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Abstracts
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Highly accelerated MRI using compressed sensing: reducing the patient burden

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MRI has revolutionised clinical medical imaging, and transformed medical research, by providing repeatable, non-invasive measurements of tissue structure and function, reducing the need for invasive techniques such as tissue biopsy or radionuclide studies. In MRI, critical factors are the cost per volunteer of the imaging (dictated principally by scan duration) and the ability of study subjects to comply with scan procedure (influenced by scan duration, since subjects have to lie still and hold their breath for abdominal/thoracic applications). A balance must be achieved between the physiological parameters that could be measured, the demands made of the patient, and the cost of the scan session. Lengthy image acquisitions are a barrier to the further development of MRI, particularly in children and the elderly.

Magnetic resonance imaging acquires raw data in a Fourier transform space, named k-space. Once an imaging matrix has been defined by the desired field of view and resolution, it is necessary to acquire complex data from an equivalently sized k-space matrix to get an artefact-free image (Nyquist-Shannon theorem). The advent of phased-array coils in the late 1990’s permitted a relaxation of this condition by regular undersampling of the k-space matrix and subsequent artefact unfolding using spatial sensitivity information.

The compressed sensing theory asserts that if our target image is sparse (i.e. such that there are few significant non-zero pixels in the matrix), or can be made to be sparse under a mathematical transformation, then we will be able to recover a high quality image from substantially fewer k-space samples than Nyquist-Shannon states by non-linear reconstruction. MR images are, in general, not sparse but can be made to be so by a mathematical transform such as a discrete wavelet transform. The k-space undersampling patterns must not give rise to coherent artefacts in image space (Figure 2).

As part of an MRC-funded project, we have developed and applied both compressed sensing and parallel imaging to accelerate image acquisition and demonstrate image quality and the fidelity of the image content compared with conventionally sampled images in muscular dystrophy (1, 2) and type 2 diabetes (3 and Figure 1). This talk will describe research in compressed sensing and the challenges to accepting compressed sensing methods more widely in research and clinical practice (4).

Figure 1: The top row shows a section from conventional fat fraction maps for Becker muscular dystrophy (scan time 273s) and for the liver (16s breath hold). The bottom row shows the accelerated images, accelerated by 5x for the leg images (scan time 55s) and 4x for the liver (4s breath hold).

Figure 2: k-space sampling patterns for the 3D liver fat-fraction measurements, seen in the phase encoding (ky-kz) plane moving from fully sampled (left) to progressively fewer samples using a variable density Poisson disk pattern.

Non-invasive wave reflection quantification in patients with reduced ejection fraction


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The non-invasive quantification of arterial wave reflection is an increasingly important concept in cardiovascular research. It is commonly based on pulse wave analysis (PWA) of aortic pressure. Alternatively, wave separation analysis (WSA) considering both aortic pressure and flow waveforms can be applied. Necessary estimates of aortic flow can be measured by Doppler ultrasound or provided by mathematical models. However, this approach has not been investigated intensively up to now in subjects developing systolic heart failure characterized by highly reduced ejection fraction (EF). We used non-invasively generated aortic pressure waveforms and Doppler flow measurements to derive wave reflection parameters in 61 patients with highly reduced and 122 patients with normal EF. Additionally we compared these readings with estimates from 3 different flow models known from literature (triangular, averaged, Windkessel). After correction for confounding factors all parameters of wave reflection (PWA and WSA) were comparable for patients with reduced and normal EF. Wave separations assessed with the Windkessel based model were similar to those derived from Doppler flow in both groups. The averaged waveform performed poorer in reduced than in normal EF, whereas triangular flow represented a better approximation for reduced EF. Overall, the non-invasive assessment of WSA parameters based on mathematical models compared to ultrasound seems feasible in patients with reduced EF. Replacing flow measurements with estimates derived from the pressure wave would greatly reduce the costs and complexity involved and could therefore facilitate the quantification of wave reflections by central WSA in large population studies.

Roberts’ Prize for best paper in Physics in Medicine and Biology

Multi-Color Magnetic Particle Imaging

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Philips Healthcare, Vantaa, Finland.

