for the total 30 fractions to record plan evaluation parameters along with assessments of plan deliverability.

Results: For all groups, the dose coverage at D98% and D50% for both PTVs were comparable. All dose levels associated with PTV54 remained largely unaffected by the dose escalation regimens. Conformity indices for PTV65 and PTVAll (PTV65 plus PTV54) reveal comparable target volume coverage across all three groups. Despite the GTV being escalated by 12.3% and 26.2% in groups II and III respectively, percentage dose increases to pertinent OARs for these escalated groups (group II; range: 1.4-6.0% and group III; range: 4.1-13.7%) compared to the control group, were not clinically significant. Also of importance was the volume of GTV receiving > 84 Gy which was considerably less than 1.75 cc for both escalation groups. Modulation factor (MF) values of 0.31, 0.35 and 0.38 and average leaf pair opening (ALPO) values of 2.61, 2.87 and 2.90 were recorded for group I, II and III, respectively.

Discussion: The results from this feasibility study exploring RP combined with MCO has, rather promisingly, enabled the dose to the GTV to be escalated during RT without, significantly increasing dose to OARs or compromising on plan quality, suggesting it is likely to be a safe approach. Given locoregional control remains an unmet need, adaptive dose escalated RT has the potential to improve outcomes for those who need it most.

Conclusions: This treatment planning study has laid the foundations for a clinical investigation of response adaptive dose escalated RT in poor prognosis OPSCC. Ongoing work includes design and implementation of an interventional clinical trial, which will employ this planning approach together with apparent diffusion coefficient (ADC) RT response scores recorded from MRI scans acquired at specific treatment time points.

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Imaging at (Ultra-)High Field

Graeme Keith

Keywords: ultra-high field MRI, structural imaging, vascular imaging, functional imaging

Ultra-high field MRI, such as at 7 tesla, offers both significant benefits and challenges to prospective users. While the inherent increase in signal-to-noise ratio allows acquisition of very high resolution images, allowing the visualisation of very small structures of the brain, the resultant smaller voxel size will increase the sensitivity to subject motion. And while greater frequency dispersion in MR spectroscopy increases the spectral resolution, allowing individual metabolite peaks to be better resolved than at lower field strengths, the increase in chemical shift also leads to greater displacement error. In this presentation I will discuss how the advantages of UHF-MRI bring researchers the tools to probe to a much greater degree the mechanisms underlying disease and the intricate functions of the brain, along with the novel solutions designed to overcome some of its inherent challenges. It will cover areas including structural, vascular and functional imaging, spectroscopy and novel hardware.

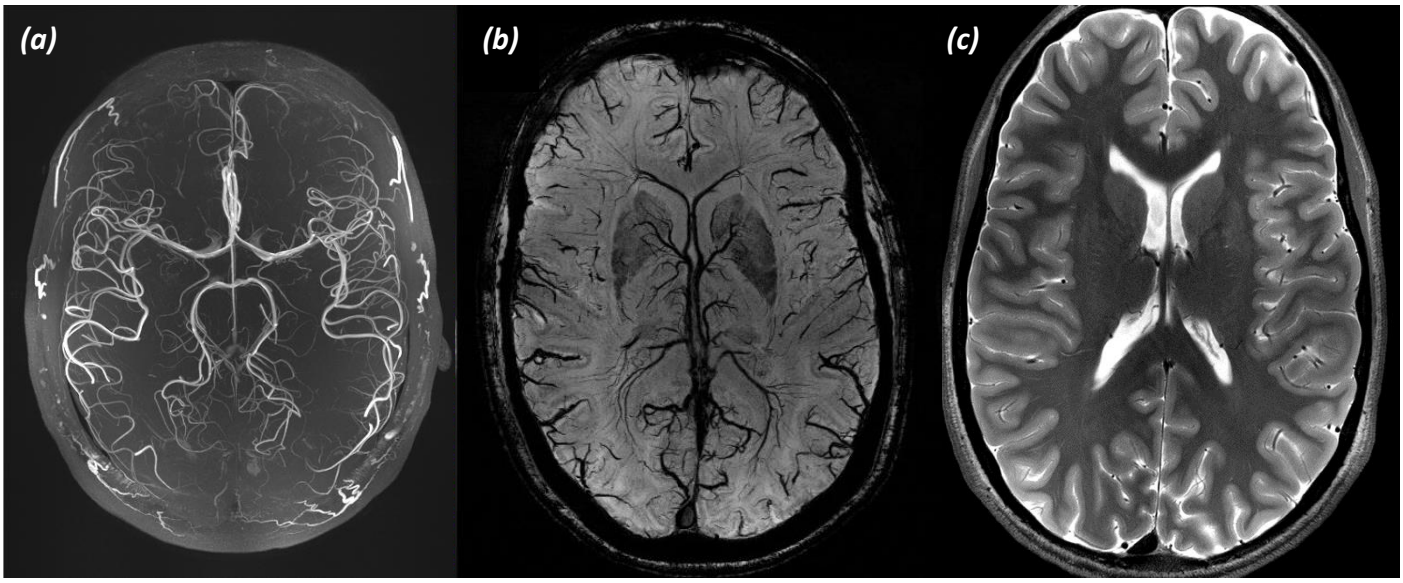

Figure 1: High resolution images used to look in detail as the blood vessels by (a) time-of-flight imaging, and (b) susceptibility weighted imaging, and (c) a T_2 weighted anatomical image.

Clinical Applications of Ultra-Low Field MR Imaging: Progress & Potential

Paul Cawley

Keywords: MRI, developing brain, perinatal, clinical application, research application, low field MRI

Background: Technological advances in permanent magnet design and post-acquisition imaging processing techniques have led to the advent of portable ultra-low field Magnetic Resonance imaging systems. These disruptive technologies have the potential to democratise access to imaging in global healthcare and transform availability of imaging options in high-resource intensive care and clinic settings. Low field imaging of the developing infant brain shows particular promise, but bespoke sequence optimisation and normative/pathological datasets are required before widespread dissemination beyond the research setting.

Methods: We have acquired a large paired dataset of high-field and ultra-low field magnetic brain acquisitions; across a range of infant gestations and ages in the presence and absence of developmental and acquired abnormalities. Using experimental and iterative sequence parameter optimisation we are able to describe a range of quantitative and qualitative imaging applications for ultra-low field scanning. UK Ethics approvals: 12/LO/1247 and 19/LO/1384.

Results: Ultralow field imaging can provide sufficient contrast, signal, and resolution for both structural imaging (figure 1) and quantitative MRI – longitudinal relaxation time changes as a function of gestational maturity (figure 2).

Conclusion: Low field MRI has promise to be a transformative clinical and healthcare research tool.

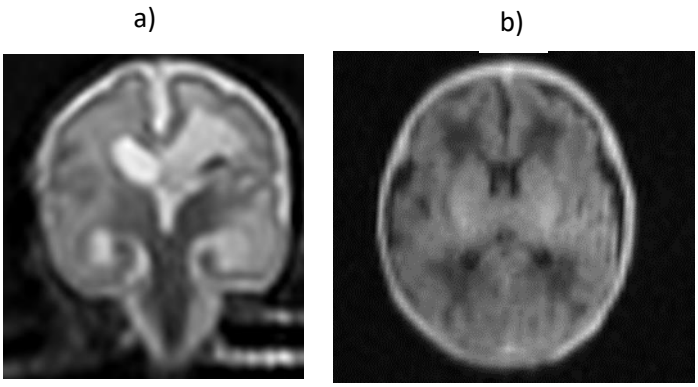

Figure 1: Example structural imaging in a) T2w Preterm infant with haemorrhagic parenchymal infarction and b) T1w term normally developing brain.

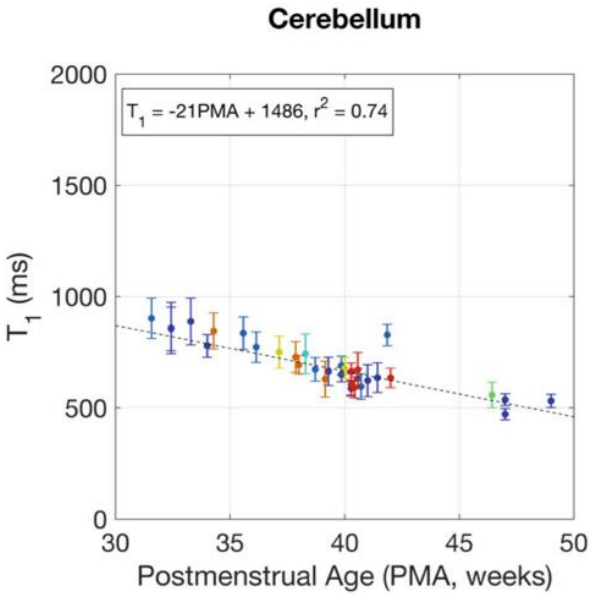

Figure 2: Longitudinal relaxation time with the cerebellum

The IPEM MRSE Certificate of Competence Scheme

John Foster[1]

Keywords: MR Safety Expert, competence certification

This presentation will give a short introduction to the scheme, practical steps to achieving a certificate of MR Safety Expert (MRSE) competence and then how to plan for renewal once achieved. This is from my own perspective of being one of the assessors, as well as directly involved with some of the team in Glasgow working towards it, with one success already, the first in Scotland.

First of all, the scheme is not just for NHS people but constructed to be suitable for university and industry applicants too, anywhere that the role of MRSE is needed.

It provides a degree of governance to the role of MRSE and should help strengthen the role alongside colleagues such as MPEs.

IPEM are not though setting up an MRSE register but this is rather a certificate of competence scheme.

The certification model that IPEM has adopted requires both knowledge and experience.

The knowledge is demonstrated by successfully completing the American Board of Magnetic Resonance Safety (ABMRS) MRSE exam adjusted for UK and Ireland.

The MR Safety experience of an applicant is assessed from a structured portfolio demonstrating a broad range of activities typical of an MRSE role.

The scheme is not mandatory but a good way of demonstrating ongoing competency and personal development in the role. There is no grand-parenting option. Some hospital sites may require it in the future. National guidelines are starting to highlight that certification is a good means of ensuring sufficient competency for someone to undertake the role of MRSE.

It will take time given the number of MRSEs in the UK and Ireland alone, as well as the logistics around the exam and portfolio building. Further details and tips for the application process and renewal will be provided in the presentation.

For further information:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/958486/MRI_guidance_2021-4-03c.pdf

https://www.ismrm.org/smrt/safety_page/Recommended_Responsibilities_for_Management_of_MR_Safety_JMRI2016.pdf

https://www.rcr.ac.uk/clinical-radiology/service-delivery/clinical-imaging-board/cib-statements/ipem-magnetic-resonance

https://www.ipem.ac.uk/learn/cpd-and-post-registration-learning/mrse-certificate-of-competence/

Application of Synthetic Data in the Training of Artificial Intelligence for Automated Quality Assurance in Magnetic Resonance Imaging

J.Tracey[1], L. Moss[2], J. Ashmore[1]

Keywords: MRI, quality control, convolutional neural networks, coil element failure

Background: Magnetic resonance imaging scanner faults can be missed during routine quality assurance (QA) if they are subtle, intermittent, or the test being performed is insensitive to the type of fault. Patient images offer a novel method for assessing scanner performance. Here we apply convolutional neural networks specifically to identify coil element failure in clinical MRI data, allowing for real time scanner monitoring of machine malfunction.

Method: A neural network was trained using artificially induced coil failure in 3958 abdominal or pelvic images from 497 patients. The accuracy of the trained network was then tested on an unseen dataset of 109 images, where real coil element failure was present in 47 patients. Five MRI radiographers were shown 249 images with and without real coil failure, assessing their accuracy in identifying the scanner malfunction. To ensure resilience against false detections, we developed a “momentum" style algorithm, where consecutive detections of coil element failure are required before an error is flagged. This bolsters against such false classifications and improves performance (Figure 1). Within the momentum algorithm, sets of 9 patients are considered per run. When coil element failure is detected within a patient, the “speed” increases. This yields a large response when several patients exhibit coil element failure in a row. If this speed breaches a threshold, that set is labelled as containing coil element failure. Finally, a graphical user interface has been developed for the proposed methodology, to allow the ease of deployment within a clinical environment.

Results: The neural network achieved an accuracy of 91.74% in identifying coil element failure in the unseen data. Radiographers tasked with identifying coil element failure had an average accuracy of 59.99%. In the same test case, the neural network outperformed all radiographers with an accuracy of 91.57%. With implementation of the momentum algorithm, the ability to detect coil element failure within samples increased to 100%.

Conclusions: This work demonstrates that neural networks trained with artificial data can successfully identify MRI scanner coil element failure in clinical images. The method provided better accuracy than MRI radiographers at identifying coil element failure and potentially provides an alternative method to traditional QA. Further, our methodology of training neural networks with simulated data has the potential to identify other faults, allowing centres to produce robust fault detection systems with minimal data.

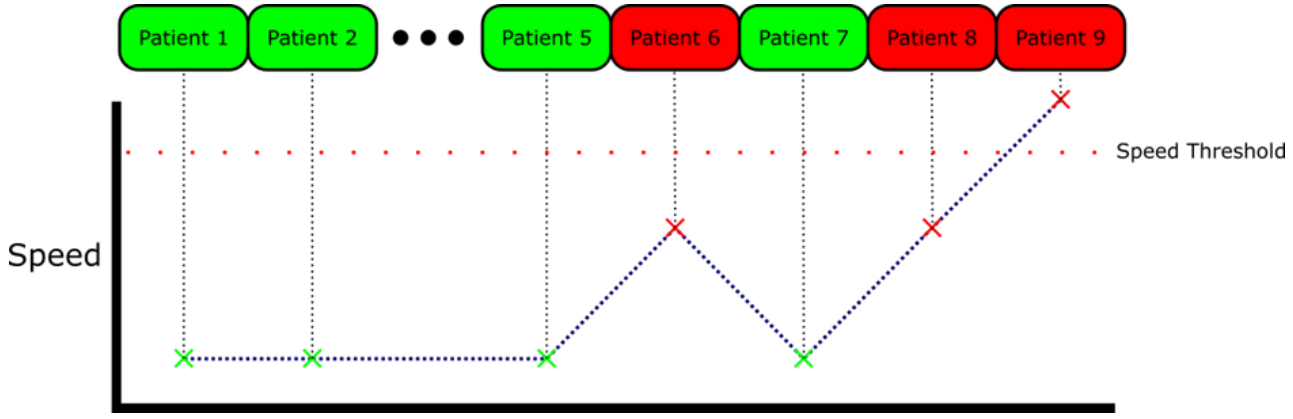

Figure 1: Momentum algorithm, where a higher speed suggests coil element failure is more likely. Note the false detection at patient 6 which doesn't breach the threshold.

Recent History of Development of MDR

Paul Campbell

Keywords: MDR, medical devices, regulations, software, SaMD

This presentation will provide an overview of the recent history and current state of medical device regulations for Software as a Medical Device (SaMD) in the UK. It will cover key developments in the regulatory landscape, including AIaMD, relevant to the health and care industry. The presentation is aimed at helping attendees stay informed on the latest regulatory developments for SaMD.

Practicalities of In-House Manufacture in Relation to Medical Devices Regulations

Justin McCarthy

Keywords: MDR, medical devices, regulations, in-house manufacture

The original time scale for the full application of the EU MD Regulation (26 May 2020) would have seen it fall within the Brexit transition period (31 January to 31 December 2020) and therefore the EU MDR would have become 'retained EU law' and implemented in the UK.

However, the EU postponed the full application of this Regulation by one year, outside of the transition period. Therefore the pre-existing UK Regulations based on the EU MD Directive (first published in 1993, though amended a number of times since) continue to apply in Wales, Scotland and England [1]. The Northern Ireland Protocol mandates that EU law applies in NI in respect of 'goods' so as to allow unrestricted flow across the Irish border, in line with the Belfast Agreement of 1998. Therefore the EU MDR is being applied in NI.

The original proposal was to have new UK/GB regulation come into force in July 2023, at which point CE marking alone would no longer meet GB regulations. They called this a 'standstill period'.

In September 2021, the MHRA conducted a significant consultation exercise on the future shape of GB regulations [2]. IPEM responded, as did a joint group of officials from Welsh Government plus clinical scientists and engineers from NHS Wales. There was no conflict between these two responses. In June 2022, MHRA published a formal Government response to this consultation exercise [2]. In October 2022, the Government extended the standstill period by one year to July 2024 by which time new regulations will have been developed and brought into force [3]. However, it seems that before then (in spring 2023) there will be some legislation to bring into force not only the transitional arrangements but also some post-market surveillance requirements ahead of the full new UK regulations. This "… reflects the high priority assigned to patient safety in the future framework."

The response to the consultation also points to the use of guidance over regulation, so that we may see regulations that are less detailed than the EU regulations, but which will be supplemented by detailed guidance. This allows the MHRA more flexibility because guidance can be adapted and updated without resorting to legislation.

The existing UK MD Regulations are silent about in-house manufactured and used devices and there are no regulatory requirements. However, in respect of a 'health institution exemption' (HEI) from full conformity assessment in the future, read section 8, particularly 8.2, of the consultation response [2].

If an in-house developed 'thing' (including software) is determined to be a medical device (as defined) key requirements and best-practice are to:

- develop and manufacture under a QMS
- follow the 'essential safety and performance requirements'; use the EU MDR ones for now
- establish and maintain detailed technical documentation
- use a formal risk assessment and risk management process
- undertake appropriate clinical, technical, performance and safety evaluations
- plan for ongoing support, post-deployment surveillance and clinical follow up of the device.

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Certainty in Protons in Uncertain Times

McKay, R

Keywords: proton beam therapy

In 2018 the first proton centre in the NHS commenced treatment at The Christie. This talk will examine the reality of running a proton, particularly concentrating on the physics service. Progress in our service will be outlined against progress in proton therapy worldwide. Contrasting reality with what is often a much-hyped headline therapy.

Cancer Research UK RadNet and Translation from Research to the Clinic

Anthony Chalmers[1]

Keywords: radiotherapy, research, RadNet, clinical translation

Historically, radiotherapy research in the UK has suffered from a chronic lack of funding. In 2019, following years of lobbying from the radiotherapy research community, Cancer Research UK launched a new funding scheme aimed at developing a network of centres of excellence in radiotherapy research. The RadNet network comprises seven centres and oversees five Working Groups which co-ordinate collaborative projects and initiatives and encourage engagement and participation of researchers from other UK centres.

In this talk I will give an overview of the RadNet network and describe some of the activities of the Working Groups, with an emphasis on the processes involved in translating research findings to the clinic. Examples of successful pipelines will be provided, and opportunities for collaboration highlighted.

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[1]Chair of Clinical Oncology, University of Glasgow, Director, CRUK RadNet Centre Glasgow

The PROSECCA Study: Improving radiotherapy in PROState cancer using EleCtronic population-based healthCAre data: The PROSECCA study, answering new questions in prostate cancer

Nailon, B[1]

Keywords: prostate cancer, radiotherapy, artificial intelligence, machine learning, deep learning, radiomics, image analysis

Background: Being able to accurately predict an individual patient's response to prostate cancer radiotherapy within the clinic would transform radiotherapy delivery. Personalisation of treatment technique, dose and fractionation based on such a predictive tool would maximise cure and minimise treatment related toxicity, well known to have a major impact on quality of life. A greater understanding of an individual patient's tumour biology holds great promise, however to date a full understanding is lacking and incorporating such data into everyday practice within the NHS is currently impractical and expensive. In this multi-centre, multi-disciplinary project called PROSECCA, "Improving radiotherapy in PROState cancer using EleCtronic population-based healthCAre data", an alternative approach is proposed to predict an individual's response to treatment, namely big data. By applying bespoke artificial intelligence and machine learning algorithms on very large population-level data sets, combined with radiotherapy data, this project will identify previously unrecognised patient or treatment factors that predict individual outcome [1-3].

Methods: Radiotherapy planning data from 15,000 prostate cancer patients previously treated at the 5 Cancer Centres in Scotland, Glasgow, Aberdeen, Dundee, Inverness and Edinburgh will be curated in this study. In addition, the vast quantity of clinical data held within each patient's healthcare record will be linked with the radiotherapy-specific information. On this longitudinal data set a combination of deep learning and more conventional radiomics analysis methods will be used to extract features, which will be used as input to a range of different classification schemes [4,5].

Anticipated results: There are a number of key results anticipated from this study, examples of which are: 1) A method for predicting the likelihood of radiation toxicity from artificial intelligence and machine learning of all images, and data, associated with a patient's healthcare record; 2) The generation of outcome-specific survival curves, stratified by factors of interest, from population-level healthcare data; 3) Data showing whether the interrogation of healthcare records, from birth to death, improve prediction of radiation response.

Discussion: The curation of such a large diverse collection of digital healthcare data to answer specific research questions requires expertise in several different areas. The PROSECCA research team has been assembled to specifically address all the key challenges with involvement of medical physicists, radiographers and uro-oncology clinicians from every Scottish Cancer Centre. Experience of delivering on large scale public health projects will be provided by the Usher Institute, and on machine learning and artificial intelligence algorithms, The Institute for Digital Communications (IDCOM), Edinburgh. To support the computational effort required, the Edinburgh Parallel Computing Centre (EPCC), one of the leading supercomputing centres in Europe, will be involved throughout.

Conclusions: The aim of this project is to combine big data from previously treated prostate cancer patients and use artificial intelligence and machine learning algorithms to interrogate for factors that predict clinical outcome. Early results are expected in late 2023.

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Body Temperature Measurement

Prof Mark Tooley FREng[1] and Dr Rob Simpson[2]

Keywords: temperature measurement, physiological measurement, accuracy, calibration

Temperature is one of the more frequently made physiological measurements, and can be made in the home, in primary or secondary care. Temperature is taken so often, that it is almost universally assumed by users and clinicians to be a completely reliable and robust measure, and that no more research or development is needed. However, when electronic based thermometers replaced traditional mercury-based thermometers for reasons of health, safety, environmental and data transference, a number of issues quickly became apparent. The 'new' generation of devices have often been viewed as less accurate, less reproducible, poorly or not calibrated, lower user confidence and other real challenges with being used correctly. The fundamental role temperature measurement plays in screening, diagnostic and monitoring means that any reduction in measurement performance and confidence undoubtably resulted in increased mortality and morbidity in a considerable number of patients.

In this session, the two speakers will give the background to the problem of body temperature measurement, and the formation of the national body temperature measurement group which is aiming to address this issue. The talk will present some initial findings of a recent study to examine variability in measurement between different devices commonly used in healthcare settings. It will give some findings of a recent patient and public investigation on temperature measurement and their perception of the temperature issues. There will be some discussion on the way forward, and possible solutions to the problems. Finally, there will be a session involving the audience, to find out people's personal experience with temperature measurement, both in their private and working lives, and to have a question and answer session with the speakers and audience.

We acknowledge the material provided by Prof Graham Machin FREng (National Physical Laboratory) and Dr Susannah Flemming (University of Oxford).

[1] University of Bath and Royal United Hospitals. [2] National Physical Laboratory

Initial Comparison of the Carbon Footprint of Radiotherapy Across Cancer Centres

R Chuter, C Stanford-Edwards, E Holden, R Razak, C Taylor, J Cummings, G Lowe

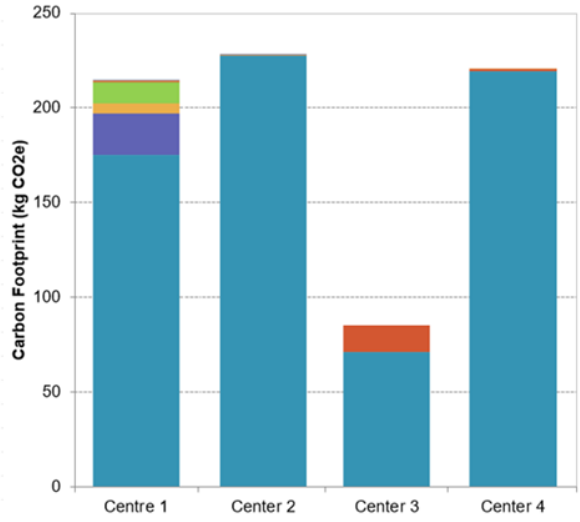
Keywords: climate change, carbon footprint, radiotherapy

Background: Climate change is a significant threat to our lives and wellbeing. The NHS has recognised this by pledging to become net carbon zero by 2040 [1]. Radiotherapy with its extensive use of energy intensive technology and large amount of associated patient travel could contribute significantly to the NHS's carbon footprint. We aim to find carbon footprint hotspots in the patient pathway to highlight where work is most needed. We build on a previous study by the authors estimating the carbon footprint of the radiotherapy pathway in a large centre (Centre 1) and assess the generalisability of the results in 3 other centres.

Method: Data for 10 prostate patients (60 Gy in 20 fractions) were collected in each of the four centres, along with information on technical equipment and patient transport, where available. Each centre collated the patient's post codes from their records and used an online mapping tool to calculate the distance travelled. The power used to deliver the treatments was measured in 3 centres, with Centre 3 and 4 using the same monitor and analysis to ensure a fair comparison. The number of CT scans was collated from patient records in 3 centres, and MR scans in 2 centres. The number of Personal protective equipment (PPE) items used and amount of SF_6 gas leaking from the linacs was also measured at Centre 1. A questionnaire and focus group were conducted at Centres 3 and 1 respectively to determine how patients travelled for treatment. This activity data was then converted into a carbon footprint using government databases for the travel and power consumption, and literature for the CT and MR conversion [2], and PPE [3] within a clinical environment.