Magnetic Particle Imaging (MPI) is an emerging tomographic imaging method that is capable of quantitative 3D real-time imaging of magnetic nanoparticles [1], [2]. Due to its speed, it has high potential for dynamic medical imaging, e.g. quantification of coronary stenosis and myocardial perfusion in cardiac imaging [3]. By trading speed for sensitivity, promising results have been achieved in tracking of stem cells labelled with magnetic nanoparticles in vivo [4].

The particle magnetization response to an applied imaging field sequence is influenced by both the properties of the magnetic particle core (via Néel relaxation) and the interaction of the particle with its environment (via Brownian rotation). The acquired signal thus contains information about the particle type [5] as well as local parameters such as viscosity [6], binding state [7], or temperature [8]. To date, local information was only accessible in dedicated spectroscopic experiments that did not provide spatial information [9].

Multi-color MPI provides a method to separate differing magnetization responses into different colors in image reconstruction. It thus combines spectroscopic with spatial information. Our paper demonstrated the feasibility of separating the response of different particles types into different color channels using a unmodified imaging sequence [10]. Meanwhile, real-time catheter tracking has been demonstrated in a vessel phantom with concurrent multi-color visualization of catheter and phantom fluid using two different particle types [11]. Recently, viscosity contrast [12] and temperature contrast have been demonstrated in imaging as well. These capabilities make multi-color MPI a powerful and promising tool for functional imaging but also for monitoring applications, e.g. temperature monitoring in magnetic particle hyperthermia [13].
Perkins Prize for best paper in Medical Engineering & Physics

Bioresorbable scaffolds for bone tissue engineering: Optimal design, fabrication, mechanical testing and scale-size effects analysis

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Bone scaffolds for tissue regeneration require an optimal trade-off between biological and mechanical criteria. Optimal designs may be obtained using topology optimization (homogenization approach) and prototypes produced using additive manufacturing techniques. However, the process from design to manufacture remains a research challenge and will be a requirement of FDA design controls to engineering scaffolds. This work investigates how the design to manufacture chain affects the reproducibility of complex optimized design characteristics in the manufactured product. The design and prototypes are analyzed taking into account the computational assumptions and the final mechanical properties determined through mechanical tests. The scaffold is an assembly of unit-cells, and thus scale size effects on the mechanical response considering finite periodicity are investigated and compared with the predictions from the homogenization method which assumes in the limit infinitely repeated unit cells. Results show that a limited number of unit-cells (3–5 repeated on a side) introduce some scale-effects but the discrepancies are below 10%. Higher discrepancies are found when comparing the experimental data to numerical simulations due to differences between the manufactured and designed scaffold feature shapes and sizes as well as micro-porosities introduced by the manufacturing process. However good regression correlations (R² > 0.85) were found between numerical and experimental values, with slopes close to 1 for 2 out of 3 designs.

DOI: http://dx.doi.org/10.1016/j.medengphy.2015.01.004
Radiotherapy is part of the standard of care for high-grade primary and metastatic brain tumours. Response is assessed by measuring tumour size on contrast-enhanced T1-weighted MRI. However, early increases in tumour size can reflect treatment effects as well as disease progression, causing uncertainty and delays in clinical decision making. Our aim is to evaluate the accuracy of combined MR perfusion, diffusion-weighted imaging (DWI) and MR spectroscopy (MRS) (multimodal MR) for differentiating disease progression from transient radiotherapy related effects in brain tumours. Two groups of patients who had a 3T MRI scan including multimodal MR within the clinical workflow 4-6 weeks after completion of radiotherapy were included, consisting of primary glioblastoma (GBM, n=10) and brain metastases from primary melanoma, breast and lung cancer (n=7). Relative cerebral blood volume (rCBV), apparent diffusion coefficient (ADC) and maximum choline-creatine ratio (Cho/Cr) within the contrast enhancing lesion were measured. Clinical and MRI follow-up were used to assign cases retrospectively as disease progression, stable disease or partial response, with 6/10 GBM and 5/7 metastases having disease progression. Using cut-offs suggested in the literature, the combination of high rCBV, high Cho/Cr and low ADC correctly identified disease progression in all cases. Patients without disease progression showed an inconsistent pattern with some cases showing high rCBV or Cho/Cr, but also high ADC. Interestingly, a positive correlation was seen between rCBV and Cho/Cr (r=0.89, p<0.01) in metastases but not in GBM. These preliminary results indicate the value of multimodal MR for improved early assessment of response to radiotherapy in both primary and metastatic brain tumours.

Potential non-invasive visual function assessment in children with optic pathway glioma (OPG) using fractional anisotropy (FA) difference maps from sequential diffusion tensor imaging (DTI).

Visual function tests play a vital role in the management of children with optic pathway glioma (OPG), yet they are unreliable in young children. Conventional MRI is routinely used in sequential follow-up, but lacks sensitivity to visual function changes. Our hypothesis is that changes in Fractional Anisotropy (FA) within the optic pathway, measured by sequential Diffusion Tensor Imaging (DTI), may indicate changes in visual function, potentially providing a reliable non-invasive test. Three OPG cases with available visual function test results and sequential DTI at 5, 4 and 5 time points for case 1, 2 and 3 respectively, were selected for analysis. FSL software was utilised to calculate, co-register and project FA maps at each time point onto a standard brain template. FA difference maps were calculated for each pair of consecutive scans, applying a threshold of ±0.15, derived from variations in distant normal appearing white matter, to identify noteworthy changes. Table 1 summarises visual test results for each case, with corresponding FA difference maps in Fig.1. In case 1, reduced FA in the right optic radiation corresponded with loss of left visual field. Case 2 and 3 show increased FA in the lateral geniculate nucleus bilaterally, corresponding with improvements in acuity. These preliminary findings suggest that FA difference maps may be useful for visual function assessment in OPG, warranting further investigation in a larger cohort.
### Table 1 - Example visual function changes over time

<table>
<thead>
<tr>
<th>Time period (months)</th>
<th>Visual Field (VF) changes</th>
<th>Acuity changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Eye</td>
<td>Right Eye</td>
</tr>
<tr>
<td>Case1 3</td>
<td>complete loss left VF</td>
<td>mild increase right VF</td>
</tr>
<tr>
<td>Case2 6</td>
<td>no change</td>
<td>no change</td>
</tr>
<tr>
<td>Case3 13</td>
<td>too young</td>
<td>too young</td>
</tr>
</tbody>
</table>

### A Different Field for Physicists: First experience of pitchside radiological medical physics support

Susan Maguire (1), Paddy Gilligan (1) Anne Marie Smyth (1) Adrian Adams (1) Alan Byrne (2) Conor McCarthy (3) Stephen Eustace (1) Marie Smyth (1)
Mater Private Hospital, Dublin, Ireland (1) Football Association of Ireland, Dublin, Ireland (2) Irish Rugby Football Union, Dublin, Ireland (3)

Player wellbeing and fitness is a priority of top national and international sporting teams. Recognising this, the FAI (Football Association of Ireland) and IRFU (Irish Rugby Football Union) planned that the Aviva stadium become the first Irish stadium to house a radiographic unit as part of its medical facilities. Medical physics and radiologists were involved in the design of the facility from the start. Considerations in the design and specification of the radiographic unit were different from traditional medical facilities. These included the intermittent use, the requirement for on the spot diagnosis, ability to give referring team physicians images immediately, robust environmental conditions, cost, legislative requirements and security. The ultimate configuration consisted of a mobile radiographic unit, lead shield, single plate CR reader, and ultrasound. The service was launched in May 2012 and covered soccer, rugby and an American football game. A number of clinical x-rays have been taken since start up and reported by musculoskeletal radiologists. Medical physics support consisted of unit design, specification, licensing, regulatory, IT, functional workflow, training and acceptance testing. Due to various technical reasons the medical physics involvement was significant on project start up. Further support was given to the national teams in delivery of electronic images from international locations for reporting in Ireland.