Results: Figure 1 shows the carbon footprint of the parts of the radiotherapy pathway observed at each centre. Among the variables assessed, patient travel is the largest contributor making up 70-80% of the total radiotherapy carbon footprint. At Centre 3 60% of patients travelled via public transport for treatment whereas at Centre 1 this was only 27% which makes a large difference to the carbon footprint of travel. The Linac power used during treatment also varies between centres using two Elekta centres (Centres 1 and 4) using less than the Varian centre (Centre 3).

Conclusions: These initial results have shown the carbon footprint of radiotherapy is about 215 kg CO_2e and preliminary results of a comparison between four cancer centres shows large variation. Patient travel is the largest contributor to this but if public transport is used by a large fraction of patients this is significantly reduced. However the lack of standardisation between approaches, low



	Centre 1	Center 2	Center 3	Center 4
	kg CO_2e			
Travel	175.0	227.9	71.4	219.3
Linac (Idle) power	22.2			
SF6	5.2			
Treatment power	0.7		14.0	0.9
CT power	0.4	0.3		0.3
MR power	0.4	0.5		
PPE	11.0			

Figure 1. Carbon footprint in kg of carbon dioxide equivalent (CO_2e) per patient of the observed parts of the patient pathway across the four centres.

number of patients and incomplete datasets across centres illustrates the need for ongoing work in this area.

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Clinical Linear Accelerator Power Consumption: Can We Reduce Financial and Environmental Cost?

C Stanford-Edwards, S Herbert, R Lewis, R Chuter, M Edwards

Keywords: climate change, treatment costs, energy efficiency

Background: Previous studies have shown that climate change is leading to an increase in cancer incidence[1]. Healthcare itself has a large environmental impact and reductions in carbon footprint of treatments is required to reduce the risk of harm to current and future patients. Motivated by NHS Wales's targets for Net Zero carbon emissions by 2030[2], recent energy price increases, and an assessment of SABR and surgery identifying a need for deeper understanding of linac energy use[3], the power consumption of a linac is being investigated to determine the cost of treatment, financial and environmental. This initial investigation aims to compare power measurements against manufacturer values[4]. Through understanding current power consumption under different conditions, efficient workflows could be developed to reduce power.

Method: A Fluke 1738 power monitor has been attached to the three-phase power supply of an Elekta Versa HD linac. The monitor samples at ~10kHz and collected data over 1 week of clinical use logging the average power consumed every 1s. The typical running power under conditions of 'Standby', 'Preparatory' and 'Irradiating' were assessed throughout the week of monitoring. The Mosaiq record and verify system was used to identify 10 prostate patients treated on the machine during this period and the energy consumption estimated for the full course of treatment (60Gy in 20#). Published values were used to convert this into financial cost and carbon footprint.

Results: Variation in power was seen during the day, with clear peaks during irradiation, however there are additional peaks between treatments requiring further investigation (*Figure 1*).

The average apparent power over 1s is comparable with the manufacturer quoted values of maximum use (Figure 2)

The typical linac energy consumed for delivering a prostate course of treatment averaged over 10 patients was 19.7kWh (s.d. 2.3). Based on costs of £0.34/kWh[5] and 0.19338kgCO2e/kWh[6], the estimated energy cost of a treatment is ~£6.70 with ~3.81kgCO2e.

Conclusions: The apparent power measured in a clinical setting is comparable to the specifications

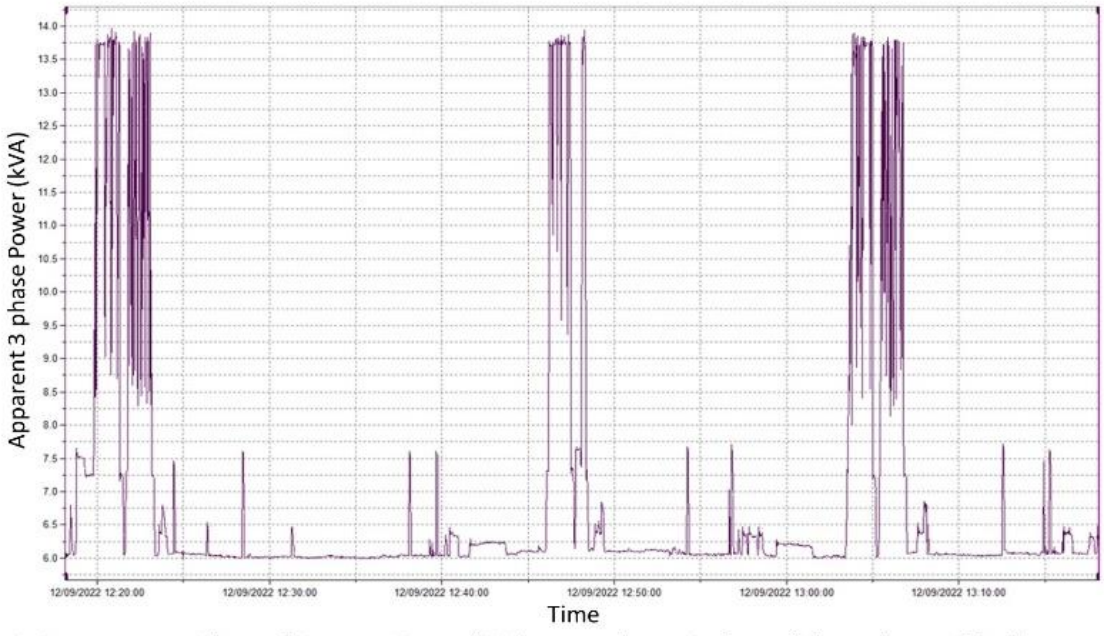

Figure 1: Summary over 1 hour of Apparent Power (kVA) averaged over 1s, from all three phases of the linac power supply.

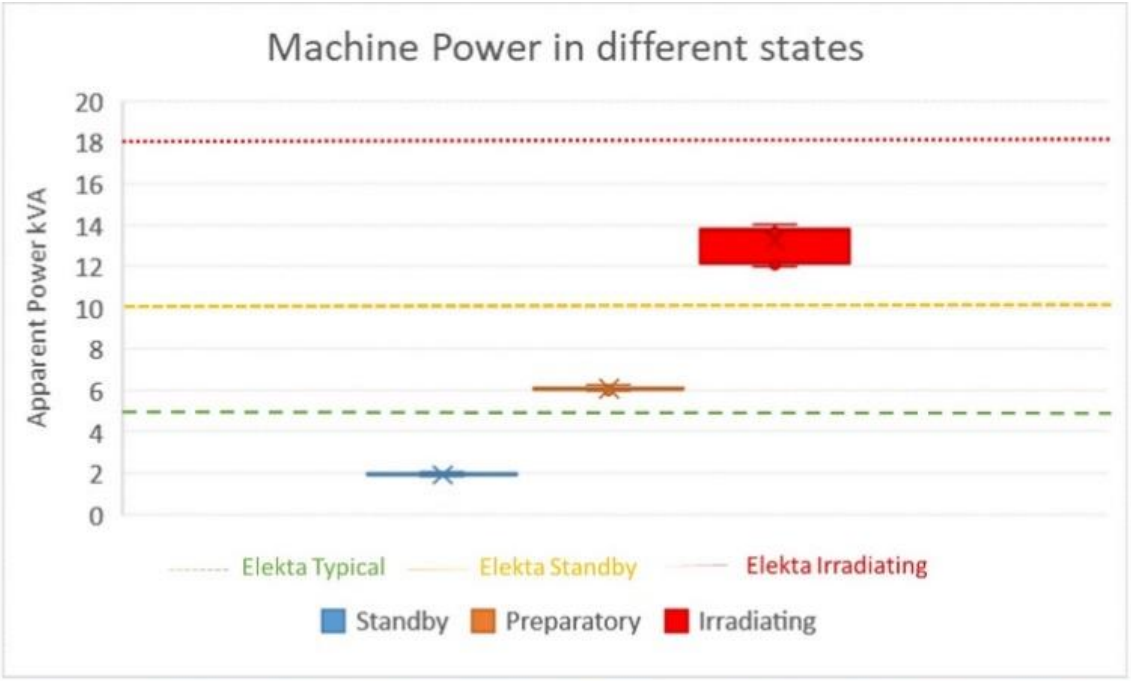

Figure 2: Box plots of measured power in different situations, compared to Elekta quoted values in site planning documentation.

for installation, with 'Irradiation' measurements reduced by ~4kVA. Lower values than published are expected, as the site 'Setting to Work' documents provides maximum power requirements. The energy consumption used by the linac for delivering a 20# prostate treatment costs ~£6.70 and ~3.81kgCO2e. Further work is currently ongoing to improve reliability of results, collecting more samples over a range of machines and including additional treatment sites. The long-term objective is to optimise power consumption in radiotherapy to reduce costs.

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Sustainable Healthcare: Accurately Reporting Waste Volatile Anaesthetic Gas Capture

Mr Liam Jones[1,3,4], Dr Madhvi Vaghela[2], Dr Craig Johnstone[2], Mr Thomas Wright[2], Dr Rebecca H Kay[1]

Keywords: biomedical engineering, anaesthetic gases, sustainability, emerging technology

Background: Volatile anaesthetic gases (VAGs), such as Sevoflurane, account for 5% of the carbon footprint for the acute hospital sector [1] and 42% of carbon emissions generated during surgical procedures [2]. VAG waste capture technology has presented itself as a potential solution to reducing VAGs carbon footprint [3], [4]. However, in order to quantify potential impact, the technologies performance requires assessment. Accuracy concerns regarding VAG delivery volumes reported in anaesthetic machines logbooks potentially makes this challenging [5], [6]. The aim of this study was firstly to assess the capture efficiency of a VAG capture system *in vitro*, and secondly to understand the accuracy of delivered VAG volume reported by the anaesthetic machine.

Methods: The VAG capture technology was connected to an anaesthetic machine. The flow rate and concentration of Sevoflurane was systematically varied and delivered in a laboratory set-up. A total of 23 tests were run with concentrations varying from 2 to 8 vol. % and flow rates 0.5 to 15 L/min. The system was flushed to remove any residual after each test. The capture systems 4 canisters and the vaporiser were weighed at the start and end of each test. These values were recorded alongside the recorded volumes from the logbook. After completing testing, the canisters with waste VAG were sent to the manufacturer for extraction.

Results: Overall, VAG capture efficiency was 94.9%. At high flowrates the mass of Sevoflurane delivered was consistently higher than that captured. However, at low flow rates, the mass change of the capture canisters was consistently greater. The delivered volume of Sevoflurane was consistently overestimated by the anaesthetic machine (range: 5% to 75%).

Discussion: Our study showed that the capture efficiency of this technology to be high (94.9% across a range of delivered concentrations and flow rates). However it was impossible to calculate the efficiency for each test as we do not have the separated extracted data for each. The measured delivered VAG volumes from the anaesthetic machine were shown to be inaccurate. This needs to be improved or accounted for if accurate data regarding delivered dose or VAG usage is to be sought. This variation will also contribute to challenges around interpretation of the performance and value of VAG capture technologies.

Conclusions: The capture technology performed very well in an *in vitro* environment. Delivered VAG values reported in the anaesthetic machine logbook were consistently inaccurate and this error would need to be accounted for in future studies. This study uniquely facilitates a better understanding of the potential of VAG capture. In a clinical study lower capture rates may be recorded.

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[1]Clinical Engineering, Guy’s and St Thomas’ NHS Foundation Trust, [2]Theatres, Anaesthesia and Peri-operative Medicine, Guy’s and St Thomas’ NHS Foundation Trust, [3] Department of Medical Physics, King’s College Hospital NHS Foundation Trust, [4] School of Biomedical Engineering and Imaging Sciences, King’s College London

Multimodal AI Analysis of Prostate Cancer Indicators to Reduce Patient Backlogs and Improve Patient Care

Professor Chris Hopkins[1]

Keywords: imaging, MRI safety, AI, machine learning.

Background: Prostate cancer affects 1 in 8 men throughout their lifetime. Due to increasing longevity and increased awareness the incidence and prevalence of prostate cancer is increasing. Prostate cancer is predominantly diagnosed using Magnetic Resonance Imaging (MRI) scans; however, these scans require specialist interpretation and timely reporting. A lack of radiologists and particularly urology specialist radiologists can be a limiting factor, especially as demand grows lead to delays in the diagnostic pathway.

An artificial intelligence (AI)/machine learning (ML) based MRI diagnostic aid for prostate cancer may support clinical decision making and reduce time to interpret MRI. JivaRDX (a class IIa medical device, pending MHRA approval) is a radiology facing application that predicts the presence of cancerous tissue from prostate MRI scans, and is intended for use as a diagnostic aid. Operationally, JivaRDX can integrate into the radiology workflow non-disruptively by automatically annotating imaging files and therefore requires minimal intervention and training. Jiva have previously demonstrated a proof-of-concept achieving detection and localisation of prostate cancer from MRI scans (87% sensitivity, 67% specificity); bone, tissue and organs differentiated with 96.8% specificity. It has been found to perform within reported MRI diagnostic accuracy in the clinic (58-96% sensitivity, 23-87% specificity).

Methods: We built a data pipeline and acquired end-to-end data transmission in order to validate the machine learning model. The data collection and systems pathway is outlined below:

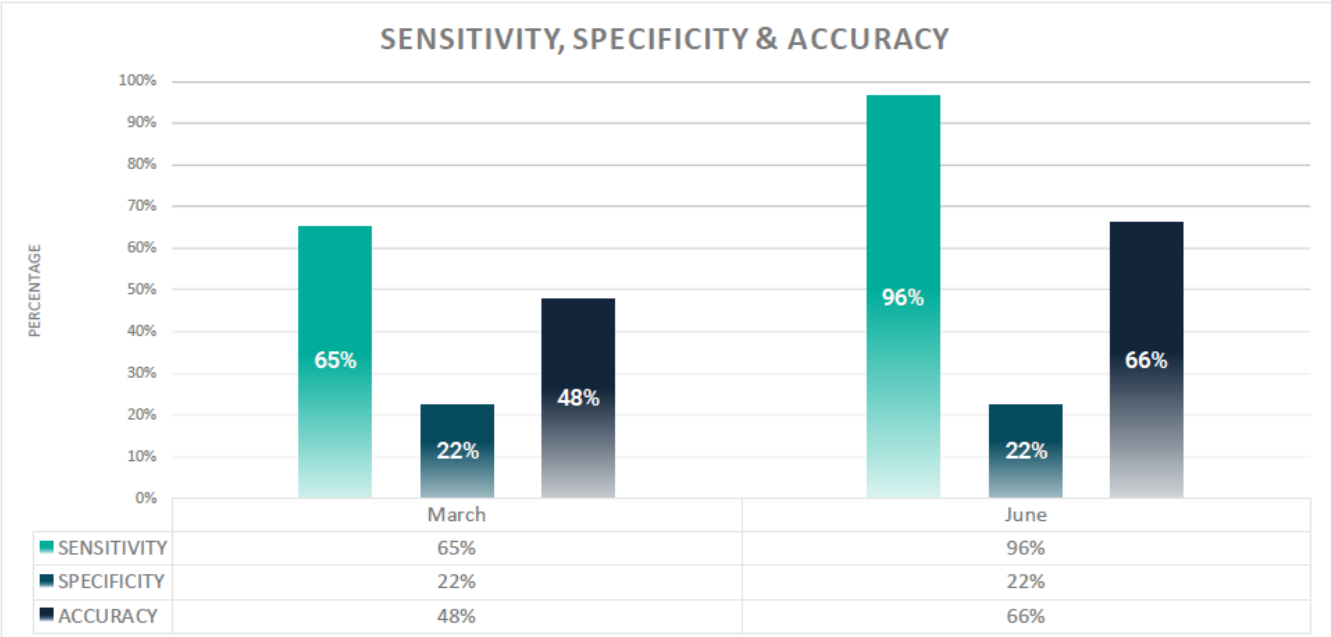
1. Patient data was anonymised at source from the Radiology system to provide anonymised patient studies (an example of the anonymisation can be seen in figure 1).

2. A local record was kept of each patient study to allow analysis of the images at the end of the project (see point 8 below).

3. Inclusion and exclusion criteria were applied in order to determine study participants.

4. Anonymised patient studies were shared with a Consultant Urologist in order to validate Likert scoring data (Table 1) and biopsy results (where available).

5. Anonymised patient studies were transferred by our cyber team to Jiva. ai via an encrypted file sharing platform.



[1]Head of Innovation & the Tritech Institute, Hywel Dda University Health Board, Clinical Director of the Assistive Technologies Innovation Centre, University of Wales Trinity Saint David.

6. Anonymised patient studies were passed through the JivaRDX ML platform.

7. The outcomes of the anonymized patients' studies was passed back to the Health Board via the cyber team and encrypted file sharing platform.

8. Anonymised patient studies were de-anonymised.

9. Patient studies were shared with Mr Moosa, Consultant Urologist in order to clinically validate the outcomes of each patient study.

10. Sensitivity, Specificity and Accuracy results were shared with Jiva.ai after iteration 2.

Results: ResNet models generally outperformed the CBRT in terms of accuracy: ResNet variant A (the base model) was selected as the candidate model to take forward based on highest performance characteristics of 97.4% sensitivity, 90.8% specificity and 92.7% accuracy.

The JivaRDX ResNet A model was applied to the HDUHB patient cohort data to predict the presence of clinically significant prostate cancer. The individual results on a patient-by-patient basis and the overall sensitivity, specificity and accuracy of the predictions are shown in the graph below. Compared to the prior ProstateX JivaRDX assessment, the results indicated an improved sensitivity (96%) and accuracy (66%) in detecting prostate cancer. However, specificity remained low at 22% suggesting many people would need further testing including many unnecessary biopsies.

Discussion: The findings from this work indicate that there is a clinical need for new diagnostic processes in prostate cancer. JivaRDX looks feasible in the real world and is popular at least with clinical staff. However, more work needs to be undertaken to improve JivaRDX accuracy with more training. More work also needs to be undertaken looking at clinical outcomes including the impact on diagnosis times, biopsy rates and survival, to assess its true value.

Conclusions: The JivaRDX system has proven to be sensitive but not specific in terms of its diagnosis potential and further studies are required to refine the model. We found that the system has the capability to integrate into our current clinical systems and pathways. Furthermore, our engagements with clinical teams and patients identifies a general positive reaction to the use of AI as long as there are safeguards in place. Further work is now being undertaken to improve the specificity of our results.

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Eye Can See Clearly Now – How NLP Can Be Used to Extract Greater Value from Existing Clinical Data in Ophthalmology

[1]Catherine Macleod, [1]Ross Crawford, [1]Sarah Francis, [2]Jacquie Dougall, [2]Janet Pooley, [1]Lorna Harper

Keywords: natural language processing, clinical risk management, healthcare data, informatics, medical device software

Background: Access to clinical data is vital for effective management of patient pathways, clinical audit, and quality improvement within clinical services [1,2]. However, clinical data can often be buried within paper-based or electronic documents such as GP referrals, clinic letters etc. Nationally, NHS Scotland Ophthalmology services are addressing this issue by introducing a new electronic patient record (EPR), OpenEyes™ [3,4]. However, the benefits of the new EPR will only be fully realised if ophthalmic clinical histories are transferred with the patient to the new system. In this pilot study, we investigate the feasibility of using Natural Language Processing to extract relevant clinical information from electronic patient documents for transfer to the new EPR. This initial work focuses on glaucoma patients within NHS Greater Glasgow and Clyde.

Methods: The number of glaucoma patients using NHS services across Scotland is currently unknown. In this study, the patient cohort was identified using glaucoma-specific prescription and surgical lists as a proxy for diagnosis. Patient demographics and historical electronic patient notes were then extracted from an existing EPR. A data analysis pipeline was developed to convert the documents into structured data items useful for tracking the progression of glaucoma. The pipeline starts by extracting text from electronic documents. Clinical data is then extracted from this text using Regular Expressions and the Medical Concept Annotation Tool (MedCAT) [5]. MedCAT extracts concepts from unstructured text using a data model fine-tuned via unsupervised and supervised machine learning approaches [5]. Finally, manual verification of a subset of the extracted data is carried out based on a risk-based approach to data validation.

Results: 14,356 glaucoma patients were identified, and 261,657 documents were extracted, dating back to 2006. Ophthalmic clinical data was extracted for 13,634 patients, visual acuities (VAs) were identified for 12.912 patients (94.7%), intra-ocular pressures (IOPs) for 12,498 (91.7%) and cup-to-disc (CtD) ratios for 6,730 patients (49.4%). A confidence score was automatically applied to extracted measurements. 76% of IOPs and 66% of VAs and CtD ratios were scored with maximum confidence.

Discussion: The developed data extraction pipeline demonstrates a valuable new mechanism for extracting useful information from existing healthcare documents. By connecting the pipeline to a cornerstone application used in all clinical health boards in Scotland, this work can be rolled out nationally to support the EPR implementation and other local initiatives.

Conclusions: This work can be extended to other healthcare specialties to support better data management, and drive service improvement and research.

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QNI-CE - Clinical Deployment of Novel Quantitative Neuro-Image Analysis Techniques Using Containerisation Technology

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Keywords: medical device, software, SaMD, AI/ML, image analysis, neuroradiology, DICOM

Background: Translation of any technology from the research to the clinical domain is notoriously challenging and medical device software is no exception. The [1]Quantitative Neuroradiology Initiative (QNI) was established as a model framework to facilitate the transition of AI/machine learning image quantification software from the research domain into hospital neuroradiology workflows. Tools to support neuroradiology reporting are developed under this framework and delivered as containerised packages using [2]Docker. These containerised applications are then deployed and run using an in-house software, QNI-CE, that integrates the analysis into a conventional, DICOM based radiological workflow.

Methods: The QNI is supported by a multi-discipline team of NHS neuroradiologists and clinical scientists from UCLH and university medical imaging computing scientists and software developers based at UCL. MRI biomarkers addressing radiological needs are identified in the clinical domain, and techniques for their quantification and validation pursued in the research domain before a tool is implemented for evaluation and deployment in clinical practice.

From a regulatory perspective, deploying medical device software (whether developed externally or in-house), needs a careful multi-disciplinary approach, with robust risk assessment undertaken under a quality management system (QMS). There are long-term support issues to be considered: research activity developing software rarely factors in life-cycle management responsibilities and best-practice in academia does not commonly equate to development under a QMS.

There are also challenges in the choice of software platform and data formats between the two domains: MRI research data is normally processed in nifti format using Linux based tools whereas in the clinical domain DICOM data is stored and accessed from Windows servers or PCs.

We address these challenges by using containerisation technology, specifically Docker[2]. This allows our analysis tools to be built for a Linux environment and then deployed via a Docker engine with minimal external dependencies rather than being reliant on a specific operating system that might not be available within a hospital's IT infrastructure. Analysis modules are configured and run using our QNI Central Engine (QNI-CE), a Python application integrating the analysis modules with a DICOM workflow, brokering data exchange and analysis execution. Image series are pulled or pushed from PACS to QNI-CE and results are returned as DICOM series associated with the original MR study. The QNI-CE was developed in-house under a QMS, with the technical file (including risk management documentation) written alongside the software development and testing processes. In-line image quality control is currently supported as a manual process: fully automated QC is a work in progress.

Results: Our first use-case is a tool providing neuroradiologists with a quantitative visual report of hippocampal volume and T2 relaxation time in epilepsy patients, available at their PACS reporting workstations. This has supported radiology reports for 142 patients over 16 months. Further applications are under development to support reporting across other neurological indications: the QNI-CE has been developed to support single- and multi-modal MRI data for both cross-sectional and longitudinal analyses.

Conclusions: A multi-disciplinary approach to the development and life-cycle management of novel software, combined with the use of technology such as Docker, offers a way to move prototype analysis pipelines into clinical practice. Regulatory concerns can be partially addressed by developing software under an appropriate QMS. However, long term support can still present a challenge, as

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does conformance to clinical IT system legislation and medical device regulations.

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ProCEED with Caution: The Challenges of Developing a Real-Time Clinical Dashboard for the Prostate Cancer Service

Olivia Lala[1], Sarah Francis[1], Martin Shaw[2], Hing Leung[3], Lorna Harper[1]

Keywords: **n**atural language processing, clinical risk management, healthcare data, medical device software, clinical engineering workforce planning

Background: Sprawling electronic patient record systems and inconsistent data management practices can make it difficult to manage the flow of information through complex clinical pathways and add a substantial administrative burden to clinicians. The ProCEEDS (**Pro**state **C**ancer – **E**nhancing **E**xisting **D**ata **S**ystems) aims to reduce this burden by presenting a concise view of the clinical data required to efficiently guide patients through the prostate cancer diagnostic pathway. By using existing data and integrating a bespoke dashboard with a cornerstone clinical application, we hope to demonstrate an efficient and effective means of improving clinical data management within existing IT infrastructure. Here we present the unique challenges encountered during the design and development of this medical device software, and discuss the resources needed to sustain this clinical engineering led approach.