### The Automated QA of Clinical Images for Physics Testing

Alexander Fergus Dunn (1)
Integrated Radiological Services Ltd, Liverpool, UK (1)

The use of quantitative image analysis has grown with the development of protocols, the cheapness and availability of computing power and the rise of digital images. Currently these quantitative tests are performed on flat field or simple test object images for digital diagnostic x-ray detectors. The aim of this project is to establish methods to prove that quantitative tests can be carried out on clinical images. If it works for a small selection of the recommended tests, every clinical image could be used to track baseline performance of a unit and reduce the time required to carry out physics checks, which are normally only done on an annual or biennial basis.

First, a phantom study was carried out to establish the methods required to replicate tests described in IPEM Report 32 part VII. This was done by using features in a pelvis x-ray to locate a given area where a Region of Interest can be placed and statistics, such as the Mean Pixel Value, measured. For this to occur images require pre-processing before data extraction can occur, this was carried out using an image processing program, CVIPTools. Once processed the pixel statistics and information from the DICOM header were extracted using IQWorks, a package designed for medical physicists carrying out image analysis. It was found that this was over complicated and using a large, centrally located ROI gave results that replicate those in Report 32 VII better than smaller ROIs placed on a given area of anatomy. Once the phantom study was complete clinical images were obtained from PACS and subjected to the same process as the phantom images.
Results showed that it is possible to carry out a number of tests using clinical images and obtain comparable results as if flat field images were processed. These tests include the accuracy of the DDI value, and the signal transfer properties. As DICOM header also indicates the dose to the patient in form of the DAP, a dose audit for any given examination can also be carried out at the same time.

This study only looked at Pelvis images and further work is required to prove that this concept will work with other examinations. However, the basis for testing clinical images has been shown and will be easily reproducible for any other examination that is deemed appropriate and form the basis of statistical process control mechanisms.
Tuesday 13th September 2016, 11.00 – 13.00

Protons

The Christie Proton Therapy Research Facility

Merchant M.J., Taylor M.J., Owen H, Kirkby N.F., Chadwick A, Mee T, Aitkenhead A.H., Mackay R.I., Kirkby K.J.

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The Department of Health has committed £250 million to developing high-energy proton beam therapy services in the UK. Two facilities are currently under construction located at the Christie NHS Foundation Trust, Manchester, and University College London Hospitals NHS Foundation Trust.

The Christie proton beam therapy centre will host three clinical treatment rooms featuring a ProBeam proton therapy system supplied by Varian Medical Systems. Joint investment by Department of Health and the Christie Charity into the Manchester Proton Therapy Centre has allowed the development of a dedicated proton therapy research space in a fourth room at the Christie proton therapy centre.

This research room will house two static horizontal beam lines, and have the capability for spot scanning beam delivery; The design philosophy for these two beamlines is to provide modular, adaptable end-stations for each beamline that give the flexibility to allow an extensive range of experiments to be performed, encompassing radiobiology, physical, and technical experiments. The research room will be a UK national facility for proton therapy research.

In this talk, I will present the design and planned technical capabilities of the Christie Proton Therapy Research Facility, and discuss how we will be able to use this facility to validate and improve in-silico models of proton-induced DNA damage and repair in cells developed here in Manchester.

Modelling for proton therapy service demand scenarios in the NHS, an application of the Malthus Project

Thomas Mee (1,2), Raj Jena (3) Ranald Mackay (2,1) Norman Kirkby (1,2) Karen Kirkby (1,2)

University of Manchester, Manchester, UK (1) The Christie NHS Foundation Trust, Manchester, UK (2) University of Cambridge, Cambridge, UK (3)

Aim: The advent of Proton Therapy (PT) within NHS England raises a number of possible implementation scenarios. Preparations for service delivery must take all scenarios into account. With 412,000 new cancer registrations in 2013, there are both political and public pressures on the NHS to make sure that the two new PT centres, with an estimated throughput of 1500 patients per year, treat the most appropriate patients to maximise patient benefit. Scenarios must consider the backlog of referrals at the start of clinical treatment, and distribution of patients between the two centres.