Methods: The ProCEEDS pipeline is fed from data originating in primary clinical applications via SQL Server. The analysis pipeline is built in Python, using natural language processing techniques to extract key data items from unstructured clinical notes. Analysed and transformed data is written back to SQL Server and this data is used to feed a web based MicroStrategy dashboard. The dashboard is integrated back into a primary clinical application via the Turas platform[1]. Design and development are managed under an ISO13485 Quality Management System[2], in accordance with standards such as BS EN 62304[3], BS EN 62366[4], and ISO14971[5].

Results: ProCEEDS is a data analysis pipeline and clinical dashboard that can be used to guide individuals referred into the Urology Service as having an urgent suspicion of (prostate) cancer. It presents a concise view of relevant clinical history, radiology, and pathology information required to make an informed diagnosis. It also allows clinicians to view an individual patient's pathway overlaid on a timeline, to make it easier to track patient progress. Key challenges faced during this project have included: identifying data sources within cornerstone clinical applications; securing access to these data sources in real-time; developing a robust pipeline suitable to the dynamic data environment; developing a risk-based approach to the application of natural language processing; and integration with existing IT infrastructure in NHSGGC.

Discussion: Easy and efficient access to clinical data is essential to safely guide patients through complex clinical pathways. Current approaches are little better than offering clinicians a digital view of hardcopy notes and do little to ease the administrative burden. The ProCEEDS approach improves on this using existing resources and feeding back into existing clinical workflows. To scale this to other services, clinical data access should be reconsidered to support this use case.

Conclusions: With a deepening funding crisis within the NHS, clinical engineering teams with software development expertise are an increasingly valuable resource to help achieve the digital maturity needed to support modern healthcare. Greater awareness of this contribution is needed within healthcare science to secure investment in workforce planning.

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Physics of Life: Future Drivers of Physics and Engineering in the Clinic

Professor Stephen Smye[1]

Keywords: physics research, clinical practice, future drivers

The Physics of Life network aims to bring researchers from the biological, mathematical and physical sciences together to tackle the challenge of integrating understanding from single molecule to systems biology.
https://www.physicsoflife.org.uk/.

Nested within the Physics of Life network, and with a similar interdisciplinary ethos to the Physics of Life, is a programme of workshops funded by the Rosetrees Trust – the Physics of Medicine network - which is intended to consider some of the major research questions in medicine by promoting collaborations between clinicians, and physical and biological scientists. Recent examples of Physics of Medicine events include workshops on Metastasis [1] and Neurodegenerative disease of the brain [2]. This session will present examples of the Physics of Life and very briefly consider a further example of research discussed in the Physics of Medicine programme which might drive clinical practice in 2050.

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Self-Generated Gradients: Cells Generating Their Own Information

Robert Insall[2]

Keywords: information, positive feedback, self-generated gradients, cell migration

The way cells respond to gradients of attractive chemicals by migrating towards them - a process termed chemotaxis - has been intensely studied over several years. A related question - where do the gradients come from? - has been relatively neglected. This is obviously important in situations where the amount of complexity and information increases, for example embryonic development, and as such is of particular interest to mathematicians and physicists.

We find that cells frequently create their own gradients of attractive chemicals, most often by breaking down local deposits and allowing new attractants to diffuse in from nearby (1). The cells thus gain information about distant parts of their environment, and adjust the signals they receive to allow the most informative readings.

We will show examples of cells reading complex mazes using self-generated gradients (4), cancer cells spreading from tumours (2), and the establishment of complex patterns from simple starting points (3).

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New Antimicrobials and Anti-Virulence Drugs Facilitated by Progress in Physics

Olwyn Byron[1], Ester Serrano, Andrew Roe

Keywords: biosynthesis, bioengineering, antimicrobial, molecular biology, antivirulence

Since the realisation around a century ago that penicillin is an effective antibiotic, the search for additional effective antimicrobials has not ceased. There are now at least a hundred anti-bacterials in routine clinical use, however, the rate at which antimicrobials are being discovered and developed is in stark contrast with the threat to plant and animal health posed by anti-microbial resistance (AMR), which is expected to impose a global economic burden of $1tn by 2050 and result in 10 million deaths annually if unaddressed.

In this talk I will describe work ongoing at the University of Glasgow to (i) engineer the more efficient biosynthetic production of novel antimicrobials and (ii) develop attractive alternatives to anti-bacterials. Common to both projects is the impact made by progress in physics-based approaches to dissect and understand complex biological systems at the molecular level. I will illustrate this by discussing our physical exploration of the bifunctional bacterial enzyme aldehyde-alcohol dehydrogenase (AdhE) which is the target of a promising new class of bacterial anti-virulence compounds, the salicylidene acylhydrazides (SAs).

AdhE is involved in the central metabolism of many bacteria and self-associates *in vivo* and *in vitro* to form long spiral complexes (spirosomes, Figure 1(a)). We chromatographically fractionated AdhE into samples dominated by spirosomes of decreasing size (Figure 1(b)) which were then analysed in a quasi-biological solvent environment using biophysical approaches such as analytical ultracentrifugation (AUC, Figure 1(c)), static small-angle X-ray scattering (SAXS, Figure 1(d)), time-resolved (TR) SAXS, cryo-electron microscopy (cryo-EM) and mass photometry. These analyses have been complemented by modelling strategies including hydrodynamic bead modelling and dummy atom modelling.

Without this biophysical investigation, we would have failed to understand the molecular basis for the function of AdhE and its response to changes in its environment, including the action of the SA compounds. This understanding is critical to elucidating the all-important mechanism of action (MOA) that will permit the future development of the SA compounds into true anti-virulence drugs.

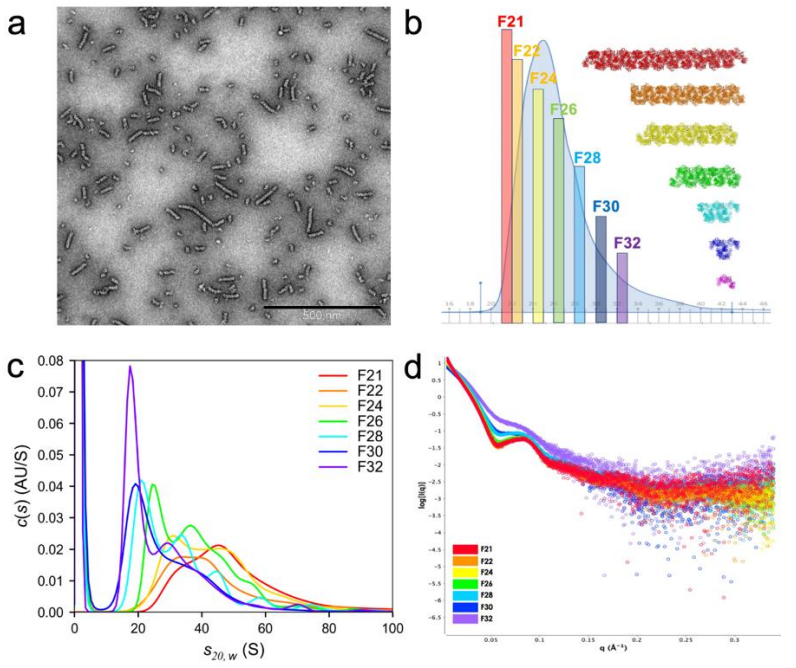

Figure 1: AdhE (a) spirosomes visualised by negative stained electron microscopy, (b) fractionated chromatographically and biophysically studied by (c) AUC and (d) SAXS.

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Current Developments in Molecular Radiotherapy

Fergus McKiddie[1]

Keywords: molecular radiotherapy, prostate-specific membrane antigen therapy, Lu-177 PSMA

The field of molecular radiotherapy is a rapidly developing one with many new therapies coming on-line and considerable investment from industry to develop and trial new treatments.

This presentation will provide a brief overview of what molecular radiotherapy is and what therapies are currently being delivered in Scotland. It will then describe new therapies coming to market imminently and will then focus on Lu-177 PSMA therapy as this is the closest to being available for eligible patients.

The background and uses of PSMA therapy will be described and then an in-depth look at the challenges of delivering this in routine clinical service will be covered. This will include an overview of projections for future workload and the implications of this for the NHS.

Finally, the presentation will look ahead to likely future developments over the rest of the decade and the potential benefit to patients that these will bring.

[1]Consultant Clinical Scientist, NHS Grampian

The Practicalities of Administering Molecular Radiotherapy (MRT)

Colin Brown[1]

Keywords: molecular radiotherapy, unsealed source, radiotherapy, radiation protection

Molecular Radiotherapy (MRT) is a rapidly evolving and expanding tool in the treatment of a range of cancer types. The administration of high-activity unsealed sources poses a number of radiation protection challenges including the delivery of the treatment and the integration of radioactive patients with the public. This presentation will describe some of the methods of MRT administration, from simple to complex, utilised in the Beatson West of Scotland Cancer Centre and will outline some of the challenges for the sector in the future.

[1] NHS Greater Glasgow & Clyde

Delivering a Ra-223 Dichloride Therapeutic Service – Pitfalls of Experience!

Matthew Talboys

Keywords: radium-233 dichloride, prostate cancer, radiation protection, radionuclide assay, case study

Introduction: Radium-223 (Ra-223) dichloride is used for the treatment of bone metastases in patients with hormone resistant prostate cancer. As an alpha emitter, Ra-223 can pose particular challenges in terms of radionuclide assay and radiation protection when compared to more conventionally utilised beta therapeutic radionuclides. Since 2019, Velindre University NHS Trust has been delivering Ra-223 therapies routinely in an outpatient setting to provide a therapy service to patients in South East Wales. During this period, various scenarios have presented requiring bespoke responses and are discussed to inform the lessons learnt from those incidents at our centre and to aide other organisations in contingency planning for Ra-223 services.

Methods: A retrospective analysis of patient and staff incidents was completed for all patients since inception of the service in 2019. All incidents were categorised as occurring if bespoke safety advice was required to be proffered to the patient or staff during or following routine service provision.

Results: Since 2019, a number of scenarios have presented that required additional bespoke radiation protection advice. These included a patient having a septic tank at home, a patient with a colostomy bag, a patient who had to undergo replacement hip surgery shortly administration, a staff skin contamination incident resulting in an equivalent dose to the skin of 10mSv and a patient extravasation incident that was reportable to the regulator. Each incident required detailed risk assessment and response to ensure regulatory compliance and staff and patient safety.

Discussion: The incident analyses that are presented highlight the particular challenges in using alpha emitting radionuclides. While adverse incidents are rare, risk assessments need to encompass a full range of potential incident scenarios including the patient's home circumstances, potential for surgical intervention, staff contamination and risks around administration, especially when using alternatives to cannulation.

Improvements in Cervix Brachytherapy Planning and Outcomes Between 2013 and 2022 at Coventry

Claire Fletcher[1], Dr Mark Hocking[2]

Keywords: cervix brachytherapy, dose statistics, interstitial brachytherapy, conformal brachytherapy planning

Background: The aim of this study was to review cervix brachytherapy planning statistics from a single centre over the last nine years. Over this time the planning technique has evolved from simple library planning using CT to outline Organs at Risk (OARs) to conformal MR-guided brachytherapy with interstitial needles.

Methods: Brachytherapy dose statistics from 191 Cervical Cancer patients treated between 2013 and 2022 were compared to the dose aims and limits from the EmbraceII trial. The only patients excluded from the study were those who could not complete the treatment course. All patients included had OARs outlined on CT or MRI and were planned using Oncentra Masterplan. Patients from 2015 onwards had a High Risk Clinical Target Volume (HRCTV) defined using MRI and patients from 2016 onwards were planned conformally using interstitial needles where appropriate.

Annual reviews were used to improve planning techniques. The impact of treatment technique, interstitial needle use and HRCTV volume on the dose statistics achieved was considered.

Results: The hard limits for HRCTV dose have been consistently met in approximately 70% of cases since 2017, when the planning method at Coventry was reviewed and changed to prioritise HRCTV coverage over achieving optimal dose aims for OARs. Optimal HRCTV dose constraints have been consistently met in 50%-60% of cases from 2018 onwards.

Since 2016 the hard limits have been met for all OARs in more than 90% of cases, whereas with standard plans before 2016 OAR doses only met the limits in 40%-60% of cases for the sigmoid and 78%-95% of cases for the bladder. Optimal OAR constraints have been met in around 40% of cases each year since 2017.

Needle usage has increased since introduction and 45% of all eligible patients in this time have been treated with interstitial needles.

Discussion. Some limited follow up data was available from patients treated between 2015 - 2019, this was analysed and compared to the dose statistics achieved. There was a marginal increase in three-year survival rates for conformal planned patients compared to standard planning. The incidence of toxicity was comparable, with a slight reduction in complications to the bladder, bowel and rectum from conformal planning but a small increase in vaginal toxicity.

Conclusion: Annual reviews of dose statistics have facilitated audit of patient treatment, to discuss outlying cases and to improve patient treatments by allowing strategies for improvement. The impact of these improvements on local control and toxicity has been seen in the move from standard to conformal planning. Techniques have continued to improve since 2019 and the OAR doses have been further reduced; follow up data from this period will be reviewed in future to see if complication rates have also reduced.

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Commissioning of MOSFET for Clinical Use: Feasibility of Real-Time in Vivo Dosimetry for High Dose Rate Gynaecological Brachytherapy

Fatima Mahmood[1], Josh Mason[1], Ruth Mclauchlan[1]

Keywords: gynaecology, brachytherapy, in vivo dosimetry, MOSFET, HDR, dosimetry.

Background: High dose rate (HDR) multi fraction treatments are used in gynaecological brachytherapy (BT) treatments. Real time in vivo dosimetry (IVD) measurements allow treatment interruption if an issue arises however, IVD in BT involves complexities so it is not routinely performed. Currently there are limited methods of measuring dose rate to target during brachytherapy (BT). Clinical in vivo dosimetry in prostate BT has been assessed using MOSFET devices which showed good agreement with predicted dose. This research focuses on the feasibility of real time IVD for HDR gynaecological BT using the MOSFET device.

Methods: Stage one of this research followed the commissioning and calibration of the MOSFET device. Stage two consisted of measuring dose in the Venezia applicator for ovoid weighted and needle based plans. The feasible options for possible treatment errors were also simulated to investigate if/how the MOSFET readings reflect errors. Stage three consisted of in vivo measurements in five fractions over two patients to analyse how the MOSFET measured dose in real-time patient treatments.

Results: The applicator results for ovoid weighted plans averaged at -11.3% (range -14.7 7 to - 8.2%) and 9.7% for needle plans (range -5.9 to -27.0%) with an overall average of -0.8% compared to predicted dose. Error simulations detected five out of six errors successfully where the errors were greater than the uncertainty calculated in this project. For the two patient measurements (over five fractions), the measured dose ranged from 2.53% to 15.48% higher than Oncentra® treatment planning system (TPS) dose. The mean was 7.08%. The total plan uncertainty (k=2), including MOSFET angular dependence uncertainties acquired from commissioning measurements, calibration uncertainties and TPS dose uncertainties, was calculated to be ±22%.

Discussion: Use of the MOSFET device for IVD in HDR gynaecological brachytherapy applicators in two patients showed good agreement with predicted dose (extracted from the TPS) within measurement uncertainties. Detection of five out of six simulated errors demonstrated the MOSFETs ability to detect gross errors. If IVD was implemented prospectively for fractionated HDR BT, this would allow the detection of an error in a fraction to be corrected for (by replanning) in subsequent fractions.

Conclusions: Use of the MOSFET device for IVD in HDR gynaecological BT applicators in two patients showed good agreement with predicted dose (extracted from the TPS) within measurement uncertainties. These results provide reassurance in the accuracy of dose delivery for BT. The next steps include further patient measurements for a range of plans and applicator sizes to increase confidence in the feasibility of the use of MOSFET for in vivo dosimetry. The use of MOSFETs for IVD BT can then be extended to other treatment sites such as rectal and skin brachytherapy.

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[1]Imperial College Healthcare NHS Trust

MR-Linac: Current Applications and Future Opportunities in the UK

Alex Dunlop[1]

Keywords: MR-linac, MRI, MR-guided online adaptive radiotherapy

Since the initial concept was first proposed more than 20 years ago, a series of technical challenges had to be overcome to bring the combination of an MRI scanner and a linear accelerator into clinical practice.

This talk will briefly recapitulate the basic technical and workflow challenges which were addressed and will provide an overview of a generalised typical clinical workflow for MR image guided online adaptive Radiotherapy. The talk will describe current applications of MR-guided adaptive radiotherapy in the UK and, based on recent clinical trials, the potential of a MR Linac platform will be highlighted and possible future clinical applications outlined.

[1] The Institute of Cancer Research and The Royal Marsden NHS Foundation Trust

PET-MR: An Update on the Clinical and Research Uses

Krithika Loganath

Keywords: PET-MR, research, clinical use

We will aim to explore the current clinical uses of PET-MR and the unique benefits it offers clinicians. We will also see some examples of ongoing areas of research utilising PET-MR technology and the exciting developments in the field with a view to the future.

The Perfect Machine and What It Means for Quantitative MRI Reproducibility

Matt G Hall[1,2], Cormac McGrath[3], and Paul S Tofts[4]

Keywords: quantitative MRI, clinical translation, in vivo imaging, biological variation

Background: In vivo Quantitative MRI (qMRI) has been a reality for more than 20 years. It enjoys an extensive research literature across multiple measured quantities (measurands), international study groups, a number of textbooks devoted to it, and applications in several major pathologies [1]. Despite this, qMRI translation into mainstream clinical applications has been very slow. One reason is that reproducibility and consistency between scanners and facilities remains a stubborn challenge. This is often framed in the MRI literature as a need for validation, but there is no accepted standard for how a technique should be validated, or what level of evidence should be sought before a technique is considered validated.

The perfect machine: A recent publication from Tofts [2] introduces the concept of the "perfect machine", which establishes criteria for the quality of a qMRI measurement process. A "perfect" qMRI machine is one that does not contribute any significant additional variation to the underlying biological variation. This is a highly useful concept, because it provides a quantitative criterion by which a particular procedure can be considered "good enough". This concept also provides the basis for a potential system of accreditation, whereby individual scanners are badged for specific quantitative applications. Such a scheme would aid clinical trial qualification, for example, and aid harmonisation between facilities for specific purposes. The idea of the perfect machine is also not specific to MRI and has applications to quantitative measurements in other modalities such as CT [3,4], Ultrasound [5] or Nuclear Medicine [6]. It also provides a conceptual framework to compare similar measurements made in different modalities.

Implementing a perfect machine framework requires the assessment of two quantities: the biological variation in the target population/tissue feature and the variability of the measurement process. Each of these is specific to the imaging application but the latter is to some extent under our control by careful optimisation of the image acquisition and analysis process and management of the scanner facility. Biological variability defines the bar we must reach in minimising measurement variability. In both cases, significant investment of time and resources is needed to first establish and then meet the criterion, but at this point the measurement process does not need to be improved further.

Key to this is the ability to measure the uncertainty and reproducibility of a chosen measurand.

Gap analysis and recommendations: The most pressing need is the ability to measure biological and measurement variability. In the case of the former, there is no one answer which will cover all pathologies and biomarkers, but we note that biological variability should ideally be characterised independently from the qMRI itself. It may be appropriate to use a more invasive or expensive approach which is not practical in a routine clinical setting and to draw from existing research literature and data. Conversely, measurement variability is a function of the techniques, hardware, and procedures used to perform the measurements and as such is amenable to the techniques of Metrology. Key to this is the ability to measure the uncertainty and bias of a chosen measurand. Similar requirements are present in many other fields, medical and otherwise. Radiotherapy dosages need to be consistent across facilities to ensure that patients receive consistent amounts of radiation. A 5mm bolt must fit a 5mm spanner regardless of manufacturer. The thousands of environmental sensors used globally to monitor the climate need to agree on units. Part of the solution to this is reference metrology, whereby measurements are assessed against reference quantities which are themselves traceable to the international

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definitions of SI units. To be fully reproducible and translatable into clinical practice, the same is needed for MRI. Individual qMRI-based measurements need to be characterised metrologically before we can make assessments against the Tofts criteria.

Reference metrology for qMRI: Assessing the measurement performance of a qMRI measurand is itself challenging but recent work allows this in certain qMRI modalities. Phantoms are key, and in particular phantoms with reference values for qMRI quantities which are traceable to international standards. The specifics of this are dependent on the measurand, but in practice we require a combination of chemical metrology, where concentrations of MR-active agents in carefully synthesised samples have known uncertainties, and reference imaging whereby MR-based assessments are made from data acquired on specialist scanners with well-characterised field strengths and timing parameters, again traceable to international standards. With both of these in place, measurements can be compared to those made on individual scanners, potentially using different pulse sequences or approaches – all that is needed are estimates of bias and uncertainty. It is also agnostic to the details of the measurement process. Any new acquisition or standard practice can be re-assessed against the same references, using the same (or similar) test objects without having to re-implement an entirely new process. The same approaches can also provide improved Quality Assurance and monitoring.

Recommendations: The perfect machine concept presents a very real opportunity to support translation of qMRI into clinical (and clinical trial) use, and points to the need for reference metrology for test objects, and independent verification of facilities in individual qMRI applications. Currently, no such scheme exists and there is little guidance available on how to perform qMRI of any form. To fully compare qMRI measurements and realise its benefits, we need an accreditation service such as that proposed in the Perfect Machine framework. This in turn requires the availability of traceably characterised test objects for a variety of modalities with test objects availably cheaply (perhaps on an on-loan basis), and with best practice guidance on how to acquire qMR images while minimising uncertainty and bias. This enables the assessment of images and image quality on a fully quantitative basis, stepping beyond current metrics like SNR which are inherently aimed at qualitative contrast, and towards the more complete assessment of measurement uncertainty needed for quantitative imaging.

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AI in Radiotherapy – Funding and Implementation

Chris Walker[1]

Keywords: artificial intelligence (AI), automatic contouring, radiotherapy treatment planning

This invited paper looks at the role of artificial intelligence (AI) in automatic contouring of organs at risk and some gross target volumes for radiotherapy treatment planning and how this fits with the Radiotherapy Transformation Programme strategic priority 2.

It presents results of a survey carried out with the Heads of Radiotherapy Physics in November 2021 and updated in July 2022 looking at national utilisation of AI for auto-contouring and present funding mechanisms.

It discusses the planned King's Technology Evaluation Centre (KiTEC) evaluation of AI assisted contouring on the behalf of the National NHS transformation AI-lab and the NHS England sponsored NICE creation of a Multi-Medtech Innovation Briefing (MIB) on 'AI auto-contouring tools for radiotherapy'. It articulates the "ask" from KiTEC in terms of providers supporting their evaluation along with potential timelines and seeks volunteers to participate.

It proposes potential routes to national centralised funding assuming positive evaluations from KiTEC and NICE and asks the community to support this initiative.

Finally barriers to implementation are considered along with potential strategies to overcome them.

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Evaluation of the Performance of OSAIRIS (Open-Source Artificial Intelligence Auto-Segmentation Software) Against Two Commercially Available Software Packages Used in Radiotherapy Planning

Amy Edwards[1], Alexandra Constantinou[1], Tom Griffiths[1]

Keywords: auto-segmentation, SaMD, artificial intelligence (AI), radiotherapy treatment planning

Background: OSAIRIS is an open-source artificial intelligence auto-segmentation software device using InnerEye machine learning models to analyse CT scan images. The software identifies and highlights organs at risk (OARs) of exposure to radiation during radiotherapy. This forms part of the personalised radiation treatment planning workflow. Methods of auto-segmentation aim to reduce the time and interoperator variability involved in manually delineating structures. This labour intensive process can result in delays to patient treatment and increased costs to the hospital. The requirement for hospitals to train machine learning models and validate their performance has thus far prevented the widespread adoption of the InnerEye machine learning models used by OSAIRIS. To enable widespread adoption of these models, Cambridge University Hospitals (CUH) was awarded an NHSX AI award to pursue medical device registration of the InnerEye models trained on CUH data.

Objective: To evaluate the performance of the machine learning models utilised by OSAIRIS against commercially available auto-segmentation software packages.

Methods: Each auto-segmentation software was run on 5 head and neck and 5 prostate scans. The contours produced by each software package for each scan were compared to 'gold standard' contours manually produced by clinicians. The accuracy of each software package was compared through the calculation of comparison metrics including overlap-based metrics (Dice, Jaccard), distance-based metrics (Hausdorff distance (HD), mean surface distance, mean distance to conformity, absolute centroid) and volume-based metrics (absolute and relative volume differences). An overlap-metric score of 1 indicates perfect overlap of software and clinician contours. A distance-metric score of 0 indicates a perfectly accurate contour. Statistical significance of the difference in the distributions of Dice scores and HD values was tested using a Wilcoxon-signed rank test. Statistical significance of the difference in mean values was tested using a paired t-test.

Results: For head and neck data, OSAIRIS achieved a median Dice score of 0.98 compared to 0.83/0.85 and a median HD of 3.08 compared to 5.29/6.32 for the two commercial software packages. Bland Altman analysis indicated OSAIRIS outperforms both other software packages. Differences in Dice scores and HD values were statistically significant (p-values > 0.05). For prostate data, OSAIRIS achieved a mean Dice score of 0.80 vs 0.79/0.80 and a mean HD of 45.3 vs 30/33 for the two commercial software packages. Differences in Dice scores were not statistically significant. A statistically significant difference was present for HD values compared to one commercial software package only. The removal of femoral heads from the analysis of prostate data resulted in a mean Dice score of 0.92 for OSAIRIS compared to 0.91/0.90 and a mean HD of 13 compared to 14.7/13.7 for the two commercial software packages. A statistically significant difference was present for Dice scores compared to one commercial software package only when femoral heads had been removed from analysis.

Conclusions: For head and neck data, OSAIRIS outperforms the two commercial software packages across all metrics and most individual OARs. For prostate data, OSAIRIS data was more variable with a wider spread. OSAIRIS performed similarly in terms of overlap-based metrics but less well in terms of distance-based metrics. This suggests OSAIRIS performs well at determining overall shape but less well at delineating contours. Femoral heads showed poor performance generally across all software packages. Prostate performance improved across all software packages when these structures were removed from analysis. OSAIRIS then performed best in terms of overlap and distance metrics. In general,

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OSAIRIS outperforms or performs similarly to the two commercially available auto-segmentation software packages creating significant opportunity for the transformation of radiotherapy planning with widespread adoption of this software.

Limbus AI and AI Rad Companion Organs RT for Radiotherapy Treatment Planning of Head and Neck Cancer

Virginia Marin Anaya[1]

Keywords: artificial intelligence (AI), head and neck, contouring, treatment planning

Background: Manual contouring is tedious, time-consuming, and prone to inter- and intra-observer variability. The time spent by clinicians on contouring reduces their availability for other tasks and can delay the start of patients' treatments. This can lead to poorer tumour control probability, and for some patients, reduced probability of survival. Thus, auto-segmentation methods, which can be deployed in the existing workflow, are needed in order to improve contouring consistency, optimise patient treatment pathways and improve patient outcomes, whilst enabling effective use of staff resources. Limbus AI and AI Rad Companion Organs RT are commercial solutions for auto-contouring based on deep learning. The objective of this study was to assess the accuracy of AI auto-contours for head and neck treatment planning.

Methods: Head and neck patients treated with RapidArc were selected retrospectively. The manual contours on the planning CT were used as reference. Inter-observer variability was eliminated since all the delineations were performed by the same clinical oncologist. Geometric analysis of the auto-contours was performed using several evaluation metrics such as the Dice Similarity Coefficient (DSC) and the Mean Distance to Conformity (MDC). Dosimetric analysis was performed by re-calculating the original plan on the auto-contours and comparing Dose Volume Histogram (DVH) metrics to the original plan.

Results and discussion: Both AI tools tend to underestimate the volumes of brainstem and cord. For brainstem and parotids, median DSC values were ≥ 0.8. For all auto-contours, median MDC values were ~ 3-6mm. Median differences of up to ±7% in DVH points on the auto-contours relative to the planning CT contours were found.

Conclusions: The auto-contours are not able to replace manual contouring by the clinician completely. However, they could be used as a tool to assist the clinician with the manual contouring of structures on the planning and re-scanning planning CT.

	Limbus AI		AI Rad Companion Organs RT	
Structure	**DSC**	**MDC (mm)**	**DSC**	**MDC (mm)**
Brainstem	0.87 (0.82, 0.92)	3.34 (2.52, 4.38)	0.83 (0.78, 0.91)	3.96 (3.18, 6.39)
Cord	0.71 (0.57, 0.88)	2.71 (2.14, 63.67)	0.54 (0.34, 0.79)	3.37 (2.98, 21.19)
Left Parotid	0.87 (0.79, 0.88)	4.19 (3.66, 5.30)	0.80 0.69, 0.84)	5.37 (4.65, 8.95)
Right Parotid	0.85 (0.62, 0.86)	4.36 (3.33, 9.14)	0.79 (0.59, 0.83)	5.59 (3.77, 12.56)

Table 1. Geometric analysis. Results are expressed as median and range between brackets.

Structure	DVH Point	Limbus AI (%)	p-value	AI Rad Comp (%)	p-value
Brainstem	Dmax	-4.6 (-9.1, -0.1)	0.08	-6.9 (-20.1, 0.2)	0.03
	D0.1cc	-4.4 (-9.6, -0.1)	0.04	-6.1 (-0.3 -6.1)	0.07
Cord	Dmax	-1.6 (-5.1, 0.0)	0.13	-3.1 (-5.9, 0.0)	0.05
	D0.1cc	-1.9 (-4.6, -0.3)	0.03	-2.1 (-5.7, -1.3)	0.02
Left Parotid	Dmean	0.4 (-0.7, 6.1)	0.25	3.2 (0.8, 18.6)	0.24
Right Parotid	Dmean	1.6 (-10.3, 4.3)	0.55	6.9 (-2.0, 10.4)	0.10

Table 2. Dosimetric analysis. Results were expressed as median and range between brackets.

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AI Segmentation as a Quality Improvement Tool in Radiotherapy Planning

Samantha Warren, Neil Richmond, Ashleigh Wowk, Michele Wilkinson

Keywords: AI segmentation, breast radiotherapy, VMAT, delineation

Background: Modern highly-conformal radiotherapy requires correctly delineated target and organ-at-risk (OAR) volumes, yet this is time-consuming and subject to large inter-observer variation. Awareness of delineation as the 'weak link' in radiotherapy planning has prompted international guidelines for harmonisation of OAR definitions [1], consensus guidelines for targets [2], and recommendations for peer review [3]. Following careful commissioning and evaluation [4], AI segmentation not only offers an efficient way of meeting these challenges, but can drive improvements in treatment technique, distribute tasks across different staff groups, and accelerate adoption of best practice into clinical routine.

Methods: AI segmentation has been introduced in our department for breast nodal radiotherapy delineation and planning, including for patients requiring internal mammary node (IMN) irradiation. OAR and target delineation quality was scored by experienced staff. For a cohort of breast patients with nodal volumes, clinician feedback on editing of AI contours was reviewed. These AI volumes were then used for field-placement, instead of a manual bony anatomy based technique. For IMN treatments, the roll-out of VMAT (volumetric-modulated arc therapy) was monitored during this period, and compared with a 3-field technique to investigate changes in plan quality. Time elapsed from CT scan to plan approval was also analysed.

Results: For 30 consecutive patients requiring nodal irradiation, clinicians assessed that 67% of nodal target volumes required no edits or minor edits only. For patients with IMN treatment, the improvement in technique (3 field to VMAT) resulted in a dose reduction to ipsi-lateral lung: lung V_{17Gy} for the 3-field technique was median 51.5% (range 20.7-68.4%) vs VMAT lung V_{17Gy} median 26.5% (range 3.2 -34.8%). All VMAT IMN patients meet the mandatory constraint of lung V_{17Gy} <35%, and 68% meet the optimal mean lung dose limit. Median time from CT scan to VMAT IMN plan approval reduced from 12 days (with manual contouring) to 7 days using reviewed AI generated volumes. The option of breath-hold radiotherapy (DIBH) with associated heart and lung sparing is now feasible with a VMAT technique.

Results: For 30 consecutive patients requiring nodal irradiation, clinicians assessed that 67% of nodal target volumes required no edits or minor edits only. For patients with IMN treatment, the improvement in technique (3 field to VMAT) resulted in a dose reduction to ipsi-lateral lung: lung V_{17Gy} for the 3-field technique was median 51.5% (range 20.7-68.4%) vs VMAT lung V_{17Gy} median 26.5% (range 3.2 -34.8%). All VMAT IMN patients meet the mandatory constraint of lung V_{17Gy} <35%, and 68% meet the optimal mean lung dose limit. Median time from CT scan to VMAT IMN plan approval reduced from 12 days (with manual contouring) to 7 days using reviewed AI generated volumes. The option of breath-hold radiotherapy (DIBH) with associated heart and lung sparing is now feasible with a VMAT technique.

Discussion: Introduction of AI segmentation in the routine clinical pathway has streamlined existing workflows, as the clinician only needs to review and amend the contours. This has reduced clinician workload, and allowed experienced dosimetrists to individualise radiotherapy treatments more efficiently. AI segmentation has been particularly beneficial for the transition to VMAT delivery for high-risk patients requiring IMN treatment, with dosimetric benefit to all patients. This has been achieved in only a few months, due to growing staff confidence in the quality of the AI generated contours, and the efficiency gains realised. Work is underway to further expand VMAT for breast radiotherapy delivery, including the offer of DIBH for suitable patients.

Conclusions: Evolution from manual anatomical field-placement to true target volume planning for breast radiotherapy has been enabled by use of AI delineation. Workflows have been simplified, DIBH radiotherapy is available to more patients, with significant time-savings. Additionally, consistent, high-quality contours for 9 OAR and breast PTVs

for all patients now facilitates comparison with NHS-E scorecards as a benchmark for plan quality.

References:

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Classifying Nuclear Medicine Staff: Legalities and Practicalities

Graham J Whish[1]

Keywords: nuclear medicine, staff classification, IRR17, radiation protection, skin contamination

Background: For several years, the HSE have had a growing expectation that staff working with unsealed radiopharmaceuticals in both healthcare and veterinary sectors, should be classified. It is understood that they have formed this view based on several incidents that have occurred (in the UK and beyond) where the estimated skins doses to staff following skin contamination or needle stick injuries have exceeded the skin classification level of 150 mSv.

Summary: The talk starts by briefly summarising the relevant Ionising Radiation Regulations (IRR17) and associated Approved Code of Practice (ACOP) that define when a worker will need to be classified. Whilst the legal criteria for classification are reasonably objective, recent studies [1] have shown very large variation between centres in the scientific methods used to calculate skin doses following incidents, and highlights the need for a nationally agreed approach to this problem. Variations in methods are so large, particularly for needle-stick doses, that the same incident interpreted by two different centres could conclude skin doses are less than typical skin dose investigation levels (20 mSv) or in excess of the annual legal skin dose limit (500 mSv).

Against this backdrop of uncertainty, EARRPS as a Radiation Protection Advisor (RPA) Body have historically recommended that nuclear medicine staff do not need to be classified based on either routine or accidental exposures. The only exceptions to this have been radiopharmacy and PET staff who often receive high skins doses from their routine work.

An overview of the main regulations that come into play once staff become classified workers is then given.

The remainder of the presentation is based around an unforeseen skin contamination incident which occurred within an NHS Nuclear Medicine department. A worst case skin dose estimate was made which was in excess of 150 mSv (263 mSv), so the HSE were informed under IRR Reg 24 (Accident Dosimetry). The follow up HSE inspection resulted in enforcement action requiring the classification of staff dispensing or administering radiopharmaceuticals. As EARRPS are an RPA Body, the HSE also made it clear that they expected EARRPS to advise all their other relevant customers to take the same steps (5 NHS Trusts and 2 specialist Equine centres).

The steps EARRPS took in advising its customers in mass-classification of staff are described. Various obstacles and challenges are covered as well as outstanding challenges imposed by various IRR regulations. Some of these will be further explored in Matthew Memmott's talk.

Conclusions: Once the decision to classify staff has been made, IRR Regulations 21 – 27 become activated. As clinical scientists and radiation protection professionals, we have a duty to advise our clients how to comply with these regulations so that their staff are safe and the organisation operates legally. What is emerging is that there are far reaching complexities and administrative challenges which have a significant impact on classified workers, their managers, Approved Dosimetry Services, RPAs and Appointed Doctors.

Further work is needed to ensure that optimal methods are established that balance legal compliance to IRR with the practicalities of providing a vital NHS service. This work should include a nationally agreed skin dose calculation protocol, optimised activity-based contamination monitoring processes and a cost-benefit analysis of classifying large number of Nuclear Medicine staff.

References:

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[1]East Anglian Regional Radiation Protection Service (EARRPS), Addenbrooke's Hospital, Cambridge University Hospitals NHS Foundation Trust

Potential Skin Doses in Nuclear Medicine Incidents

Bill Thomson[1]

Keywords: skin dose, needlestick, nuclear medicine, radiation protection, contamination

Background: Skin doses are generally the area for concern in nuclear medicine incidents (1). VARSKIN+ is increasingly being used for skin dosimetry calculations (2). I have previously presented contamination data and have summarised some of the main contamination situations. (3)

Methods: Using VARSKIN+v1.1 , I have examined different scenarios and estimated the activity of some common radionuclides that would lead to skin doses of 500mSv. In particular the situations of percutaneous absorption and needlestick are presented as having the potential for high skin doses.

Results: Direct skin contamination can often lead to skin retention from percutaneous absorption (4,5). Modelling this in EXCEL leads to the following activity values (MBq) to give 500mSv. A similar situation is a needlestick injury, with an assumption of activity deposited along the needle track, modelled with the VARSKIN+ new wound dose model (with a weak retention biological half-life of 6hr).

Discussion: Although fortunately rare, incidents of direct skin contamination or needlestick injury still happen. These have the potential to exceed the 500mSv annual skin dose limit (or the 150mSv non-classified worker limit). As potential consequences of an incident, these need to be included and identified in risk assessments. The incidence is extremely low, and local measures may be introduced to mitigate this e.g. gloves and PPE are always worn when handling any open source work. These measures may not be directly effective for needlestick however. Particularly for alpha emitters such as Ra223, these may also be seen as in the category of 'never events'. An important element is staff awareness and training.

HSE have noted that in recent years they have had reported incidents which have exceeded 500mSv. It is in essence due to the high dose potential of such incidents that HSE consider staff carrying out such open procedures should be classified workers.

Conclusions: Incidents of high skin dose are fortunately rare, but can exceed the 500mSv dose limit. Measures such as increased PPE can mitigate this risk but It is difficult to avoid any potential for them. Staff training and education regarding such incidents and doses are also key components.

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[5] Covens et al 2013 J. Radiol. Prot. 33: 381

	Retained activity in skin that may lead to 500mSv skin dose	
	Percutaneous Absorption for 500 mSv	1mm Needlestick for 500mSv
Tc99m	1.5 MBq	1.7 MBq
F18	0.23 MBq	0.36 MBq
Lu177	0.11 MBq	0.06 MBq
Y90	0.04 MBq	0.03 MBq
Ra223#	71 Bq*	15 Bq

#With QF = x20 applied

**Percutaneous absorption unlikely, and activity (Bq) relates to being on skin surface only.*

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Estimating Skin Dose from Contamination for Risk Assessment Using Varskin+ v1.1

Katherine McLellan[1], Janice O'Neill[1], Short Life Working Group (SLWG) on Classification of Nuclear Medicine Workers in NHS Scotland[2]

Keywords: classification, skin dose, Varskin+, contamination, nuclear medicine, PET

Background: Recent updates from the HSE encouraging employers to review potential skin doses have prompted the Scottish RPA group's formation of a Scottish short life working group (SLWG) [1] to consider the issue and in particular if NM or PET workers should be classified. If it is reasonably foreseeable that a worker will receive an equivalent dose to the skin of 150 mSv or more in a calendar year, then they must be designated as a classified worker. The new Varskin+ [2] computer code enables more complex modelling of personal contamination but various sources of uncertainty including subjective choice of input parameters can lead to significant variations in skin dose estimates. The aim of this work is to reduce variation in skin doses estimated using Varskin+.

Methods: An in-depth investigation of the parametric sensitivity of the Varskin+ v1.1 input parameters was undertaken; by incrementally varying individual parameters and plotting the estimated skin dose, the influence of each parameter was better understood. This information aided the development of a user protocol, for the SLWG, containing reasonably foreseeable worst case scenarios and standardised input parameters. Previous work and available evidence was considered in detail and used to improve the protocol where possible [3],[4].

Results: The protocol developed by the SLWG provides standardised input parameters for direct skin contamination, glove contamination and needle stick injury scenarios for risk assessment purposes. For example, in the glove contamination scenario a 20 µm thick cylinder source is defined on the surface of a 20 µm thick cover with density equal to that of a nitrile glove. A simplified version of the protocol has been developed as an operational document in conjunction with four .XML calculation templates to minimise user error and reduce time taken to perform calculations.

Discussion: Significant uncertainty in skin dose estimates will arise from various assumptions including the fixed activity, the depth of the basal layer of skin cells, source geometry, skin retention and absorption. Therefore the protocol will be kept under regular review and further evidence will be collected from centres across Scotland. Skin doses estimated for risk assessments using this protocol help to inform decisions regarding classification of staff in nuclear medicine and PET in a standardised way across the Scottish Health Boards.

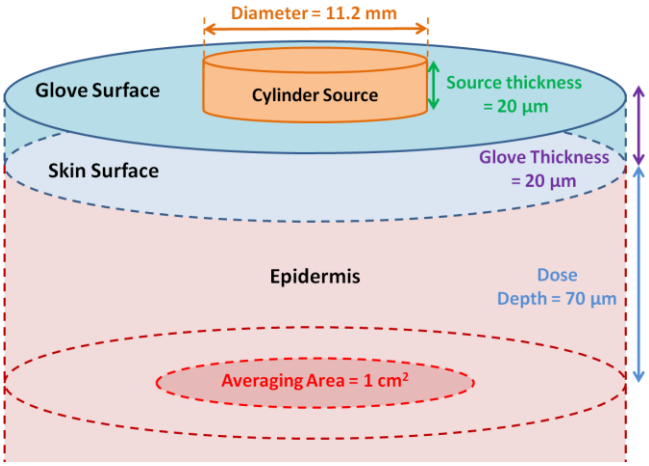

Figure 2: Glove Contamination Risk Assessment Scenario

Conclusions: A protocol standardising the estimation of skin dose arising due to personal contamination has been developed to reduce variation in these estimates across the Scottish Health Boards.

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[1]NHS Tayside; [2] NHS Grampian, NHS GGC, NHS Highland, NHS Ayrshire and Arran and NHS Lothian

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Additive Manufacturing Techniques for Smart Prosthetic Liners

Ben Oldfrey[1]

Keywords: rehabilitation engineering, prosthetic limb, smart prosthetic liner, nanocomposite

Elastomeric liners are commonly worn between the prosthetic socket and the limb. A number of improvements to the state of the art of liner technology are required to address outstanding problems. A liner that conforms to the residuum more accurately, may improve the skin health at the stump-socket interface.

Previous work has shown that for effective thermal management of the socket environment, an active heat removal system is required, yet this is not available. Volume tracking of the stump could be used as a diagnostic tool for looking at the changes that occur across the day for all users, which depend on activity level, position, and the interaction forces of the prosthetic socket with the limb. We believe that it would be advantageous to embed these devices into a smart liner, which could be replaced and repaired more easily than the highly costly and labour-intensive custom-made socket.

This talk will present work done to develop these capabilities in soft material technology, with: the development of a printable nanocomposite stretch sensor system; a low-cost digital method for casting bespoke prosthetic liners; a liner with an embedded stretch sensor for growth / volume tracking; a model liner with an embedded active cooling system. The talk will also elaborate briefly on additional current workstreams being conducted towards further functionality of liner technology.

[1]University College London

Evolution of Environmental Control Systems

Zoë Clarke

Keywords: environmental control systems, assistive technology devices

Environmental Control (EC) systems enable people with physical and/or cognitive disabilities to control the things in their immediate environment. This can include calling for assistance, controlling for comfort, (bed, chair, lighting), controlling entertainment (television, radio), controlling door, and computer access. The aim of EC is to increase independence and agency. With no disabilities, it is easy to take for granted the ability to do these things; however, for people who may need considerable support in their lives, having this agency and control is extremely important. As with many aspects of technology not everyone necessarily wants to use it or wants to use it for everything, but ensuring that people are able to access assessment to make that decision is essential.

Technology has evolved considerably since the 1960s when EC was first developed. This presentation will consider how technology has evolved against the backdrop of technology evolution in the whole of society. It will highlight the benefits this evolution has had and the potential advantages and challenges that we see as we move forward in a world where the line between specialised and mainstream equipment (that which we could all use) is blurring.

The presentation will consider the place for EC and why it is still important and what we need to consider as things develop, including how we evaluate technology for use by EC users. In addition, the need to be open-minded to these developments and ensure that we do not become inequitable in our assessment and provision due to technology moving on and our considerations of what can and should be controlled not keeping pace.

[1]Environmental Control Lead/Lead Healthcare Scientist, Barnsley Hospitals NHS Foundation Trust

The Challenges of New Technology in the Disabled World

Jon Graham

Keywords: assistive technology, voice-controlled devices, emerging technology

My talk will focus on the emergence of new technologies and how they try to fit in within the disabled sector, particularly voice-controlled devices.

I will speak about the challenges of voice-controlled devices taking into account:

1. Speech Quality
2. Speech Volume
3. Dialect
4. Cognition
5. The frustrations
6. Equipment availability

I'll make reference to user experiences and their families, my own vast experiences with users, especially from the points when we have a group of us involved in the clinical assessments of patients. I'll also make reference from knowledge as a Research and Development team member with us as a manufacturer and also the effect on other manufacturers.

Continuing onto the results from these experiences and what that means for individuals as well as manufacturers.

I'll conclude with the overall effect on selecting what is right for the individual, which absolutely must involve several professionals, the individual and their families as part of the decision making.

Addressing the Challenges in Rehabilitation Engineering Service. A Case Study – Development of a Clinical Gait Analysis Service in South Wales

Jonathan Hosking

Keywords: gait analysis, biomechanics, challenges in rehabilitation engineering.

Background: Prior to 2018, there was no clinical gait analysis service in Wales. Patients requiring gait analysis were being referred across the border to Trusts in England for assessment. This had implications for patient care and due to the distance only a select number of patients, 10-12 per year, were benefitting from these arrangements.

In 2018, a pilot began to determine the feasibility of developing a local clinical gait analysis service in Cardiff and Vale University Health Board. On the back of a collaboration with Cardiff University's School of Engineering and the recently developed Musculoskeletal Biomechanics Research Facility a local pathway for gait analysis was established.

Methods: Feasibility of the pilot was determined by an increase in referral numbers per year and outcomes from the pilot were assessed by comparison of pre and post-surgical decision making.

Results: Pilot results found that gait analysis was having a clear impact on surgical decision making with surgeons following the majority of all gait analysis recommendations and in half of all cases less surgery was performed than previously planned. However, we were unable to prove that gait analysis was cost effective on a marginal basis.

Discussion: Following the pilot, several attempts at securing funding for a full service were attempted with the challenges of achieving this detailed in the presentation.

Conclusions: The challenges of developing a new service in rehabilitation engineering were addressed in this presentation with key learnings identified.

A Quality Improvement Project in a Clinical Gait Analysis Service

Emma Pratt[1]

Keywords: quality improvement, clinical service, gait analysis

Background: This aim of this Quality Improvement (QI) project was to optimise current processes completed by Clinical Scientists (CS) within a clinical gait analysis session, identifying and minimising controllable variation in sessions times.

Methods: To identify a target process for QI, process mapping was completed, baseline timing metrics identified and collated, and structured 4N® charts completed documenting feelings towards mapped processes [1].

Retrospective metrics from 27 clinical sessions were analysed using Statistical Process Control (SPC) system behaviour charts [2], identifying the timing metric "initial data processing time" to be the most variable. Within this time-period the process 'Knee Alignment Device (KAD) adjustment' occurs, and following review of 4N chart 'niggles' this was identified as the target for the QI work.

Using the NHS Model for Improvement (MfI) framework [3], the overall aim was clarified and outcome metrics defined as total session time, reduced variation in initial data processing time, and improvement in staff satisfaction working within the service. Following review of change ideas, three PDSA cycles were completed: Cycle 1 objective assessment of inter-CS reliability in KAD adjustment decisions; Cycle 2 delivering a KAD training package; Cycle 3 repeating inter-CS reliability in KAD adjustment decisions. Outcome metrics were then evaluated, with timing metrics collated from a minimum of 10 clinical sessions.

Results: Post QI project, a change of 43min in the mean overall session times and reduced variation was seen (mean pre 3:20hrs, post 2:37hrs). Figure 1 shows the SPC chart of the metric 'initial data processing time', with a mean 19min reduction, and 12min reduction in standard deviation. Staff satisfaction questions showed a slight improvement.

Discussion: Limitations are recognised, including the reduced post data set, and the potential for increased familiarisation with post-covid protocols to influence overall session times; although the metric 'initial data processing time' was unlikely to be affected by the latter.

Conclusions: Although not without difficulties, mostly due to time-pressures, the QI process has led to demonstrable improvements within the clinical gait analysis service across all outcome metrics. In future, commitment to the QI process and associated time required would be sought in advance from managers, with this project used to demonstrate potential impact.