Method: The Malthus Project has been utilised within the NHS since 2011 to assist in the prediction of conventional radiotherapy demand. The project methodology will be utilised to provide a demand-side scenario-based planning tool for the ramp-up period of PT delivery. As with previous modelling tools, evidence based treatment guidelines for PT will be encoded in clinical decision trees. Malthus Ramp-Up will also contain additional patient specific factors, such as anaesthetic burden, adjuvant or concurrent chemotherapy and GIS data for accommodation requirements.

Output: The tool will offer a robust decision support tool to the clinical teams responsible for initiation of PT services in England, but the model architecture lends itself to other countries and healthcare systems with high-quality cancer incidence data.
Reducing Range Uncertainties in Proton Beam Therapy through Radiation Metrology
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The University of Manchester, Manchester, UK (1) The Christie NHS Foundation Trust, Manchester, UK (2) University of Surrey, Guildford, UK (3) National Physical Laboratory, Teddington, UK (4)

The beauty of proton therapy over conventional x-ray therapy is that the majority of the therapeutic protons stop within the patient. The problem lies in the fact that we cannot tell, with a great degree of accuracy, exactly where they stop. Curative radiotherapy aims to establish local tumour control whilst minimising the damage to healthy surrounding tissue. Although proton therapy can spare healthy tissue beyond the distal edge of the dose distribution there are uncertainties associated with the proton range. Treatment plans incorporate range uncertainties by adding a margin to the distal edge of the tumour volume. If the range of the delivered protons remains within this margin the target volume receives the planned dose. If an organ at risk is located distal to the tumour then another margin is required to ensure that the proton beam will not impinge on the critical organ tissue. Making treatment plans robust against range uncertainty has major clinical impact due to the compromises imposed, which can result in additional dose to the patient. Reducing the range uncertainty in proton beam therapy is, therefore, highly desirable. This is a very active field of research and radiation metrology plays a key role. An overview of the research being undertaken along with the radiation detection and measurement techniques being employed will be discussed.

Incorporating the effect of fractionation in the evaluation of proton plan robustness to setup errors
Matthew Lowe (1,2) Francesca Albertini (3) Adam Aitkenhead (1,2) Antony Lomax (3) Ranald MacKay (1,2)
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Compared with photons, proton beams are more sensitive to various uncertainties which must be mitigated for their advantages to be realised. Set-up uncertainties may be particularly important for the use of intensity modulated proton therapy (IMPT) where the misalignment of steep in-field dose gradients can lead to large dose discrepancies. As such it is desirable to generate plans that are robust to uncertainties.

For fractionated treatments the uncertainty in the dose over the treatment course will be reduced compared to that of a single fraction due to the convergence of repeatedly sampled random variables. However, this is neglected by current approaches to evaluating proton plans resulting in an overly conservative estimate of the uncertainties. As plan robustness presents a trade-off against plan quality this can lead to sub-optimal plans. We present a method of incorporating this convergence to quantify the uncertainty in the total dose delivered during a treatment course.

The effect of set-up errors on the dose distribution was evaluated by first recalculating plans for 14 rigid patient shifts based on the residual set-up errors after daily patient positioning correction for a patient population. Systematic set-up errors were considered to be negligible. With each fraction, the distribution of possible dose values in each voxel converges towards a normal distribution. The standard deviation of each voxel’s distribution over n-fractions can be determined by dividing the standard deviation of the values over the 14 initial error scenarios by \( \sqrt{n} \). For each voxel, upper and lower bounds for the probable dose value were taken using the 99.9% confidence limits of this distribution. Using all voxels, various 3D dose distributions can be created.

This approach was validated through a Monte Carlo simulation of treatment courses. The worst-case distribution for these simulated courses was derived and compared with the estimated upper and lower bounds of the dose distribution. Results showed good agreement between these distributions providing comparable dose volume histogram bands across a range of treatment sites and fractionation schedules. This provides a more realistic robustness analysis, allowing for robust plans to be produced without unnecessary degradation of the nominal plan quality.
Development of a beam model for Monte-Carlo verification of spot-scanning proton therapy treatment plans
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The Christie NHS Foundation Trust, Manchester, UK (1) Paul Scherrer Institut, Villigen, Switzerland (2)

The time required to perform pre-treatment verification of proton therapy plans by physical measurement is substantial. Independent dose calculations have potential to reduce the physical pre-treatment verification workload. We describe the development of a Monte-Carlo (MC) system for verification of clinical spot-scanning plans, and demonstrate its validation against measured data.