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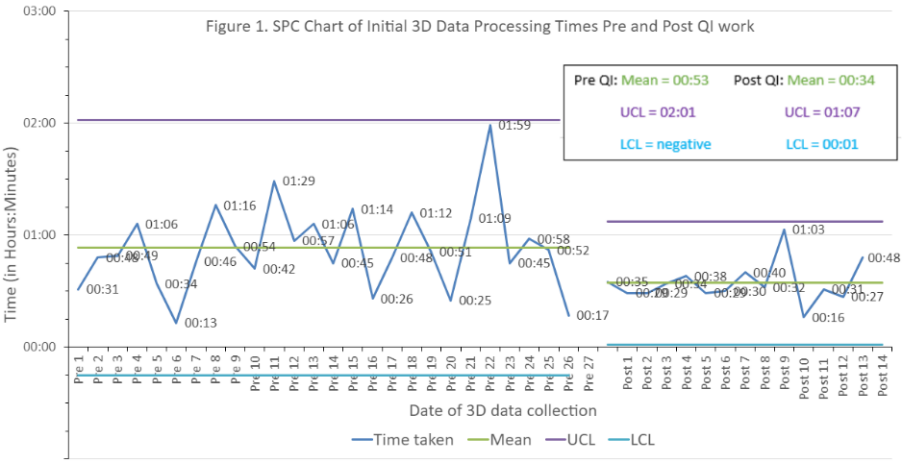

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Inter-Departmental Audit Group Update and New IPEM Phantoms for National Audits

Sarah Misson-Yates[1], Antony L Palmer[2], Patricia Diez[3], and Catharine H Clark[3,4,5,6]

Keywords: national audit, interdepartmental audit group, radiotherapy, standardisation, phantom

Background: The IPEM interdepartmental dosimetry audit group (IDA) facilitates regional audits across the UK, through a network of 8 regional groups [1]. It was setup in the 1990s following the results of the first megavoltage photon audit [2]. The IPEM IDA is now a well-established and successful network; organising, conducting and utilising NHS staff resources and equipment to conduct audits on new radiotherapy treatment equipment, clinical radiotherapy techniques and undertaking annual audits. All dosimeters are traceable to the National Physical Laboratory's (NPL) primary standard via the IPEM codes of practice.

NPL and the Radiotherapy Quality Assurance Trials Group (RTTQA) perform audits for new techniques and clinical trials in the UK. Once these initial audits have been run or the trials have closed there is no funding or ongoing or follow-up audits to check that accuracy has been maintained and standards continue to be met. This is required as techniques and equipment evolve over time.

Future direction and national audits: The IPEM IDA, NPL and RTTQA have a joint vision to complete the audit cycle (figure1) and bring together all UK dosimetry audit data within a centralised database. This will allow centres to access their data for benchmarking anonymously against other UK centres to enable quality improvement in routine practice as well as to provide evidence of ongoing QA for clinical trial participation.

Data comparison across centres requires standardisation of the current audits taking place. The IPEM IDA is working on national reference templates for photon, electron and kilovoltage external audits.

Standardisation is one part of the process; the greatest challenge is enabling more national audits to reflect current clinical practice. One of the highest costs associated with auditing is for appropriate equipment that can be utilised for multiple audits. In the case of audits for specialised techniques such as brachytherapy, bespoke phantoms must be designed. As an example, IPEM has a phantom for brachytherapy applicator dosimetry auditing (known as BRAD) within its central phantom library. Since its original application for a national HDR cervix brachytherapy audit in 2014 [3], these treatments have developed, with increasing use of advanced techniques including CT-MR registration for planning, interstitial needles and ring applicators to sculpt the dose distribution. BRAD will require modification to make it fit for purpose and future-proof.

The last head and neck national audits were conducted in 2010 [4] for IMRT and 2014 [5] for VMAT, with advances since in treatment planning and imaging, there is now a need to provide an up-to-date audit. The CIRS SHANE phantom has been developed by a research group for the IAEA and can be used for national end-to-end auditing [6].

Figure 1

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In October 2022, funding from IPEM was secured for these two phantoms. The IPEM IDA are currently working with NPL and RTTQA on the development and implementation of these audits and the collection of the data.

Through greater collaboration, standardisation and data sharing we believe the UK can be a world class model for national dosimetry auditing in radiotherapy.

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Dosimetric Accuracy of the Eclipse Treatment Planning System at Extended Source-to-Surface Distance for Total Body Irradiation Treatments with Use of Boosting/Shielding Fields

George Thickett[1], Alison Starke[1],Jackie Poxon[1], Niall MacDougall[1]

Keywords: radiotherapy, total body irradiation, TBI, extended source-to-surface distance, Eclipse, AAA

Background: Total body irradiation (TBI) treatments, used primarily prior to bone marrow transplants, are a unique challenge in radiotherapy requiring that the whole body of the patient receives a homogeneous dose [5]. This is commonly achieved using an extended source-to-surface distance (SSD) and planned without using a treatment planning system (TPS) [3]. Progression to TPS planning would allow utilisation of shielding fields to homogenise the dose distribution, limit dose to organs at risk and reduce the amount of in-situ shielding required which is time-consuming to position [1, 2]. This study investigated the dosimetric accuracy of the Eclipse TPS at extended SSD, using the standard SSD AAA algorithm, with a particular emphasis on the ability to accurately calculate doses for smaller boosting/shielding fields.

Methods: A10MV beam on a TrueBeam (Varian) Linac was measured at 406cm SSD in a homogeneous water-equivalent phantom, with a Perspex TBI spoiler. Results were compared to doses calculated with the Eclipse v15.6 AAA algorithm. Relative percentage depth dose (PDD) and absolute depth dose curves for 40×40cm, 20×40cm and 4×4cm field sizes and diagonal profiles at 5cm, 15cm and 30cm depths with a 40×40cm field were measured. Output factors were measured for square and rectangular jaw sizes between 1×1cm and 40×40cm. Profiles were measured for both a jaw and multileaf collimator (MLC) defined 4×4cm field at 5cm depth, with a particular emphasis on the penumbra region.

Results: Excellent relative agreement was seen between Eclipse and linac measurements with deviation <1% for the PDDs at depths over 0.5cm and <2% across the central region of the diagonal profiles. Absolute doses were consistently overestimated by <4% in Eclipse beyond very shallow depths. Measured and calculated output factors agreed within 1% for all jaw sizes over 1cm. All penumbra results were within 3%/2mm for both the jaw and MLC defined 4×4cm field.

Discussion: The current manual planning method employs a dose tolerance of ±5% of the prescription dose along the patient's midline and does not examine doses elsewhere within the patient. Absolute dose differences between Eclipse and the linac measurements were consistently <4% deviation within the central field beyond very shallow depths, showing that using the standard Eclipse beam model a TPS-based planning method could achieve better accuracy than the current technique.

The excellent agreement between measured and calculated output factors for field sizes down to 2cm x 2cm, and the small distances-to-agreement measured in the penumbra of jaw and MLC-defined fields suggest that a future TPS planning method could incorporate these to define shielding fields. An optimised beam model could improve absolute dose agreement [4], but introduces additional risks, so centres will need to decide locally if this is worthwhile.

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[1]Radiotherapy Department, St Bartholomew's Hospital, UK.

Assessment of the Sensitivity of Various Quality Control Devices to Linear Accelerator Beam Steering and Energy Adjustments

Rebecca Hughes[1], Catherine Stanford-Edwards[1], Gareth Lewis[1], Mark Edwards[1]

Keywords: radiotherapy, uniformity, Beamscan, Octavius, Startrack, Elekta Versa HD

Background: A number of manufacturers provide various pieces of equipment [3,4] as a quick solution to measure flatness, symmetry and energy of a Linear Accelerator (Linac) beam. These are often set up as a constancy check to report any changes from the baselines of an optimised beam. This work investigates: how sensitive these devices are to flatness, symmetry and energy changes; how the devices correlate with the actual errors seen in the tank; and the differences between the devices.

Methods: 2R and 2T steering coil currents were adjusted on the linac to alter the beam steering of 6MV on an Elekta Versa HD. The profile of the beam was measured with the PTW Beamscan Water Tank, the PTW Octavius[1500] array and the IBA Startrack. Bending coarse, bending fine and electron gun currents were altered to introduce a hump error, therefore changing the energy of the beam, which was also measured with the equipment. The water tank measurements were analysed at +/-12cm off axis as per Elekta's method of calibrating the 2T, 2R and hump error items on the linac[1].

Results: Preliminary results show that the 'crossline' Beamscan profiles agreed well with the linac 2T steering errors, showing an R-value of 0.998, indicating a strong correlation *(Figure2).* The initial crossline beam symmetry measured with Startrack and Octavius agreed well with the Beamscan error, approximately 0.2 % difference from the tank symmetry and a 0.02 % difference between the equipment was seen. Results show an average difference of 0.5 % (SD = 0.4 %) between StarTrack and Octavius with the max difference of 1.1 % across all adjustments *(Table1).* A better agreement between the Beamscan and Startrack has been seen in comparison with Octavius *(Table1, Figure3).* Results have also demonstrated a better agreement between the two arrays and the Beamscan when the linac 2T errors were adjusted in the positive direction.

Linac 2R value	Tank % error	Startrack Symmetry	%Diff from tank	Tank % error	Octavius Symmetry	%Diff from tank	Octavius Startrack %diff.
0	0.3	0.55	0.25	0.3	0.53	0.23	0.02
-3.8	3.7	5.62	1.92	3.7	6.75	3.05	1.13
-2	1.7	2.45	0.75	1.7	3.19	1.49	0.74
-1	0.8	1.07	0.27	0.8	1.98	1.18	0.91
5.1	5.1	6.06	0.96	5.1	6.27	1.17	0.21
2	1.9	2.33	0.43	1.9	2.16	0.26	0.17
1	1.1	1.44	0.34	1.1	0.93	0.17	0.51
		ave	**0.7**		ave	**1.1**	**0.53**
		sd	**0.6**		sd	**0.9**	**1.13**
		max	**1.9**		max	**3.1**	**0.39**

Table 1: Table showing % difference between equipment

Discussion: There is uncertainty over the optimal build up used for Octavius which may explain the results for this device, therefore this could possibly be improved. The initial beam was asymmetric in the inline and crossline direction which, if repeated, could be adjusted prior to measurements. Due to the shape of the flight tube in the crossline axis, there are limitations in the 2T steering adjustments before the dose rate drops and the vacuum starts deteriorating, due to some of the electrons hitting the side of the flight tube. This was seen when adjusting the 2T error in the negative direction. The beam had limited steering in this direction, which was hard to reproduce when measuring with each device, which may have had an impact on the results.

Conclusions: Based on these initial findings, further work and analysis is needed to evaluate the sensitivity of the devices. 2R errors (inline) and the change in hump error are yet to be evaluated. This work will be repeated for 6MV again; carried out for 10MV and 6FFF; and possibly will include other equipment including the Electronic Portal Imaging Device (EPID). This investigation will also help to inform appropriate tolerances for the devices depending on their sensitivity and with the

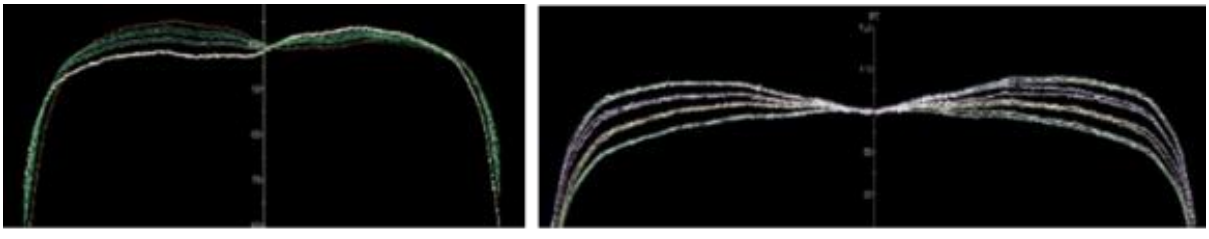

Figure 1: Beamscan profiles showing beam steering and energy adjustments.

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implementation of annual beam steering indicator checks[5].

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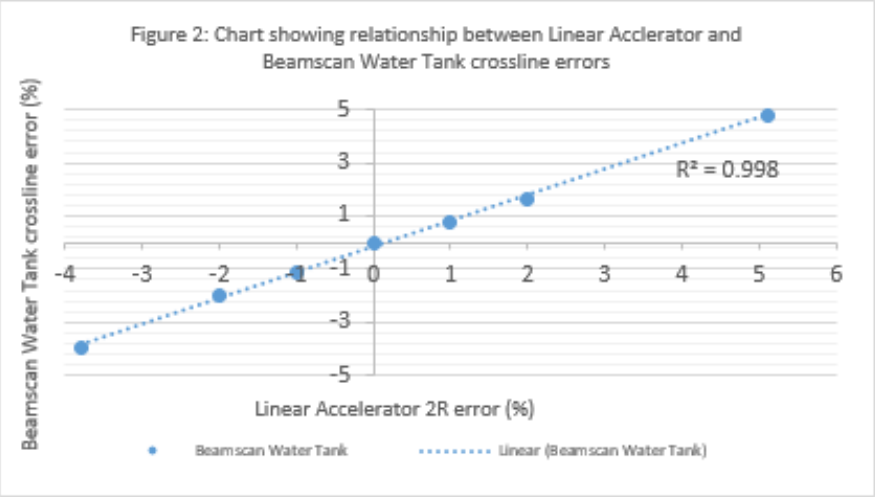

Figure 2: Chart showing relationship between Linear Acclerator and Beamscan Water Tank crossline errors

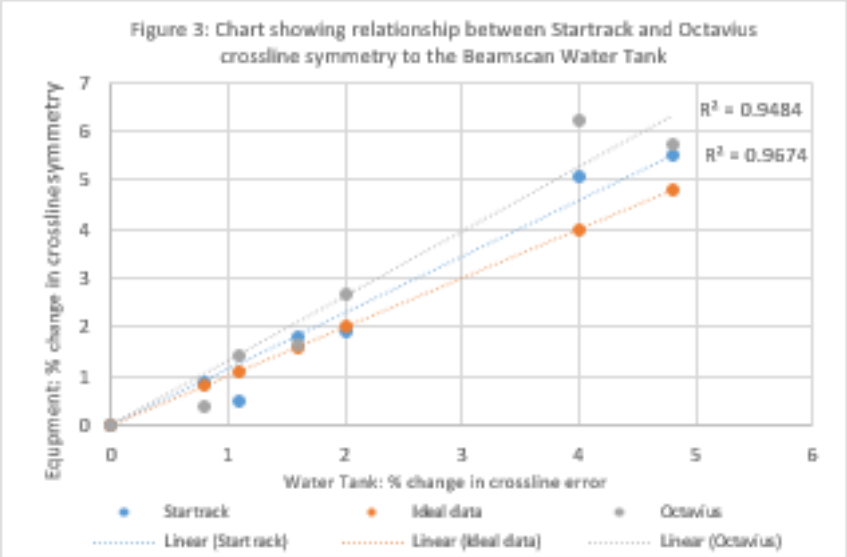

Figure 3: Chart showing relationship between Startrack and Octavius crossline symmetry to the Beamscan Water Tank

A Multi-Institutional Evaluation of a Novel 3D-Printed Phantom for Daily 6DoF QA Checks

Hannah Marshall[1], Tamil Selvan[2], Raymond B King[2], Reem Ahmad[3], Mariana Bento[3], Catarina Veiga[3], Gordon Sands[4], Ciaran Malone[5], Catharine H Clark[3,4,6], Conor K McGarry[1,2]

Keywords: 3D-printing, phantoms, quality assurance, 6DoF

Aims: To validate a novel 3D-printed phantom for use in daily quality assurance (QA) of a 6 degrees-of-freedom (6DoF) treatment couch and to demonstrate the reproducibility of 3D-printing in phantom production for radiotherapy applications across multiple centres.

Methods: A phantom (Figure 1) containing complex high-contrast cube structures and alignment crosshairs, with and without pre-defined rotational offsets, was 3D-printed at five centres utilising several different 3D printers and manufacturers of Polylactic Acid (PLA) filament. CT images were acquired of each phantom to obtain both geometrical measurements and HU (Hounsfield Units) of the internal structures.
Daily translational alignment and rotational couch correction testing was performed on a Varian TrueBeam STx (v.2.5) using one of the phantoms for a period of 20 months, with inter-comparison of all other phantoms performed to demonstrate reproducibility. The phantom was setup to recessed markers on its surface to within ±2mm, a kV-CBCT was acquired, and image registration was performed by 3D-3D matching using HU thresholding. Correctional couch shifts were applied and recorded, with verification of position using laser alignment to central crosshairs.

Results: Rotation (rot), pitch and roll correctional shifts were within ±0.3° from the designed offset values of 3.5°, 1.5° and -2.5° respectively, over the 20-month measurement period. The average rot, pitch and roll measurements were 3.25±0.12°, 1.28±0.24° and -2.32±0.17° respectively (Figure 2a). Dimensions of the internal cube structures were on average 4.17±0.04cm (Figure 2b), with average HU of 186±23.

Conclusions: 3D printing can produce phantoms capable of sub-degree 6DoF couch correction. Phantoms printed from a single origin file can perform consistently in QA, where the vast availability of 3D-printable thermoplastics allows for easy customisation. The relatively low cost of 3D printing could provide opportunity for this method of phantom production to be utilised in low and middle-income countries, as well as for multi-centre audits.

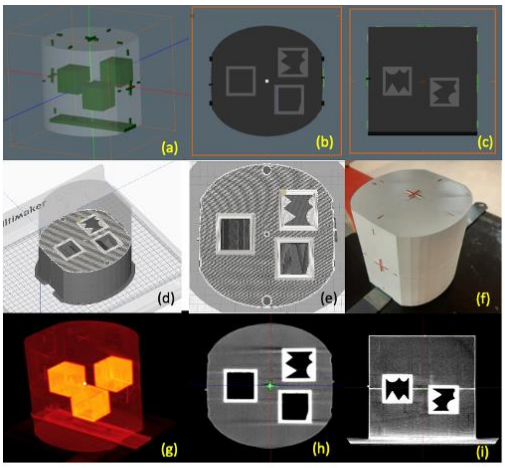

Figure 1: Series of images demonstrating the development process of the 6DoF phantom. Initial virtually designed phantom (a-c) is shown in slicer software for 3D-printing (d). The exterior of the printed phantom with alignment marking is shown in (f), followed by CT slices demonstrating the complexity of the interior structures.

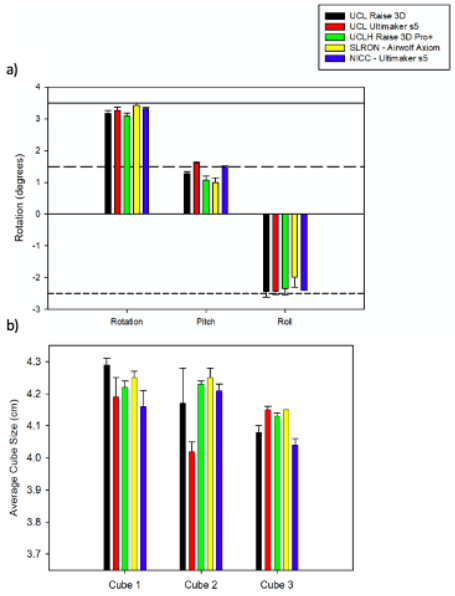

Figure 2: a) Average rotation, pitch and roll corrections for five independent PLA phantoms b) The average size of each cube structure, across all three dimensions, for all five phantoms.

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Investigation of Beam Central Axis Position Offsets Using an Automatic Analysis Tool with an EPID Panel

Sam Baker[1], Patrick Downes[1] and Michael Thomas[1].

Keywords: beam steering, central axis, EPID, quality assurance

Background: Beam focal spot alignment is a crucial element of accurate and consistent radiotherapy treatment. With the increasing prevalence of treatment techniques with a need for high geometric accuracy such as SRS and SABR, it is essential to test and optimise such parameters effectively. Patient specific plan verification methods, such as deliveries to the Delta^4 phantom or EPID dosimetry, have highlighted the significance that small positional offsets can have on the expected dose distribution [2]. Inter-fraction motion, which is similar in result to focal spot misalignment, has been well studied and can have a significant effect on tumour control probability [1]. Thus, any reduction in positional offsets of delivered beams is beneficial.

Aim: Previous investigations into the beam focal point have concentrated upon single energies [3, 4]; while these provide valuable insight into the behaviours of these beams, this work aims produce a software tool to introduce a fast check of the beam's central axis across the three clinical MV photon energies (6MV, 6FFF, and 10MV) in daily or weekly quality assurance procedures. A comparison between energies is valuable because 6MV beams alone are generally used for MLC and isocentre calibration. The other energies, particularly 6FFF, are also used for high-precision treatment and thus their offsets from the 6MV beam are relevant in clinical use.

Methods: The emphasis of the method was on ease of use and speed. By employing the EPID panel for the measurement, no additional equipment setup would be required and positioning errors are reduced significantly. Exposures of 40MU 10x10cm fields were imaged using the iView EPID panel for the three energies at gantry angle 0^o and collimator angle 0^o. Two methods were used to determine the central axis of the beams from an average of the three central pixels of the images in both the x and y directions: by finding the 50% dose level or the inflection points of the penumbra (recommended for unflattened beams [5]). The central axis was identified as the average position between them in each case. Offsets relative to the 6MV beam could then be reported for analysis.

Results: The offsets were calculated across several Elekta VersaHD machines using both calculation methods. These were found to agree within 0.2mm, which is expected due to the resolution of the iView panel with a pixel width of 0.25mm. An independent tool was then used to confirm the validity of these results.

Conclusions: An automatic beam offset assessment tool was successfully developed. Two analysis methods were developed for determining the central axis of the beam and both were confirmed against an independent tool, giving confidence in the results. This tool can be introduced to daily QA procedures to monitor the variation of beam offset over time, giving additional information especially for investigations into failed verification plan delivery on the Delta^4.

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ALETRI: A Novel Phantom for Triggered Imaging Auto Beam Hold

Alexandros Pagonidis, Tristan Wright, Brian Gibson

Keywords: Truebeam, triggered imaging, auto beam hold, phantom, quality assurance

Background: Triggered imaging (TI) - Auto Beam Hold (ABH) is a function of Truebeams which acquires an x-ray image every 30 degrees gantry interval to monitor if the patient's implanted marker-seeds (fiducials) are in place and allows or holds the treatment beam accordingly. A phantom to daily test the safety of TI-ABH function was requested for the PACE-C clinical trial.

Methods*:* ALex and TRIstan designed and constructed a small, portable, inexpensive, reproducible phantom called ALETRI that avoids metallic artefacts caused by motors and drive-shafts when simulating lateral, longitudinal and vertical (XYZ) marker-seed motions. ALETRI is a Perspex cube containing capsules with implanted silver seeds, driven in all directions pneumatically by micro-pumps. The first micro-pump retracts the capsules to the initial position and the second one extends them away inside the cube. To make ALETRI more user-friendly we made it wireless by using the Dual Tone Modulated Frequency (DTMF) communication protocol via the existing intercom speaker with the help of a microphone for detecting the audible signals. Next, the signals are decoded and fed to a microcontroller that activates the micro-pumps. The DTMF generator casing was 3D printed in-house.

Results: A dedicated QA patient plan was developed and the ALETRI prototype successfully triggered a live TI-ABH on demand via a push button attached on a long cable. We also achieved the ability to remotely trigger the functions 'extend', 'retract' and 'stop' wirelessly by dialling the DTMF commands 'D1#', 'D0#', 'DD#' respectively.

Discussion: At the time, commercial phantoms were found less than ideal for daily checking multiple Truebeams. The CIRS thorax phantom moves the markers on demand but it is bulky, has long cables and a computer running the software which makes its set up time consuming. The Markerblock phantom can trigger a beam hold, but not remotely since the operator must move this phantom manually mid-treatment. This movement also causes a shift a lot bigger than the 7mm range the ABH detection algorithm is set to. Currently our DTMF communication protocol works, but the micro-pump's noise is interfering with detection, something our team is still working on.

Conclusions: At Edinburgh Cancer Centre we succeeded in developing a novel phantom that is easier and faster to set up compared to CIRS, with the extra feature of remotely triggering an ABH on demand, something not available with the Markerblock phantom. Work is on-going to refine the design and the code and to produce a 3D-printed version of ALETRI and integrate it into routine machine QA. The DTMF protocol helps bypass special IT privileges and could benefit future projects. ALETRI is an easy to use, cheap, open-source solution that every radiotherapy department could utilise since it has clear advantages over the commercially available phantoms.

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Introduction to Part-Time PhD Project: Developing an Evidence-Based Approach to Neonatal and Paediatric Radiation Dose Optimisation Methods

Belinda Gorell

Keywords: dose optimisation, ionising radiation, audit, paediatric, neonatal, radiation risk management

Imaging with ionising radiation is an integral part of paediatric and neonatal healthcare. Whilst the use of ionising radiation is fundamental to modern diagnostic medicine, it causes cellular damage with the potential to become cancerous. This risk is of greater significance for children, because of their increased radiation sensitivity and longer life-expectancy compared to adults.

Optimisation is the concept that seeks to balance the need for diagnostic quality images, while keeping the radiation dose delivered as low as reasonably practicable. Despite the legal requirement for paediatric optimisation, there is a paucity of evidence available regarding how to practically optimise paediatric imaging. There is also a lack of national standardised paediatric diagnostic dose reference levels to guide local optimisation.

This study will firstly audit current patient exposure factors, dose indicators and referral guidelines for paediatric imaging in South-East Wales NHS UHBs. Novel optimisation techniques will be undertaken with specifically designed test objects (with consultant radiologist input) to identify and reduce unwarranted variation in procedures and radiation dose. This work would permit the development of paediatric diagnostic reference levels including specialist imaging undertaken at the Children's Hospital for Wales. This project will also explore the generation of paediatric radiation doses (using computer modelling techniques), as a basis to consider the communication of radiation risk and benefit to patients and parents/guardians as mandated under medial exposure regulations.

Children are not "small adults" and a "one-size-fits-all" approach is neither applicable nor appropriate. This is the guiding principle that would be central to the research.

Determining Bone Position Using Microwave Imaging: A feasibility Study

Vignesh Radhakrishnan, Martin Robinson, Peter Ellison, Samadhan B Patil, Adar Pelah

Keywords: microwave imaging, movement analysis, soft tissue, antennas, Sim4Life

Background: Errors in bone position estimation, due to movement of underlying soft tissues in clinical skin-mounted marker-based systems, are the most critical source of error in movement analysis. Fluoroscopy is used to ameliorate these errors, but its adoption is limited due to high costs and its highly ionising nature (1,2). Microwave imaging, a low-cost, non-ionising imaging modality, whose application in breast tumour detection has been widely researched (3), has been increasingly used in studies for detecting strokes, brain-haemorrhages, fractures and in determining the variation in bone properties due to osteoporosis and osteopenia (4,5).

In this study we analyse the feasibility of detecting bones using microwave imaging.

Methods: Simulations were implemented using the finite-difference time-domain solver in Sim4Life (6) (Figure 1). Seven wearable antennas (7) were placed around the thigh of a virtual population model, Duke. Three multiport simulations were performed with the dielectric properties of the right femur varied to match that of bone, muscle and air. Scattering parameters were calculated in Sim4Life and the results were plotted.

Results: Variation in magnitude, resonant frequency and phase were observed in the scattering parameters when the bone dielectric properties were switched between bone, muscle and air, with greater variations between muscle and bone/air (Figure 2). Diametrically opposite antennas show increased variation. Electric field penetration in to the thigh is shown in Figure 3.

Discussion and conclusions: Variation in scattering parameters has been used to indicate the presence of strokes, fractures and to show variation between osteoporotic and normal bones (4,5). Our results show differences in scattering parameters when the bone dielectric properties are varied, indicating the presence of the bone. The variation in scattering parameters, and penetration of electric field into the thigh, is dependent on the location of the antenna, which underscores its morphological dependence. We hypothesise this information can be used to determine the position of the bone relative to the antenna attached to the subject's skin. Here we have shown that microwave imaging using wearable antennas, without any coupling medium, can be used to detect the presence of the bone, which can aid in accurate movement analysis.

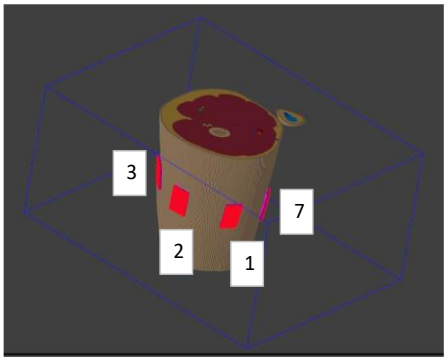

Figure 1: Voxels of right thigh with antennas in Sim4life.

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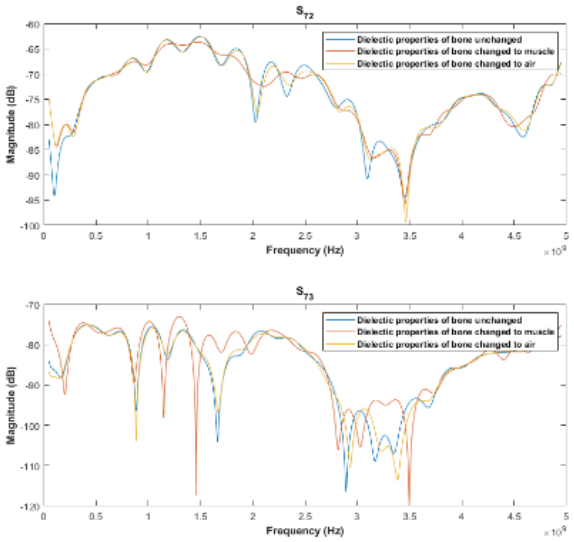

Figure 2: Scattering parameters variation across 3 simulations

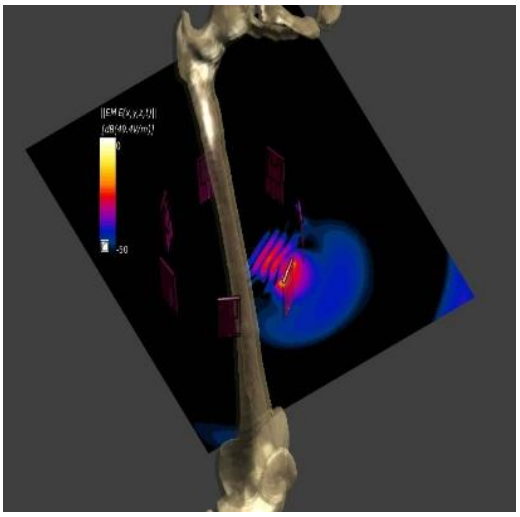

Figure 3: *Penetration of E-field into the thigh from antenna 7*

Dosimetric and Volumetric Effects of End Expiration Breath Hold Radiotherapy for Oesophageal Cancer

Christopher Mayhew, Jeyaanth Venkatasai, Marina Khan, Benson Leung, Kasia Owczarczyk, Georgios Ntentas

Keywords: EEBH, free-breathing, lower oesophageal cancer, organs at risk, volumetric effects, dosimetric effects

Purpose and objective: Respiratory gating using end expiration breath hold (EEBH) radiotherapy has the potential to reduce tumour motion during treatment in tumours near the diaphragm. This may obviate the need for an internal target volume (ITV), and reduce the dose to organs at risk (OAR) such as the heart, lungs and liver by repositioning them with respect to the target volume compared to free-breathing (FB) radiotherapy using 4DCT. The aim of our study was to evaluate the dosimetric and volumetric effects of EEBH in patients with oesophageal cancer undergoing (chemo)radiotherapy.

Materials and methods: Thus far, 12 lower oesophageal cancer patients have been planned for, using volumetric modulated arc therapy (VMAT) in both FB and EEBH scans. For patients treated in EEBH, clinicians created a new set of target volumes on the FB scans and vice-versa. New treatment plans were retrospectively generated for the non-clinical CT & structure set. The plans were optimised and evaluated in order to be comparable to the original clinical plan. All plans were reviewed and approved by clinicians using the same criteria. Paired t-tests were performed to examine within-patient volumetric and dosimetric differences.

Results: Of the 12 patients, 10 were male and two female with a median age of 73.5 years. 10 patients presented at stage T3 and two at T2, with the prevailing histology being adenocarcinoma (10/12). 11 were treated with EEBH and one in FB. Volumetrically, we observed a mean PTV volume reduction of 61.8cc [p=0.002] for EEBH plans compared to FB (Table 1). Heart/PTV overlap volumes were reduced by 1.21% [p=0.024] and Lung/PTV overlap volumes by 0.28% [p=0.010] between EEBH and FB plans. Dosimetrically, mean heart doses reduced by 0.75Gy [p=0.231] with EEBH but not with statistical significance, with lung and liver mean dose reductions of 0.61Gy [p=0.086] and 0.76Gy [p=0.096] respectively.

	Mean PTV Volume /cc (Range)	Mean Heart/PTV Overlap Volume as a percentage of heart volume /%	Mean Lung/PTV Overlap Volume as a percentage of lung volume /%	Mean Liver/PTV Overlap Volume as a percentage of liver volume /%	Mean Heart Dose /Gy	Mean Lung Dose /Gy	Mean Liver Dose /Gy
EEBH	381.1 (132.0-821.0)	4.20	0.29	1.29	17.85	7.26	10.65
FB	442.9 (153.8-904.8)	5.42	0.57	1.53	18.61	7.87	11.41
Difference (p-value)	61.8 (0.002)	1.21 (0.024)	0.280 (0.010)	0.246 (0.266)	0.751 (0.231)	0.609 (0.086)	0.763 (0.096)

Table 1 – Average volumetric and dosimetric results for comparison between EEBH and FB for lower oesophagus RT

Conclusions: Our study is one of the first to examine the dosimetric and volumetric effect of the EEBH technique in patients with oesophageal cancer. EEBH presents a promising method for reducing PTV volumes, as well as OAR doses. This, combined with the increased stability in motion that EEBH assures, compared to that of FB, may show EEBH as an effective breathing technique for optimising radiotherapy in oesophageal cancer treatment. Further work is ongoing to investigate the significance of current results in a larger patient cohort.

Comparison of Secondary Cancer Development in Rectum and Bladder After Prostate Radiotherapy, Between VMAT and SABR Regimes

Maria Koutrouli, Dr Claire-Louise Chapple, Dr Judith Mott

Keywords: secondary cancer, radiotherapy, high-dose risk, prostate, bladder, rectum

Background: Radiotherapy is one of the main forms of treatment for prostate cancer, which is the most common cancer in males in the UK, while it has a high survival rate. [1] Since the association of malignancy appearance and exposure to ionising radiation is a well-established one [2, 3], there are concerns regarding the development of secondary radiation-induced cancers to long-term survivors, and especially to bladder and rectum, which are partially inside the primary beam during treatment. [4, 5] This work aims to compare the excessive from baseline risk of secondary cancer development due to radiation exposure in bladder and rectum, between two different prostate regimes currently in use: conventional and stereotactic ablative body radiotherapy (SABR), to 147 patients, with ages ranging from 50-70 years old.

Methodology: Retrospective anonymised DVH and age data of 148 prostate cancer patients that have already been treated with one of the two different regimes, were used. Using the models developed by Schneider et al. [6] (mechanistic, bell-shaped and plateau) lifetime attributable risk (LAR) for the development of secondary radiation – induced cancer, in prostate patients, in bladder and rectum, which were partially in the primary irradiation beam, was calculated. The excessive to baseline relative risk (ERR) was derived for each individual, and mean values of the two regimes were compared statistically, using t-test.

Results and discussion: Results of this work showed that average individual relative excessive risk of secondary cancer development at rectum, for conventional VMAT regime, is considerably higher than the respective risk for SABR regime. On the other hand, no significant difference was observed between the risk of secondary bladder cancer induction caused by the two different regimes. This information could be especially helpful when optimising dose constraints for each organ, especially for conventional regime, which results to higher radiation dose to the two organs. Bladder is capable of receiving higher amount of dose without the associated risk of secondary malignancy induction increasing significantly, whereas increase in dose received by rectum has a significant respective impact, something that could be reflected in the two organs in the regime protocol. This results are in agreement with the literature. [6].

Conclusions: ERR was found to be higher for VMAT regime compared to SABR for both bladder

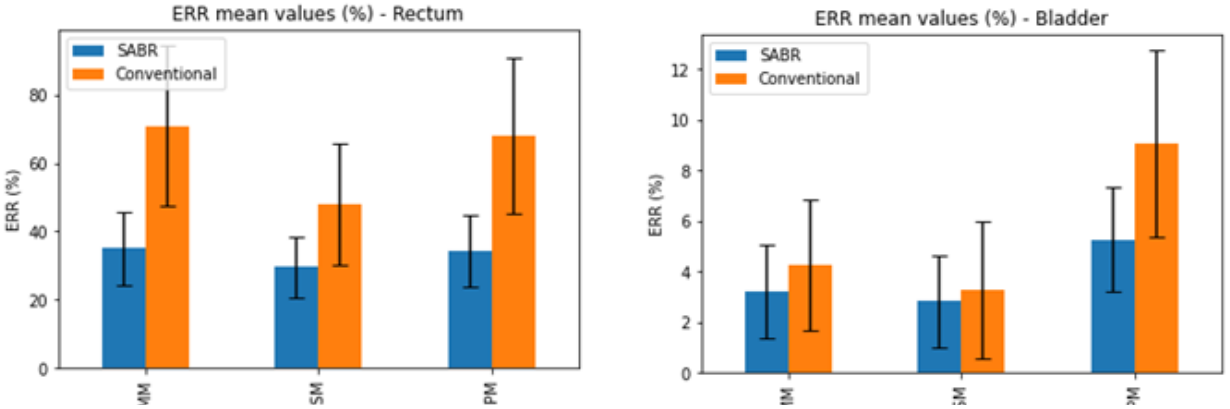

Figure 3: Mean bladder ERR (excessive relative risk) values and standard deviation of the two regimes. All differences in rectal ERR values were found to be statistically significant (p-value <0.5). All differences in bladder ERR, were not found to be statistically significant.

and rectum, which was expected, as VMAT includes a higher prescribed and consequently, delivered dose. However, all differences were found to be statistically significant for rectum, and not statistically significant for bladder. This can be indicative of the different organ behaviour in secondary cancer development due to radiation in high doses, and can be potentially utilised to building more effective radiotherapy plans, especially for patients with good prognosis.

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A Study on Skin Doses in Interventional Cardiology

Alice Gutowski, Christie Theodorakou

Keywords: high dose interventional cardiology, skin dose, radiochromic film

Background: Interventional cardiology procedures are x-ray image-guided procedures which are used to diagnose and treat pathologies in the heart. They can be complex and are associated with high radiation doses [1], which can result in radiation-induced injuries to radiosensitive organs such as the skin [2]. Skin radiation-induced injuries occur above certain dose thresholds, where the severity is directly proportional to the dose and the onset of injuries can vary from hours to several years [3]. As these effects are not immediately observable, standardised methods are needed to determine whether thresholds have been exceeded to enable patients to receive appropriate aftercare [4,5]. The aim of this study was to measure skin dose for complex interventional cardiology procedures and identify thresholds set based on dose indicators provided by the x-ray system, above which it would be expected that skin injuries would develop.

Methods: Skin dose was measured using radiochromic films for percutaneous coronary interventions and coronary total occlusions. A reproducible, standardised and accurate film calibration methodology was developed for two x-ray systems, which included characterisation of backscatter, film attenuation and the energy response of the film. When used to measure patient skin dose, the dose parameters of the procedures were recorded alongside non-identifiable patient information.

Results: Using the data collected for 28 patients, preliminary results from this study indicate an average peak skin dose (PSD) of 1.95 (0.09 - 9.22) Gy, dose-area product (DAP) of 83.6 (8.40 - 290) $Gycm^2$ and air kerma of 1.76 (0.07 - 8.75) Gy, where the range is indicated in brackets. Regression analysis of the relationship between patient PSD and dose indicators has shown that DAP is the most significant predictor of PSD ($p<0.01$). A PSD of 2 Gy was found to correspond to a DAP of 84 $Gycm^2$ and an air kerma of 2 Gy. This has also built upon previous published work [4] to investigate the extrapolation of relationships at higher doses.

Discussion: The results show that the DAP has a better correlation with PSD than any other dosimetric indicator, likely due to repeated acquisitions at the same projection angle, but more data will be collected to validate these correlations. The results can be implemented as a threshold in high skin dose policies to act as a trigger where these skin doses have been exceeded. This can also be used to inform justification and consent to enable compliance with IR(ME)R.

Conclusion. Skin doses were measured for two high dose interventional procedures using a standardised, reproducible and accurate calibration methodology. Preliminary results of this study indicate DAP is the most significant predictor of PSD. More data is needed to validate the correlations found; however, this project has built upon previous work to investigate the extrapolation of relationships at higher doses. The thresholds suggested by this data to correspond to a PSD of 2 Gy are 84 $Gycm^2$ in terms of DAP and 2 Gy in terms of air kerma.

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Facilitating Intra-Operative MR QC via 3D Printing

Robert Williams[1], Tristan Wright[2], Stuart Jamieson[3] and Gillian MacNaught[1]

Keywords: imaging, quality control, MRI, 3D-printing, neurosurgery

Background: Magnetic Resonance (MR) Imaging has long been the key modality for planning neurosurgical interventions. More recently, intra-operative MR (IOMR) has afforded the ability to monitor surgical outcomes in near real-time, resulting in improved prognoses for adult and paediatric patients undergoing surgery for neuro-oncology and epilepsy treatment [1,2]. There is a paucity of published guidance regarding QC of IOMR systems; however close analogies exist with the use of MR in radiotherapy planning, where geometric fidelity is crucial [3]. The IOMR suite in Edinburgh comprises a Philips 3T scanner room adjacent to a surgical theatre, commissioned in late 2021. The complexity of the workflows and specialist equipment required for IOMR has hindered attempts to fully commission and perform routine QC of the dedicated IOMR imaging coils. Since certain components require sterilisation prior to any live case, the manufacturer recommends a QC setup for the NORAS* IOMR head coils which uses sandbags and foam pads to support the coils and test object on a flat couch overlay. However, this arrangement is found to be unstable, introduce image artefacts and preclude reproducible image quality measurements for QC purposes.

Methods: This project sought to facilitate reproducible QC of IOMR head coils by using 3D printing to create a bespoke frame to hold the NORAS IOMR head coils. A working prototype was printed using fused deposition modelling with a Raise3D printer and Polylactic Acid (PLA) filament. This frame enables the reproducible acquisition of QC images to ensure consistent coil performance both for routine QC and checks prior to each live IOMR case. Image quality from the head coils was assessed quantitatively using MagNET test objects and methodology [4].

Results: The prototype frame was found to successfully support the NORAS coils, provide a solid base to rest upon the IOMR scanner couch overlay and securely integrate with the upper NORAS components (Figure 1). The design enables per-patient QC to be performed without the sterile components kept in surgical theatre on the day of live-cases. Image quality, quantified via signal-to-noise ratio and uniformity, using the frame is found to be comparable to that obtained using the fully assembled NORAS setup.

Conclusions: 3D printing has enabled in-house production of a bespoke frame to mount IOMR head coils and imaging phantoms. This frame will facilitate simple and reproducible assembly of the NORAS coils, enabling complete commissioning and QC to ensure consistent coil performance for each surgical case. This will ensure radiography colleagues can confidently perform reproducible coil QC within the considerable time constraints prior to an IOMR case, and ultimately help deliver the superior therapeutic outcomes associated with the use of IOMR. Further work is required to finalise commissioning, including the thorough assessment of geometric image fidelity that is critical for the integration of IOMR images with neuronavigation systems used to guide surgery.

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Intro to Scottish Training, Hybrid Training and Experiences

Stephen Gandy[1]

Keywords: SMPCETS, training scheme, Scotland, HCPC registration, STP equivalence

In this 30-minute talk I will provide an operational overview of the Scottish Medical Physics and Clinical Engineering Training Scheme (SMPCETS), where we deliver clinical scientist training leading to HCPC registration via the STP Equivalence route through the AHCS. I will focus on recent training developments and explain how we have carefully introduced an element of hybrid training to support emerging areas where there is an identified clinical need. Finally, I will take a brief look at future opportunities and challenges facing Medical Physics and Clinical Engineering training in Scotland, prior to participating in a discussion session.

[1]NHS Tayside

The Impact of Environmental Sustainability Issues on a Brachytherapy Practice

Gerry Lowe[1], Victoria Newton[1]

Keywords: environmental sustainability, climate change, brachytherapy, Greener NHS

Background: It is well known that we face a climate and environmental crisis[2], and many organisations such as WHO[4] and the UN are warning that sustainability and healthcare issues are connected. The NHS is a significant contributor to UK greenhouse gas emissions and has launched the "Greener NHS" initiative to address this.[3] This work considers how this can be implemented in a brachytherapy setting.

Methods:

- Trust staff were surveyed to gauge interest in and awareness of sustainability issues. A further survey of commuting methods was conducted within Radiotherapy Physics.
- Staff awareness was raised by a "Green Ambassador" scheme.
- Inappropriate waste segregation in theatres and the brachytherapy suite was addressed.
- Power used by IT equipment was measured, and a practice of minimising power waste was implemented.
- Discussion with two suppliers regarding sustainability of packaging was initiated.

Results:

- Trust-wide, staff reported >90% very or extremely concerned with sustainability but only 10% were aware of the "Greener NHS" initiative.
- Improved waste segregation has been achieved in the brachytherapy suite and in theatres. Suppliers have been involved in discussion regarding packaging sustainability.
- Power waste has been reduced by avoiding screens which blank but without "sleeping", saving 50 – 80W/screen. PCs were observed to "sleep" down to <1W in some cases, but 40W in others. Departmentally, optimising power use saves at least 12 kg CO_2 equivalent (CO_2e) per week.[1] Theatre air handling power is also being optimised.
- Improvements in IT links to theatres are projected to reduce the paper use in our clinical pathways, saving a small but significant amount per patient. This has yet to be fully implemented; issues such as resilience of the data storage, and ease of access need to be addressed.
- 23 responses were received from Physics staff about commuting. 70% travel by car with an average 11.2 mile journey each way. Per week, in brachytherapy, remote working saves 2 – 3 return car journeys, or about 15 kg CO_2e (EBRT planning allows more flexibility and around 70 kg CO_2e per week are saved by remote working).

Discussion: The "Greener NHS" initiative, and the NHS net zero ambition, depends for its success on the awareness and support of all NHS staff. Changes to improve environmental sustainability will also often be financially beneficial (e.g. correct waste segregation). Some changes can be made quickly; however, there is a need for ongoing effort. CO_2e savings above are significant, especially because the brachytherapy team is relatively small. In cases like power use this can be successfully replicated in the larger radiotherapy physics department.

Conclusions: Sustainability improvements are both necessary[4] and possible. A range of measures is needed; early results are reported, although ongoing effort is needed.

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[1]Mount Vernon Cancer Centre, Northwood, Middx HA6 2RN

Heuristic Evaluation of portable pulse oximeters for domiciliary use: implications and guidance for its use in assessing medical device usability

Chloe Black

Keywords human factors engineering, usability, heuristic evaluation, medical devices, pulse oximetry

Aims and background: Medical device manufacturers must consider usability during medical device design to minimise the risk of harm associated with user error. However, in home care pathways, devices may be adopted in contexts unforeseen by manufacturers. Where devices are used without supervision of a healthcare professional, usability is more important. The first aim of this research was to use Heuristic Evaluation (HE) to assess the usability of pocket pulse oximeters used in NHS home pathways. The second aim was to investigate the value of heuristic evaluation as a tool to assess medical device usability.

Methods: 10 heuristic evaluators independently assessed 5 portable pulse oximeters using 15 heuristics. Evaluators identified device features that violated heuristic 'principles' of design. Usability scores were calculated for each device, accounting for the number of heuristic violations and their associated severity (risk) score. The value of HE to assess device usability was assessed by manipulating data to account for methodological limitations.

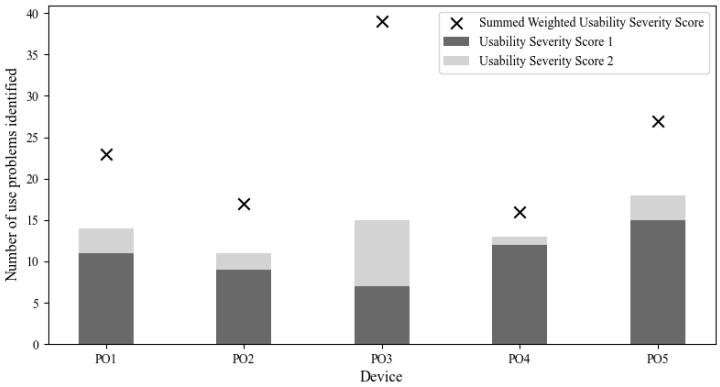

Figure 1: Usability Severity Scores for each device model assessed. Higher score equates to worse usability.

Results: A total of 42 unique use problems were identified across all devices. 76% of use problems received the lowest severity score (1). We identified limitations in the methodology used and suggested modifications to improve the evaluation process.

Conclusions: HE pre-empted use problems and allowed for quantitative usability comparisons between devices. We found value in HE used to objectively identify device design flaws, particularly with the minor modifications to improve the evaluation process

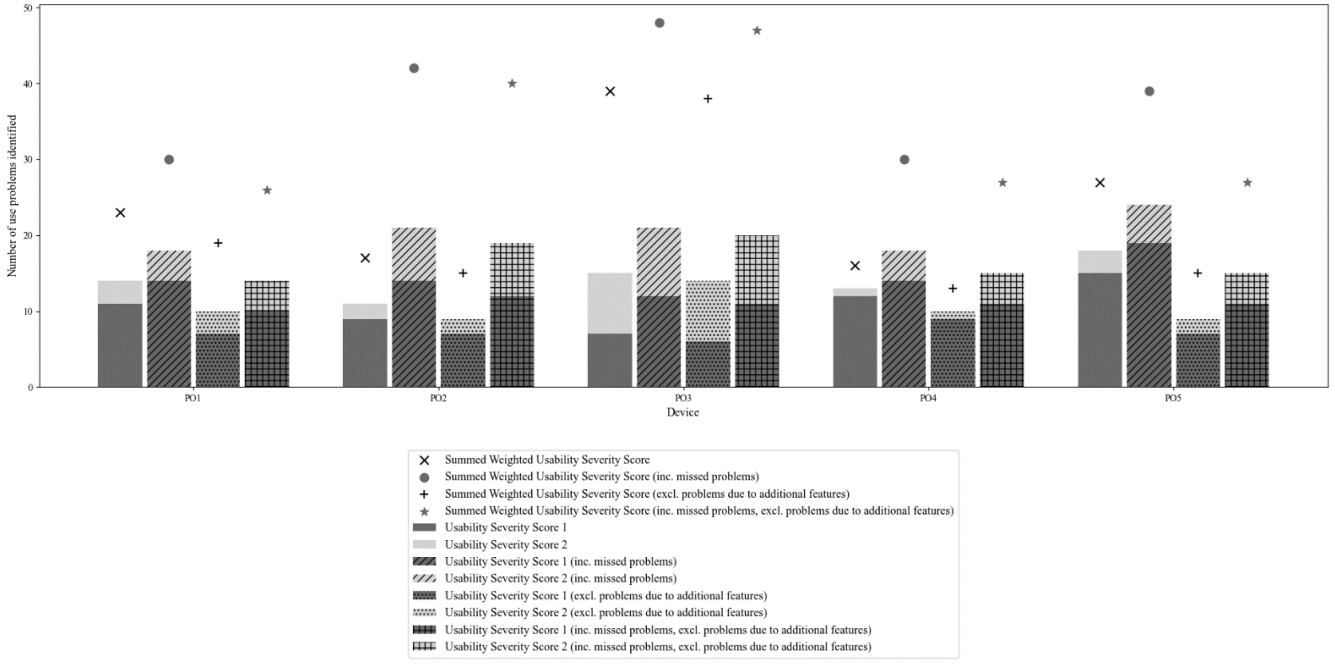

Figure 2: Effect on pulse oximeter usability severity scores when accounting for use problems which were present but undetected on other device models, and use problems that were directly linked to features which provided increased functionality compared to other models.