The MC system is based on GATE/GEANT4 with a standard physics list alongside a beam model characterizing the delivery system. The beam model defines the phase space of a virtual source positioned at the vacuum window, in terms of the beam optics (modeling each spot as fully divergent), the virtual beam energy (mean ± std) and the number of protons exiting the nozzle per monitor unit. The system is modular, allowing substitution of alternative beam models. Model generation was automated for efficiency and reliability. A beam model was derived for a clinical spot scanning system (115 energy levels from 70-230 MeV, 27 nozzle extensions, with/without a pre-absorber). Validation was performed against measured integrated depth dose (IDD) curves and measured spot widths in air and in a water-equivalent phantom.

IDDs typically agreed with measurement within 99% for 2%/2 mm local gamma analysis. Beam widths in air agreed within the 0.1 mm measurement uncertainty, and beam widths in solid water were also consistent with measurements. Simulations of treatment plans were in agreement with 2D ionization chamber array measurements.

MC recalculation of treatment plans provides a method of verifying plans prior to treatment, potentially reducing the amount of physical measurements required. Automation of several parts of the beam model process provides an efficient and reliable setup process. The resulting MC system also provides a versatile tool for other applications, such as commissioning of new techniques and testing of quality assurance tolerances.

Novel imaging for ion beam therapy
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Department of Medical Physics, Ludwig-Maximilians-Universität München, Munich, Germany

External beam radiotherapy is continuously evolving to guarantee precise delivery of a biologically effective dose to the tumour, with optimal sparing of surrounding critical organs and healthy tissue. To this aim, over the last years technological advances in beam delivery have been accompanied by an increasing integration and usage of imaging in the entire chain of fractionated treatment, from pre-treatment identification and characterization of the tumour up to anatomical guidance for patient positioning at the treatment site and, in more advanced research applications, visualization of the actual treatment delivery.

Demands on imaging become particularly stringent for the rapidly emerging technology of ion beam therapy, to enable full clinical exploitation of the favourable properties of ion interaction in tissue for unprecedented dose delivery accuracy. This contribution will thus review the role of modern imaging for ion beam therapy, from advanced multi-modal diagnostics for novel concepts of treatment planning up to integrated in-room anatomical image guidance and, more importantly, new imaging modalities aiming to reduce the main challenge of ion beam range uncertainty in tissue. Special emphasis will be given to the latter technologies, featuring pre-treatment transmission imaging of multi-energy X-ray sources or energetic ion beams for refined assessment of the tissue stopping properties, as well as online/post-treatment detection of acoustic and nuclear-based emissions induced by ion interaction in tissue for in vivo verification of the beam range. In particular, this contribution will critically review the main ongoing developments and initial pre-clinical or clinical experience, discussing the prospects of novel imaging for ion beam therapy.
Towards MR-linac Dosimetry: The Effects of Air Gaps on Ion Chamber Measurements in a Magnetic Field
James Agnew (1), Geoff Budgell (1) Simon Duane (2) Frank O'Grady (1) Ryan Young (1)
Christie NHS Foundation Trust, Manchester, UK (1) National Physical Laboratory, Teddington, UK (2)

Aims: We aim to quantify the variation caused by air gaps when performing ionisation chamber (IC) measurements in a magnetic field, with the intent of informing practice for the emerging generation of integrated MRI radiotherapy treatment machines. We also characterise the response of several ICs in a magnetic field for varying field strengths.