Measuring Quantitative ADCs with the Caliber MRI Diffusion Phantom

Emily Kilgour[1], Mark Pether[1]

Keywords: quantitative MRI, DWI, ADC values

Background: Quantification of apparent diffusion coefficient (ADC) has many promising clinical applications, for example in identifying, staging, and quantitatively monitoring treatment response in prostate cancer. For ADC values to be meaningful clinically, they must be shown first to be accurate and reproducible. This work aimed to examine the accuracy of ADC values produced clinically at NHS Grampian. An investigation into single scanner reproducibility was also made.

Methods: A commercial diffusion phantom manufactured by Caliber MRI [1], consisting of 13 vials of different concentrations of water and PVP solution and built-in MR-readable thermometers, was used to investigate the accuracy and reproducibility of ADC values measured using 4 clinical MRI scanners in Aberdeen (2 x 1.5T Siemens Avanto (MRI West and Hutchison), a 1.5T GE 450W Optima and a 3.0T Philips Acheiva dSTREAM). In Phase One of the project, the standard clinical prostate diffusion protocol (using diffusion weightings b = 0, 600, 1100 s/mm^2) was run on each of the scanners and the measured average ADC values for regions of interest (ROIs) of consistent size covering each vial were compared with the expected ADCs for each vial provided by the phantom's manufacturer. This allowed the accuracy of ADC values to be investigated.

In Phase Two of the project, a standard diffusion sequence (using 4 b values ranging from 0 to 2000 s/mm^2) provided by Caliber MRI was run on the 1.5T Siemens Avanto scanner at MRI West, Aberdeen Royal Infirmary. The sequence was repeated 10 times to investigate the reproducibility of the average ADC values of ROIs (size 400 mm^2). The reproducibility was quantified by calculating the coefficients of variation across runs for the same ROI and ROIs at different slice heights within the same vial in the same run.

Results and discussion: The results from Phase One are shown in Figure 1. The estimated difference between measured ADCs and the expected value for each scanner is shown.

	Percentage uncertainty using standard prostate sequence
MRI West & Hutchison 1.5 T (Siemens Avanto)	$\pm 5\%$ for ADC $> 800\times10^{-6}$ mm^2/s $\pm 20\%$ for ADC $< 800\times10^{-6}$ mm^2/s
Philips 3.0 T (Achieva dSTREAM)	$\pm 5\%$ for ADC $> 800\times10^{-6}$ mm^2/s $\pm 10\%$ for ADC $< 800\times10^{-6}$ mm^2/s
GE 1.5 T Optima	Up to 15% larger than expected for ADC $> 800\times10^{-6}$ mm^2/s Up to 30% larger than expected for ADC $< 800\times10^{-6}$ mm^2/s

In Phase Two, the average coefficient of variation for the Caliber sequence for 5 slices of each vial across 10 runs was 3.0%. Some vials had particularly large CoVs resulting from ghosting artefacts, but this effect was reduced by increasing the parallel imaging factor from 2 to 3 and the experiment was repeated, achieving an average CoV across all vials of 1.1%. The variations between the same region of interest over runs and spatially over different slices of the same vial were apparently random, both with CoVs of 1%. It was noted that the ADCs measured for the vials containing water were consistently around 20% lower than the expected values provided by the manufacturers, significantly worse than the variation from expected values achieved using the standard prostate sequence on the MRI West scanner. In general, the measured ADCs were highly dependent on the scanning sequence used.

Conclusions: Using the standard prostate protocol, ADCs were measured to within 10% with Philips Acheiva dSTREAM, 20% with Siemens Avanto and 30% with GE Optima compared with the expected values, although ADC measurements were more accurate for higher ADCs. This should be sufficiently accurate to

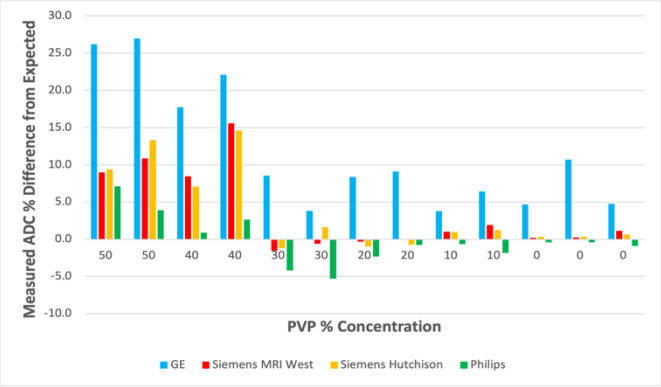

Figure 1: ADC accuracy across the four scanners. High PVP concentration corresponds with low ADCs and vice versa

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distinguish between tumour and healthy tissue, but quantification of treatment response may be more difficult, and ADC accuracy was highly dependent on the chosen scanning sequence. Artefacts must be eliminated for good quantification. The average variation across repeated executions of the same pulse sequence was 1.1%, indicating good reproducibility within sessions.

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Design and Development of an Intra-Oral X-Ray Test Object – Improving Image Quality Assurance in Dental Practices Across NHS Tayside

Caitlin McQueenie[1], Mark Worrall[1], Jaroslaw Zawacki[1], Julia Faerber[1]

Keywords: image quality, 3D printing, X-ray, dentistry

Background: The Radiation Physics department supports over 50 private dental practices and 16 different sites of NHS Tayside's public dental service. Each of these has multiple intra-oral x-ray units. This creates a requirement for easily sourced cheap intra-oral dental test objects for use by clinical users in-between visits from Radiation Physics. Regular testing would ensure that any equipment issues that may arise are discovered and reported in a timely manner meaning the quality of dental diagnostic radiology services remains consistent. Initial work locally indicates that with 70% rectilinear infill, a 3D printed object with 1.75 mm silver PLA material attenuates x-rays to a similar degree as Solid Water. This suggests that it has potential for the creation of meaningful test objects for radiography that could provide a quick visual check of image contrast and spatial resolution.

Methods: Initially, user research was carried out to identify the essential and desirable requirements. An iterative design and testing approach was utilised to optimise the design for the proposed application. Design was completed using Autodesk Inventor Professional 2023 (Autodesk, California, USA) software and was printed using a Prusa i3 MK3S (Prusa, Prague, Czech Republic) in 1.75 mm silver PLA material.

Results: Radiographic exposures at varying parameters identified an optimised design (figure 1). The design incorporated a step wedge and holes of varying depth and diameter to allow assessment of threshold contrast detail detectability.

Conclusions: A suitable test object was successfully designed and produced using 3D printing technology. According to the slicer software, each test object will take 2.25 hours to manufacture and approximately 11.93 m (35.59 g) of PLA to print – a cost of £1.01 per test object. When compared to the commercially available test object (DENTEST, Leeds Test Objects), this is a saving of around £408 per test object.

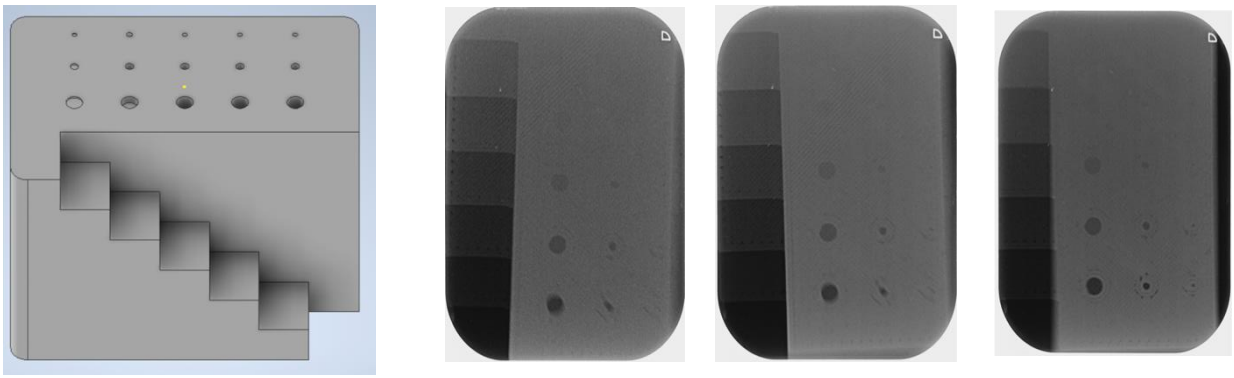

Figure 4: 3D model of the final test object design and radiographic exposures of the test object at varying tube potential, tube intensity and exposure time.

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Development of Methods to Predict Adaption Requirement in Lung Radiotherapy Using Cone Beam CT (CBCT)

Claire Lesley Fletcher[1], Jane Rogers[2], John Duffy[3]

Keywords: cone beam CT, lung toxicity, adaptive radiotherapy

Background: Radical Lung radiotherapy treatment in the UK usually consists of 55 Gy in 20 fractions. At University Hospitals Coventry and Warwickshire NHS trust (UHCW) a CBCT is performed immediately prior to each treatment fraction to position the patient accurately. During the course of treatment, a variety of changes are frequently seen in the either the tumour or lung, but such changes do not routinely lead to any adaptation of radiotherapy treatments.

This project uses data extracted from daily CBCTs to determine parameters which can be further investigated clinically to potentially adapt radiotherapy during a treatment course to reduce toxicities and/or increase tumour control.

Methods: An initial sample of 29 patients treated between 2018-2019 at UHCW was used to develop techniques which will subsequently be used with a larger patient cohort.

Deformable registration of CBCTs to the planning CT was performed in the RayStation treatment planning system for all patients. The gross tumour volume (GTV) and organs at risk (OARs) were segmented on each CBCT. The planned dose distribution was recalculated on the daily CBCTs and then the recalculated dose was deformed to the planning CT to compare the dose delivered to the lungs and GTV with that planned.

Results: For each patient, several statistics were extracted from the CBCT series and the deformed dose distribution to investigate their change throughout the course of treatment. Statistics included the GTV volume, density changes in the lung tissue (indicated by changes in pixel intensity values in the CBCTs), dose volume histogram statistics such as the volume of lung receiving 20Gy dose and the mean lung dose. The Equivalent Uniform Dose to lung-GTV and lung-PTV for the dose as delivered to the CBCT and the deformed dose distribution were also considered for each patient.

Discussion: The patient data was extracted using an automated process and analysed to obtain information about changes during treatment. The initial patient sample was used to prove that such data extraction was possible and could be automated utilising scripting in RayStation.

Conclusions: The patient sample was too small to draw meaningful conclusions about the optimal point for adaption, but the techniques developed will be applied to a larger cohort and analysed for useful trends in order to improve patient outcomes and reduce lung toxicity.

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[1]*University Hospitals Coventry and Warwickshire NHS trust (UHCW), Claire.fletcher@uhcw.nhs.uk, [2]UHCW, [3]University of Warwick*

Foot Pressure Quality Assurance Device

Chris Pearce, Stephen Prewett, Simon Wiles, Ashley Allen, Mark Reeves

Keywords: clinical engineering, quality assurance, pedobarography, device innovation

Background: The Tekscan™ HR Mat is used clinically to produce pedobarographs which indicate the spatial distribution and temporal variation of the pressure under the patient's foot while walking or standing. Areas of high peak pressure and abnormalities in the trajectory of the centre of pressure during a patient's step can be identified [3]. This data is used alongside other clinical information (such as x-rays and CT scans) to inform clinical decision making, therefore the accuracy and repeatability of pressure measurements is very important.

The mat comprises an array of 8448 force sensing resistors. It is thin, flexible (allowing easy setup in any suitable clinic room) [1] and has been shown to have high repeatability in walking trials [2]. The mat is initially equilibrated by the manufacturer to correct for variation in sensitivity between individual sensing elements. Repeating this is only possible by returning the device to the manufacturer (USA), which would be disruptive to the clinical service and has cost implications.

As part of the clinical protocol, a simple calibration is done by comparing patient's weight with the data acquired while they stand stationary on the mat. This process assumes that the sensitivity is uniform across the whole mat, but wear could cause different levels of deterioration in the sensitivity in different areas of the mat over time.

The aim of this work is to develop a device and procedure to monitor how the Tekscan™ HR Mat sensitivity varies at different pressures and in different regions over time.

Methods: A quality assurance device has been designed and manufactured that applies known pressures to specific regions of the mat by inflating a bladder. Simultaneously the raw data from the HR mat is recorded for comparison. Measurements are repeated in 25 locations (in a 5x5 grid) and are taken at pressures from 1 to 7 bar in intervals of 1 bar. This is done in accordance with the Standard Operating Procedure that has been created (ensuring measurement capture and processing are repeatable). This process will be repeated at regular intervals.

Results: *(Figure 1).*

Discussion and conclusions: Variation can be seen across the mat's surface; the central region, specifically rows Y2 and Y3 are less sensitive than those surrounding. This suggests that areas of the mat have deteriorated at different rates. Clinically, this could affect the pedobarographs as the measured pressure would be dependent on the region of the mat that the foot strikes. The QA device and procedure allow us to monitor the pressure mat and provide an evidence base of its' characteristics. By repeating measurements of the mat over time, we will be able to draw conclusions on temporal variation. With an increasing evidence base, we will be able to provide assurance that the device is performing as intended or recommend manufacturer equilibration.

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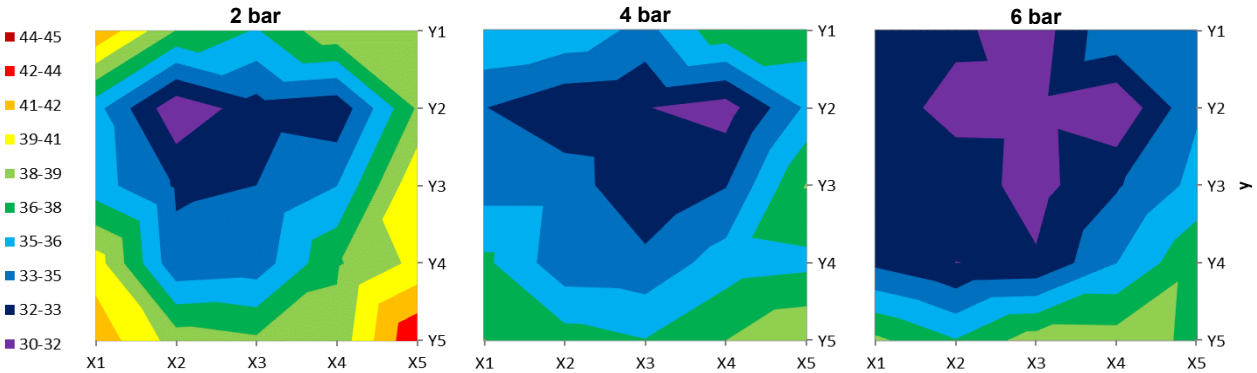

Figure 5. Contour Plots of Peak Pressure (raw) per bar of applied pressure, for 2,4 and 6 bar. Each plot represents 25 measurements of the Tekscan™ HR Mat with the Foot Pressure QA Device.

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An Audit of Patient-Specific MR Safety Queries for a Large MR Safety Expert Service

Asher Ezekiel, Guy Drabble, Steven Jackson, Mike Hutton

Keywords: MR safety, MRSE, implantable devices, GISP

Background: The Christie Medical Physics and Engineering MR Safety Expert (MRSE) service records patient-specific safety queries received from regional MR departments in a central spread sheet. These queries primarily relate to historic medical procedures or surgery, medical implants, or metal fragments within the body. The information is currently used to inform service developments, updates to safety policies and safety framework documentation, as a teaching tool for trainees and junior physicists, and to ensure consistency of advice provided. The main aims of this audit were to inform standardisation of and improvements to the recording of safety queries.

Methods: An audit of the safety query record was undertaken covering all queries added between 1st April 2021 and 31st March 2022 inclusive (412 queries in total). Examples of the information recorded for each query include the implant type, a summary of the safety guidance provided by the MRSE, the time taken to initially respond to and sign off the query, and its outcome. Each column of the record was individually assessed to determine the consistency and utility of the information recorded and to identify trends that offer insight into the way the MRSE service is provided.

Results: Insights gained from the data include that 98% of initial responses were sent and 76% of queries completed within 24 hours of receiving a query, and that the mean time spent handling each query was 32 minutes (range: 1 minute – 8 hours). Following the audit, several features of the record were identified for improvement, including but not limited to implant categorisation, query urgency and response time. A limitation identified in the safety query record was that off-label and MR unlabelled scans were not distinguished from one another. In response to the audit, changes were made to the way safety queries were recorded, both to standardise the information already being captured as well as to record additional information. Among several changes, device categories were standardised, and new columns were added to distinguish off-label and unlabelled devices and to indicate the urgency of each query.

Discussion: The high volume of safety queries already recorded in the safety query record makes it a valuable resource, but without standardisation of, for example, the device-type categories, it was challenging to extract the information for the audit. The implemented changes aim to make it possible to identify trends and extract information more easily and rapidly. For example, when the types of devices were recategorized retrospectively it demonstrated the requirement for a new generic implant safety policy (GISP) for stapes implants. The time spent on each safety query provided insight into the workforce requirements to support specific query types, for example queries requiring patient-specific risk assessment for off-label scanning. The addition of urgency information to the safety query record has meant that it can now be used to monitor our MRSE service's Key Performance Indicators (KPIs) relating to safety query responses and can inform the introduction of additional KPIs in the future. Further work will include regular repeat audits that will assess the ongoing effectiveness of the safety query record standardisation inspired by this initial audit.

Conclusions: Auditing our safety query record showed that the record is an invaluable resource from which informative and revealing information can be obtained. It also enabled us to identify ways to improve this record to increase its efficacy and accessibility. It is predicted that it will now be easier to use the safety query record to inform changes to safety documentation, policies and new GISPs. The record of all safety queries, including the time spent on each query, is also a valuable tool for workforce planning. Finally, this record will continue to provide useful information for the training of future MRSEs, setting KPIs and can be incorporated into a quality management system.

Evaluation of MR-Only External Beam Radiotherapy of Prostate Cancer

Emma Doran[1, 2], Andrew Aitken[1], John Foster[2], Marimuthu Sankaralingam[1]

Keywords: radiotherapy physics, MRI, synthetic CT, MR-only

Background: A 1.5 T Siemens MAGNETOM Sola RT Pro edition MRI scanner (MR sim) is in clinical service at the Beatson. Prostate Stereotactic Ablative Body Radiation Therapy (SABR) patients were the first clinical cohort to undergo an MRI as part of routine pre-treatment imaging. The Siemens synthetic CT (sCT) product is available on the MR sim[1]. Pelvic sCT generation is based on a Dixon sequence. A 5-compartment sCT is generated and imported into the Oncology Information System (OIS) as a CT DICOM object. The aim of this innovation project was to evaluate the quality and dose accuracy of the sCTs and explore the feasibility of their use in MR-only prostate SABR planning. The consequence of an MR-only workflow on treatment verification imaging was also investigated.

Methods: Dixon images and sCTs were visually assessed for 8 prostate patients. One patient had a bilateral hip prosthesis and did not undergo SABR treatment. One SABR patient was scanned with a rectal spacer. The 7 original SABR treatment plans were recalculated on the sCT. Target and Organ-At-Risk (OAR) volumes were copied from the real CT onto the sCT. A correction was applied to the Hounsfield Unit (HU) assigned to soft tissue to increase the mass density[2]. Dose distributions were visually assessed, the DVH analysis of each plan was compared, as well the average dose to the CTV. A consultant clinical oncologist volumed the CTV structures of all 8 patients using high resolution T_2w and large FOV MRI data. OAR structures were volumed on the large FOV image. MR-only volumes were compared to the original CT-MR fusion volumes. Implications of an MR-Only workflow were investigated including; gold seed contouring, user origin and plan isocenter placement, plan optimisation, independent MU checks and set-up verification.

Results and discussion: The sCT generated for the **prosthesis patient** was unusable and the rectal spacer could not be identified in the sCT. The tissue assignment in the sCTs resembled underlying anatomy, however issues with the rendering of cortical bone and bone marrow were identified. SABR plans were recalculated successfully on the sCT data (see Figure 1). Increasing the mass density of the soft tissue compartment decreased the average CTV dose difference across all patients from 1.11% to 0.54%. The average difference in mean dose to the OARs was below 2.2%. Differences between MR-Only and CT-MR volumes for CTV and OAR structures showed that MR-Only volumes were on average smaller. An MR-Only workflow for planning and set-up verification was feasible, however several areas of development were identified.

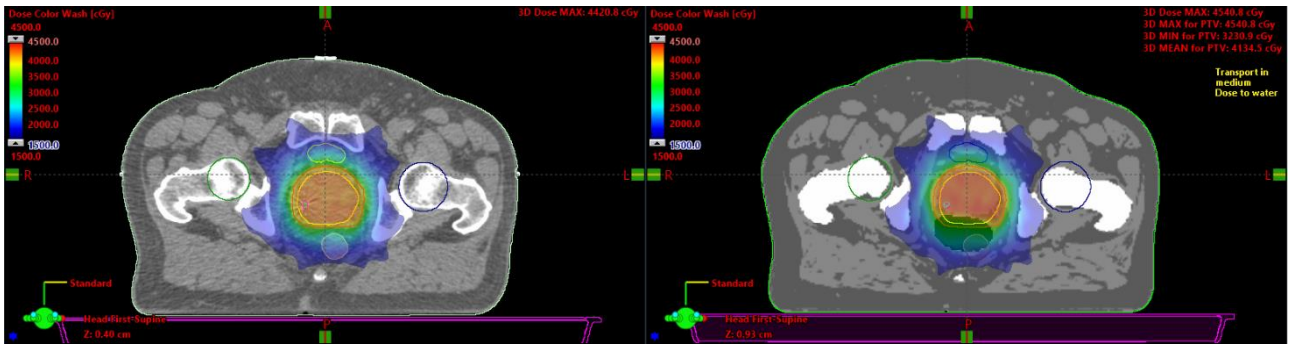

Figure 1: *SABR dose distributions calculated on (left) real CT, (right) sCT.*

[1]Radiotherapy Physics, Beatson West of Scotland Cancer Centre, NHS Greater Glasgow & Clyde
[2]MRI Physics, Imaging Centre of Excellence, QEUH, NHS Greater Glasgow & Clyde

Conclusions: The integrated sCT generation offers a convenient workflow for the development of MR-Only planning for prostate SABR. Despite reasonable dose comparison results the current version of the sCTs requires further evaluation.

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Experiences from Implementation of CIB Coding Taxonomy for Learning from Adverse Events and Near Misses in Diagnostic Imaging into an NHS Trust

Richard Raynor[1]

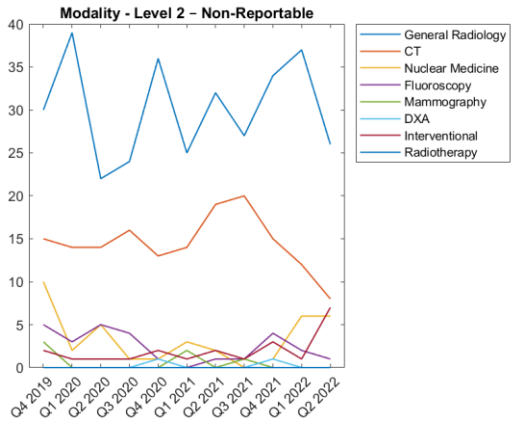
Keywords: incidents, trend analysis, diagnostic imaging

Background: In June 2019 a Working Group provided a report detailing a coding taxonomy for *Learning from Ionising Radiation Dose Errors, Adverse Events and Near Misses in UK Clinical Imaging Departments [1]* to the Clinical Imaging Board (CIB). This system includes codes for the severity of the incident, the type and modality of the exposure, a series of linked codes for common causes grouped into different duty holders' responsibilities, and a collection of causative factors. These codes were adapted and incorporated into the trust incident reporting system and utilised in parallel with existing coding structure. Once sufficient data had been collected results from the CIB taxonomy were compared with existing coding structure which followed the categories within the CQC annual reports. This talk or poster would aim to discuss early experience of implementing the taxonomy including the benefits, difficulties, and potential areas for development including the benefits of a national approach.