Methods: Perspex phantoms were constructed such that they were rotationally symmetric about the chamber stem at cardinal angles except for a small (approx. 0.3mm deep) recess next to the sensitive volume of the IC, covering 90° of the circumference of the phantom cavity. Measurements were performed with ICs in these phantoms in a Co-60 beam with and without a 1.5T magnetic field, generated by electromagnet, and the ratio of measurements $M_{1.5T}/M_{0T}$ taken with no additional media in the phantom cavity and the recess at each cardinal angle about the IC. These measurements were repeated with water added to the cavity for each IC, and again for the PTW 30013 chamber after introducing a small (approx. 40mm³) bubble into the recess, made possible by the novel phantom design. Ratios $M/M_{0T}$ were performed for all ICs across the full range of magnetic field strengths available (0 – 2T) to characterise the IC response in steps of 0.25T in an airless setup.

Results: IC measurements varied consistently when the position of the recess was rotated about the IC stem axis when the air gap was present. The maximum peak-to-peak (PTP) variation was 8.8% (PTW 31006), and the lowest was 1.1% (Exradin A1SL). This variation was essentially eliminated by the introduction of water into the cavity (maximum PTP variation 0.7% - PTW 31010), and consistent with measurements in 0T magnetic field. A large (3.9%) PTP variation was observed for the PTW 30013 IC when an air bubble was positioned next to the sensitive volume of the chamber in an otherwise airless setup, with 0.2% PTP variation when no bubble was present.

Conclusions: Small air gaps can affect the result of IC measurements in radiation dosimetry, with the magnitude of the effect dependent on the position of the air gap with respect to the chamber, beam and magnetic field direction. Introducing water to the cavity can eliminate air gaps and thereby reduce this variation. Hence, ionisation chamber dosimetry measurements for the MR-linac should not be performed in solid phantoms in which air gaps around the IC are present in unknown positions.

Use of Portal Dosimetry for Adaptive Radiotherapy Investigations in Head and Neck Cancer
Aodh Mac Gairbhith (1), Nilesh Tambe (1) Jenny Marsden (1) Peter Colley (1) Kirstie Smith (1) Andrew Beavis (1,2)
Radiation Physics, Castle Hill Hospital, Hull and East Yorkshire Hospitals NHS Trust, Hull, UK (1) University of Hull, Hull, UK (2) Sheffield Hallam University, Sheffield, UK (3)

Background
Changes in patient anatomy during the course of treatment can result in differences between the planned and delivered dose distribution. Patient imaging alone does not give a clear indication as to when the dose distribution has been significantly changed. Results of portal dosimetry could be used to trigger adaptive radiotherapy by detecting a difference in planned and delivered radiation dose [1]. The aim of this project is to investigate whether quantitative information from portal dosimetry can be used as an action level for adaptive planning in head and neck cancer.

Method
Initial tolerances were investigated using an anthropomorphic phantom. Layers of thermoplastic bolus were used to simulate various amounts of contour change. The reference portal image was acquired using a VMAT plan delivered with 24mm bolus on the phantom. Bolus was removed in 4mm thick steps and the
acquired portal images were compared to the reference image.

Clinically acquired portal images were analysed from bilateral head and neck patients. The portal images acquired weekly were compared to the image from the first day of treatment in the portal dosimetry module of ARIA.

**Results**
Gamma analysis at 3%/3mm was performed on the phantom images. The max gamma values are shown in Table 1. The gamma evaluation with 12mm reduction in contour is shown in Figure 1.

**Table 1: Max gamma for contour decrease on anthropomorphic head and neck phantom with gamma criterion of 3%/3mm.**

<table>
<thead>
<tr>
<th>Contour Reduction (mm)</th>
<th>0</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Gamma</td>
<td>0.28</td>
<td>0.92</td>
<td>2.04</td>
<td>3.05</td>
<td>4.5</td>
<td>6.94</td>
<td>8.88</td>
</tr>
</tbody>
</table>

A significant change in dose distribution was seen at max gamma >3. This tolerance was used to assess patient images. Initial results from 18 patients showed that 50% underwent dose distribution investigations. Using the tolerance of max gamma>3, portal dosimetry flagged up 61% of patients which included all the patients investigated and 2 other patients.