Methods: The coding taxonomy was implemented into Trust incident reporting system with minor changes to accommodate system limitations and match current processes. All incidents are reviewed by member of the Trust Radiation Safety Service and the incident coded following the coding taxonomy and identifying if the incident is reportable to an external agency. At the same time the incident is investigated by the clinical area and learning opportunities identified.

Data is exported from the incident reporting system for automated processing for consistent formatting. A series of run charts and control charts using standard nelson limits are produced.

Results: Data has been combined into a standardised report where run charts are used to display overall trends across time and control charts are included as appropriate to identify potential trends. This report is produced on a quarterly basis and provided to the Trust Radiation Safety Committee



Example run chart for Severity 2 (Non-reportable) incidents on a quarterly basis when grouped by performed modality.

Discussion: The coding taxonomy and control charts have proved a useful combination for identification of potential issues within the trust but is limited where categories have insufficient data for robust statistics. Comparative data for other Trusts is not available outside of the Severity 1 incidents reported on by the CQC.

Conclusions: Adoption of the coding system has improved confidence in routine analysis but highlighted limitations of the coding system when utilised this way. Greater involvement from primary investigators is needed for complete coding of incidents and trends are limited to this Trust. National adoption of the coding taxonomy and collation of data would provide valuable insight to high risk areas as well as allowing centres to identify where they differ to national standards.

References:

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[1] University Hospitals of Leicester NHS Trust

Review of Fingertip Monitoring of Radiation Doses for Staff Working with Unsealed Radionuclides

Jill Bradley, Lara Bonney, Kitty Morelli-Batters, Aida Hallam, Helen Amatiello

Keywords: nuclear medicine, personal dosimetry, classified radiation workers.

Background: In January 2022 an additional 63 staff working with radionuclides were classified under IRR17 due to the risk of exceeding the dose limit (1) in the event of certain incidents. The aim of this work is to review how practical the use of fingerstalls is for assessing dose to the skin (2) for unsealed radionuclide work which includes nuclear medicine, PET, radio-pharmacy and nuclear cardiology. Previous work (3) has recommended that staff receiving an annual extremity dose of >50mSv should have regular monitoring with finger stalls or to establish a correction ratio if rings are used. Prior to classification, staff were routinely issued ring dosimeters and a correction factor applied. The IPEM guidance on the Personal Monitoring Requirements (4) reminds us that a correction factor cannot be applied by the Approved Dosimetry Service (ADS) until approved by the HSE. The employer should also validate at regular intervals that any factors applied remains suitable.

Methods: In 2022, 50 of the classified staff were monitored monthly and issued waist and eye dosimeters and left and right fingerstalls. The number of lost fingerstalls and rings was compared for 2022 and 2021 respectively. The number of damaged fingerstalls returned was assessed for a 3-month period. A feedback questionnaire was distributed to all staff issued fingerstalls following 8 months of wear history and reviewed.

Results: The ratio of the equivalent dose to ring and finger stall measured in 2021 for nuclear medicine staff saw a wide variation with mean ± 2 s.d. of 1.8 ± 2 mSv (n=192). The left and right hand showed similar ratios and 16% showed a lower dose on fingerstalls compared to rings. The percentage of lost fingerstalls was found to be 3 times higher than lost rings. Over the period May to July 2022, 49% of the monthly fingerstalls returned were split and some were unwearable. In 2022, the thermoluminescent dosimeter (TLD) chips became detached from 14 fingerstalls whilst in use rendering them unusable and unreadable.

Staff questionnaire feedback (n=36) was as follows:

- 97% reported they felt the stalls reduced dexterity e.g., melanoma studies
- 83% reported they felt the reduction in dexterity increased source handling time
- Reports of fingers becoming sweaty, therefore stalls not being worn all day
- Reports of stalls being thrown away with gloves when they are discarded to waste

Discussion: Staff are frustrated by the design of the fingerstalls and report numerous practical problems some that result in lost or skewed dose data. Problems include altering technique so that the finger with the fingerstall is no longer the closest to the source, extending the time taken to complete a task and therefore increased dose, not wearing the fingerstall for a whole working day, so a loss in dose data and risk of not having ready access in an emergency, dosimeters splitting or loss of TLD before the end of the monthly wear period, requiring replacement which further increases cost and administrative resource.

Conclusions: In our experience, the use of fingerstalls is not fit for purpose for this work. Approved correction factors for work with unsealed radionuclides must be established between ADSs and HSE to allow classified workers to wear rings. Continued design improvement work is necessary to ensure stalls are robust enough for regular use and will reliably measure the fingertip dose to ensure any correction agreed factors remain suitable.

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Using Improvement Techniques to Reduce Backlog of Medical Devices Planned Maintenance (PM)

Stella Ejuvwevwo Otomewo[1],Edward Chapman[2], Ian Davies[3]

Keywords: clinical engineering, planned maintenance, medical devices, improvement techniques

Background: Medical devices are key in healthcare as they aid in the diagnosis, treatment, and overall care of patients[3]. Effective management of these devices ensure that they are used safely and efficiently minimizing any risk to the patient[3]. Planned maintenance (PM) is key in the effective management of medical devices to ensure that they achieve their desired aim minimizing or eliminating any adverse risk to the patient and users[4]. Although questions have been raised into the way PM is performed, the relevance cannot be ignored when performed appropriately[5]. Over the years, medical devices planned maintenance have evolved to keep up with technological advancements to ensure reliability and long lasting medical devices[1,2]. The COVID-19 pandemic put a strain on Clinical Engineering departments leading to a backlog of planned maintenance of medical devices, posing a risk to patient care. This project conducted at a Clinical Engineering department in the UK, looked at reducing this backlog to minimize any adverse risk to patient care using improvement technique.

Methods: The DMAIC (define, measure, analyse, improve and control) tool kit was applied to this project. An evidence based approach was applied with a baseline data collection analysis and subsequent data collection 3 months after the implementation of the improvement tools.

Results:

ITEM	NUMBER OF DEVICES	CYCLE TIME (HOURS)	PERCENTAGE REDUCTION (%)	DATE OF DATA COLLECTION
BACKLOG @11/06/2022	487	366.08	-	11/06/2022
BACKLOG @11/06/2022	372	266.96	23.6	06/09/2022

Discussion: The major problems identified were communication and the PM process; applying the tools to the problems led to a reduction of the backlog by 23.6% as against a reduction rate of less than 10% before the project.

Conclusions: As improvement is a continuous process, the result indicates that with continuous application the backlog could be resolved eliminating the likelihood of any adverse risk to patient care.

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Introducing Electronic ECG Results Across NHS Lothian

Abigail Attwell

Keywords: quality improvement, clinical engineering, connectivity, multi-disciplinary, cardiology

Background: This was a cross disciplinary Quality Improvement study at NHS Lothian looking at the effect on patient pathways that increased connectivity and electronic archiving has within ECG workflows.

ECG machines generate physical reports on thermal paper which fade over time. An Electronic ECG Archive seeks to ensure that ECG traces are stored centrally and made available to all clinical staff. ECGs are directly viewable by clinical staff in Cardiology, enabling a rapid and accurate assessment to be made and reported.

Previous to this project, a limited amount of areas had ECG machines connected to the Electronic Archive - Emergency Departments and Outpatient Cardiology Departments at Acute Hospitals within NHS Lothian. The aim of the project was to see ECG study results for patients referred by a GP to Leith Community Treatment Centre (LCTC) and East Lothian Community Hospital (ELCH) be accessed and stored electronically.

Methods: The community ECG teams' devices were connected to the Electronic ECG Archive.

The impact was assessed by:

- Interviewing the team lead to flowchart the patient pathway before and after implementation.
- Collecting information from the ELCH team about patient appointments from Dec-21 to May-22.
- Surveying Leith GP Cluster on their experience of accessing ECGs.

Results:

- The patient pathway process has been simplified, as paper ECGs are no longer stored.
- Patient appointment information suggested that recent ECGs were largely accessed electronically after connection to the archive.
- GP surveys made us aware that ECG results should be sent to EDT/Docman as well as SCI-Store to be a real improvement for them.

Discussion:

- The ECG team at ELCH no longer store results in paper, but only electronically. This simplified the ECG GP referral pathway significantly, as seen in the removal of the bottom left branch of a pathway flowchart. To further streamline this process the results would automatically, electronically send to the referrer without the need for postal copies sent.
- The run chart revealed a baseline median in ECGs accessed electronically increase from 40.6% to 100% median during data collection. A higher proportion of ECG traces accessed electronically suggests that less unnecessary re-referrals will take place, increasing the accessibility for others that require ECG exams.
- GP survey responses highlighted that the GPs required results to send to their EDT/Docman system to complete the benefit of electronic archiving. Currently the ECG results must still be sent by post for GP admin staff to create alerts on their system.

Conclusions: This project shows a benefit to directing patient results to an Electronic Archive within an ECG team, with results now being stored and easily accessed electronically. Further work is being carried out to connect all ECG machines in NHS Lothian to the Electronic Archive. A further project has begun to close the loop, to send ECG traces to the GP EDT/Docman systems as well as the Electronic Archive.

Implementation of an MR Safety Framework for Intraoperative MR

Gillian MacNaught, Stuart Jamieson, Robert Williams, Nick Weir, Fiona Mackenzie, Drahoslav Sokol, Jothy Kandasamy, Jill Baillie, Alan Quigley, David Summers, Jamie Hetherington and Omair Malik

Keywords: imaging, MRI safety, neurosurgery

Background and aims: A Philips 3T Ingenia MR-OR Intraoperative Magnetic Resonance System was recently installed in NHS Lothian. This is the first to be installed in Scotland and there are only a few installed elsewhere in the UK. Its value is in assessing the extent of tumour resection during neurosurgery, allowing the surgeon to carry out further resection during the same operation, thus potentially improving the patient's prognosis.[1,2]

All MR units can be hazardous, and so access is tightly controlled and staff complete regular MR safety training. The most immediate hazard[3] in the MR Environment is the possibility of ferromagnetic (i.e. MR Unsafe) objects being attracted towards the scanner. Such objects would become a projectile[4] in the high magnetic fringe field of the scanner, being pulled with force towards the scanner and potentially causing injury or fatality to anyone positioned between the object and the scanner.

The Intraoperative MR unit presents additional MR safety challenges, particularly with limited access to the patient (see Figure 1, left), the large multi-disciplinary team involved in surgery and the additional equipment used in theatre. Here we describe the MR Safety framework put in place for carrying out these cases in NHS Lothian.

Methods: We formed a multi-disciplinary working group including representatives from theatre, anaesthesia, radiology, nursing and medical physics. We developed a standard operating procedure and ran a series of simulations to determine whether MR safety processes would work effectively in practice.

Results and discussion: We found Intraoperative MR to be a complex process with a high possibility for surgical and anaesthetic items being missed during MR safety checks if standard operating procedures were not in place. This is because of the large number of items required, the number of staff members involved at different stages of surgery and limited access to the patient due to surgical drapes. To overcome this we found it necessary to carry out an additional custom MR safety checklist (Excerpt shown in Figure 1) in theatre immediately prior to transferring the patient to the adjacent MR scanner for an intraoperative MR scan. This is in agreement with findings from other Neurosurgery Centres[5,6]. Local theatre nursing staff instigated the further process of storing MR unsafe items removed from the patient in clear plastic labelled pockets (Figure 1). This ensured the removed items were instantly visible to everyone in theatre and minimised the risk of items being missed and transferred in error with the patient to MRI.

Figure 1: (left-right): MR head coil covering patient's head. Excerpt from implemented intraoperative MR safety checklist. Examples of MR Unsafe items removed from patient.

Conclusions: We have found our procedure for transferring patients for Intraoperative MRI to be effective for maintaining the safety of patients and staff. However it is imperative for all staff to keep their MR safety training up to date, to review our process regularly and to continue to be vigilant for MR safety hazards during Intraoperative MR sessions. We are now using this experience to set up MR-guided laser interstitial thermal therapy (LITT) in the Intraoperative MR suite.

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The Implementation of Patient Specific Silicone Bolus Manufactured from 3D Printed Moulds in Radiotherapy Treatment – Our Experience So Far

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Keywords: 3D bolus, 3D printing, 3D silicone bolus, patient specific silicone bolus

Background: Bolus is tissue equivalent material which is used in radiotherapy treatment. Some examples of current bolus options include the use of paraffin gauze or sheets of tissue equivalent material. While paraffin gauze can provide a good fit to the patient, it is limited in the consistency of shape and thickness. 3D printing provides the opportunity to create individualised conformal bolus, through direct (TPU bolus) and indirect (printed moulds for silicone) methods. Initially we directly printed the bolus in TPU (thermoplastic polyurethane) material, while this gave the desired bolus shape, rigidity of the bolus resulted in poor patient comfort. Hence the directly printed bolus was superseded by silicone bolus produced from 3D printed moulds. Silicone bolus can provide a custom fit to the patient which holds a consistent shape while being soft and flexible for patient comfort. Custom silicone bolus has been in clinical use for radiotherapy treatment at Northampton General Hospital since April 2022, predominantly for anal canal treatments.

Methods: The process starts following the patient's planning CT scan, clinicians and dosimetrists identify patients who would benefit from a custom 3D bolus. The process follows the below workflow:

- Clinicians – Prescribe bolus
- Treatment Planning Team (TPT) – Generate bolus structure in TPS
- Physicists – Export bolus structure, generate mould shape and 3D print mould
- Technicians – Pour silicone bolus
- CT radiographers – Scan silicone bolus and mould
- TPT – Recalculate plan in TPS with final bolus structure and measured HU

Results and discussion: When compared to standard bolus for some treatment sites, patient specific silicone bolus improves conformity compared to other bolus options. Prescribing and producing an electronic bolus contour in the TPS adds negligible time to the radiotherapy pathway overall. The process of producing 3D printed moulds currently takes around 6 - 8 hours for a typical anal canal mould (however this only requires manual input in print set up). The silicone moulding process takes around 5 hours (4 hours of which require no manual input as the silicone is curing in this time). Overall, our practical experience has meant silicone bolus production can be performed concurrently with the current patient workflow – so does not add time to the patient pathway (even in eventualities such as printing failures).

This presentation will discuss how we brought custom silicone bolus into clinical use for anal canal treatments; the challenges we faced during this process and our solutions. It will also discuss the 3D printer used, software used for generating the mould and verification measures taken to ensure quality of the silicone bolus produced. Our 3D bolus group meets regularly to review and receive feedback from treatment radiographers, this is a collaborative effort between clinicians, physicists, radiographers, and technicians.

Conclusions: We have demonstrated practicalities and benefits of implementing custom silicone bolus. With the use of two 3D printers, the department has plans to expand the use of silicone bolus to more anatomical sites where there is likely to be clinical benefit.

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Studies in the Dosimetry of Synthetic CTs in Online Adaptive Radiotherapy and its Impact in the Clinical Decision-Making

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Keywords: online adaptive, adaptive radiotherapy, AI, neural networks, optimisation, planning, Ethos, Varian, bladder, prostate

Background and aim: Online Adaptive radiotherapy has recently gained significant demand following the integration of artificial intelligence (AI), deformable image registration and the highly automated plan re-optimisation in the adaptive workflow. Varian's Ethos™ platform is now available for online adaptive treatment. This system auto-segments both the target and organ-at-risk on the daily CBCT images and re-optimises a new plan to balance the treatment volume coverage and healthy tissue sparing. The new session plan is calculated on synthetic CT (sCT) which is generated from CBCT.

The sCT is a CT image generated from CBCT that has the same anatomical structure as CBCT but accurate HU value which is desirable for dose calculations. There are however some costs to the efficiency of the workflow due to the limitation of the auto-segmentation system. The contours generated by the software may require review by experts and may need manual edits. Our aim is to quantitatively study the accuracy of online adaptive radiotherapy plans. In particular, we are interested in analysing regions where, in the synthetic CT, air either replaces or is replaced by soft tissue compared with the kV-CBCT, and how these differences affect target dose distributions.

Methods: Four prostate patients planned and treated with 60Gy in 20 fractions were analysed retrospectively. The adapted treatment plans which were previously treated on Ethos™ were exported to Eclipse TPS where density corrections are made for five fractions per patient to account for soft tissue and air location differences between the daily kV-CBCT and synthetic CT. Following the HU corrections, the same plan is recalculated and the resulting PTV dose is compared with the original calculation. Comparisons of the CTV and PTV, the mean doses (Dmean) and dose distribution to 2% of the CTV (D2%) and PTV D2%, D50%, D95%, and D98% will be analysed. The homogeneity index (HI), conformity index (CI) and conformation number (CN) of PTVs will be compared. T-tests will be performed to examine correlations between air volume changes and dosimetric changes, (significance set at $p<0.05$). A Spearman's rank test will be performed to determine if there is a correlation between air volume changes and dosimetric changes.

Results: We note that for the cases that we have studied so far, the recalculated adaptive plans for the prostate patients remains in very good agreement with the plan before HU correction.

Conclusions: Current trends of our data analysis seem to support the case for using online adaptive radiotherapy for prostate cases. The impact of larger volumes of HU kV-CBCT/sCT discrepancies has not been studied yet and will be the object of near future analysis. Future work will also look to assess the doses to OARs particularly rectal wall, and the predicted toxicities.

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Assessment of the Performance of Ultrasound Shear Wave Elastography Imaging Scanners: A Comparative Phantom Study

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Keywords: ultrasound elastography, shear wave elastography, phantom, test object

Background: Implementation and clinical applications of ultrasound elastography imaging techniques are expanding rapidly [1]. However the performance assessment and routine quality assurance of elastography scanners is limited [2, 3]. Analogous to the Edinburgh Pipe Phantom [4], we developed a novel L-STEP (Leicester- St Thomas' Elastography Pipe) phantom and demonstrated its potential benefit using a single shear wave elastography (SWE) scanner [5]. The aim of this study was to assess and compare the performance of different SWE imaging scanners using the L-STEP phantom.

Methods: A modified custom L-STEP phantom consisting of 6 soft polyvinyl acrylic-cryogel pipes of varying diameters (1-6.5mm), embedded at 45° within an agar-based tissue-mimicking material was constructed and used to acquire SWE images from 7 different scanners from 6 manufacturers (GE Healthcare, Philips, Siemens, Mindray, Toshiba, Supersonic Imagine). User selectable controls were optimised and data were acquired using the linear probe available on each scanner (probes ranged from 6-18MHz) to image longitudinal and transverse sections of the L-STEP phantom pipes. Penetration depth and colour pixel values of Young's Modulus (YM) within the visible pipes were assessed to quantify a number of performance parameters.

Results: Elastography colour map registration of the pipes coincided well with the B-mode image. However a number of artefacts and potentially misleading features were observed in L-STEP phantom images from all scanners. Images acquired demonstrated examples of vertical and/or horizontal "colour stripes/lines"; artefact colour around edge of colour box; both "bleeding" of the colour beyond the pipe boundary and insufficient "colour filling" of the pipe; small regions of localised artefactual colour filling; colour "noise" filling at deep depths; movement artefacts. There were differences in YM estimates between scanners, between longitudinal and transverse sections of the pipes, and with pipe depth and size. Resolution varied between scanners. All 7 scanners could image the 6.5, 5 and 3.5mm diameter pipes; 5 scanners the 2.5mm pipe longitudinally (only 3 scanners transversely); 5 scanners the 2mm pipe longitudinally (only 2 scanners transversely); 3 scanners the 1mm pipe longitudinally (none transversely). Sensitivity as assessed by the maximum penetration depth of visible pipes from each scanner ranged from 35mm to 73mm. We defined a new modified summative performance index as the sum of the ratios of the penetration depth/pipe diameter of longitudinal and transverse images and this ranged from 53 to 175 and correlated with subjective impression of scanner performance.

Conclusions: There was a wide variation in the ability of different scanners to image and quantify elasticity, highlighting both the suitability of our L-STEP phantom to assess SWE scanner performance and the need for such test objects for quality assurance and to help validate clinical findings.

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Reducing Radiation Burden While Maintaining Scan Quality

Courteney Kelly[1]

Keywords: cadmium-zinc telluride, solid state technology, nuclear medicine, spectrum-dynamic D-SPECT

Background: Cadmium-Zinc Telluride (CZT) Technology is revolutionary in Nuclear Medicine, replacing standard gamma camera technology, scintillator crystals and photomultiplier tubes(1). Solid-state technology advances both sensitivity and resolution, allowing for reduced scanning times and radioactive dose (2).

The introduction of the Spectrum Dynamic D-SPECT camera to nuclear cardiology technology has reduced dose to the patient and scan time while improving overall scan quality (3). Additionally, patient comfort is improved with the D-SPECT's option of up-right positioning (4).

This study aims to assess the number of counts within the Left Ventricle (LV) and compare this to the quality of the images acquired. According to the Spectrum Dynamics D-SPECT manual, to achieve optimal image quality and hence diagnostic accuracy, the LV counts should be greater than 700K (5).

Method: A retrospective audit of 40 consecutive patients who had underwent both a stress and rest Myocardial Perfusion Image (MPI) via a 1-day protocol weight based protocol was undertaken. Patients were given ~4MBq / Kg stress and three times the net activity injected for rest. All patients were scanned using the radiotracer Technetium-99m-Tetrofosmin.

Results: Within this study, the average stress LV counts are 1M and the average rest LV counts are 1.8M, indicating that lower activities and hence radiation burden could be implemented without compromising image quality and diagnostic accuracy.

Additionally, the average stress image activity was 227MBq and the average rest image activity was 617MBq. The average total dose was therefore 844Mbq for both scans which is around half of what was being administered with the standard previous gamma camera technology, the Administration of Radioactive Substances Advisory Committee (ARSAC) limit for a stress and rest MPI is 1.6GBq.
Discussion: CZT technology, use a 1-day protocol for both stress and rest examination, allowing the procedure to be completed within the same day, while increasing image quality and simultaneously reducing the radiation dose to the patient. With previous technology, IS2 PULSE auger gamma camera two day protocols were required to optimise scan quality using the upper ARSAC activity limit of 800MBq per part of the examination. CZT technology has enabled for radioisotope activity to be as low as 200MBq e.g. stress only required. The departmental protocol is patient weight dependant, therefore activities vary from 200MBq - 500MBq.

Conclusions: CZT technology has greatly improved image quality and hence aided diagnostic accuracy, while reducing activity and the radiation burden in comparison to auger gamma camera technology. This initial data suggest that further reductions in activity can be made without sacrifice to image quality and hence diagnostic accuracy.

Further work will be done assessing image quality on a 3-point scale with blinded expert observers to independently assess quality vs count in LV.

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Does the Aperture Shape Controller, and Separate Optimisation Objectives for the PTV in Tumour and in Low Density Lung Tissue, Improve Plan Robustness for Lung VMAT Patients Treated at RSH?

Adam Williams

Keywords: aperture shape controller, robustness, VMAT, optimisation, lung, tumour regression

Background: The impact on robustness of lung VMAT plans against tumour regression was assessed for two adaptations to the VMAT optimisation process. The first adaptation was the aperture shape controller (ASC) in the Eclipse v15 optimiser, designed to reduce the complexity of MLC defined segments. The second was to separate the PTV into solid and low-density ('air') parts for optimisation with separate objectives. The aim of this was to reduce the potential for hotspots in solid tissue moving into air parts of the PTV. This allowed the determination of the robustness of a range of dose metrics.

Methods: Each patient (n = 19) in the study was optimised and calculated on the planning CT dataset before the same plan was recalculated on a new structure set in which the regressed volume (either identified via CBCT or artificially modelled) was converted to the Hounsfield Units of the surrounding lung tissue – with the same number of monitor units. The change in certain dose metrics between these calculations was used to indicate robustness against the regression, with a lower difference meaning better robustness. These differences were compared for plans optimised according to the various adaptations.

Results: For the ASC adaptation, no statistically significant impact was found on the robustness of any of the metrics. The ASC gave a statistically significant reduction in monitor units (Moderate p = 0.006, Very High p = 0.001) in line with the literature. That robustness was unaffected coupled with the reduced MUs suggests an overall advantage. For the split PTV adaptation, the single PTV method, i.e. the standard, demonstrated statistically significant improvements in robustness of PTV (p = 0.010) and PTV-in-air V95% (p = 0.050) compared to the split PTV adaptation. However, the clinical significance of these improvements is questionable. The split PTV method was associated with reduced MUs (p = 0.005).

Discussion: Though increasing the ASC was not found to significantly improve robustness in those data metrics, it is noted that robustness was very good anyway – dose differences with tumour regression were very small. Effectively, there was very little margin for improvement. The ASC should be tested with more irregular PTVs, where the optimiser may overmodulate. Another goal in a further study would be to evaluate the impact of the ASC on robustness against other sources of interfraction variation. It was interesting that the single PTV optimisation method showed significantly better robustness, as this seems counterintuitive. Though statistical significance was found for robustness in the above metrics, the clinical significance of the improvement over the split PTV method was questionable.

Conclusions: The study found that neither adaptation improved robustness. Indeed, for the latter, the adaptation suggested slightly worse robustness. Both results were unexpected, and further study with different sources of interfraction variation, with more sites, would be of great benefit.

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