**Discussion**
The portal dosimetry technique detected all cases which were investigated. Of the two flagged up and not investigated, one exceeded the tolerance only on the third last fraction and would not have been acted upon. The other patient experienced some pitch issues.

The method only takes into account changes that occur during the course of treatment. This means that it does not detect changes that occur after the planning CT but before treatment begins. It does however act as a consistency check during treatment.

**Conclusion**
The initial results show that the gamma index metric could be suitable as an action level for a replan due to a shape change when the portal dosimetry method described above is used. This method gives no extra dose to the patient and could provide quick and useful information on dose distribution changes.

**Key Reference**

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**Patient Size Specific CBCT Optimisation using IQ Works**

Stephen Milner (1)

Mount Vernon Cancer Centre, Hertfordshire, UK (1)

Currently at our centre, Cone Beam CT (CBCT) is used for 3D image matching to assess changes in patient size and shape during radiotherapy. Our current imaging protocol sees a different set of imaging...
parameters, kV, mA and ms, used for the routine CBCT imaging of each physiological site. For prostate patients, variations in patient size means that, the use of a single set of parameters for all patients for each treatment site is likely to lead to unnecessarily high dose to smaller patients, and impaired image quality for the larger patients. To address this, it was proposed to develop an imaging protocol based on patient size and optimising the CBCT settings for each group.

A retrospective patient audit was performed on 50 prostate patients. These were grouped into small, medium and large categories based on multiplying their Ant-Post separation by their lateral separation distances. Measurements were made using the Catphan 504 image quality phantom, modified with bolus to simulate each size group. This was scanned using CBCT on a Varian OBI system using different exposure settings.

The IQWorks automated image analysis software package was used to analyse the contrast to noise ratio for each scan to determine the optimum imaging parameters for each phantom size based on the required CNR to fulfil the CBCT’s purpose and the CTDI of the scan. For the small patient protocol a dose reduction of 53% was proposed whilst maintaining the CNR at the level expected with the current protocol for a medium sized patient. For the large patient protocol a dose increase of 45% was required to maintain the CNR at the current protocol for a medium sized patient.

Following this study a trail run on a small number of patients is being implemented to judge the practical feasibility of using patient size specific protocols.

**Development of a software tool for the assessment of 4DCT breathing traces acquired using Varian’s Real-time Position Management (RPM) system.**

Robert Lally (1), Barry O’Connell (1) Denise Irvine (1)
Belfast Health and Social Care Trust, Belfast, UK (1)

During a four-dimensional computed tomography scan (4DCT) acquisition, the patient’s breathing pattern is monitored to enable images to be correlated to a particular phase in the breathing cycle. At the Northern Ireland Cancer Centre (NICC), Varian’s Real-time Position Management (RPM) system is used to acquire these traces. The RPM system is capable of identifying erratic breathing patterns and can exclude images identified by the filter. Inclusion of these images can lead to differences in target contouring.

The aim of this work was to develop a tool which uses the measured breathing trace to facilitate the assessment of 4DCT scans. This tool generates a graphical representation of the breathing trace, and highlights the position of filtered data, along with the target location. By comparing the maximum range of motion of the target to the mean amplitude across the entire trace, it is possible to determine if the scan is affected by breathing irregularities around the target location. Furthermore, the tool can be used to verify that suitable scan parameters, such as cine-duration and time between images, were chosen.

In summary, the tool developed using Microsoft Excel to analyse traces from the RPM system can aid the assessment of 4DCT scans and is useful for determining whether or not a repeat scan is necessary. In addition, this tool has the potential to aid patient breath monitoring during Lung radiotherapy treatment delivery, to ensure that patient breathing during treatment delivery represents that acquired during simulation.

**A comparative study of Volumetric Arc Therapy (VMAT) vs Static field Intensity Modulated Radiotherapy (IMRT) for the treatment of stereotactic ablative body radiotherapy (SABR) Spine Metastases**

Abdul Sattar Khalid (1,2) Mahmud Moallim (1) Phillip Cooper (1) Phillip Whitehurst (1)
The Christie NHS Foundation Trust, Manchester, UK (1) The University of Liverpool, Liverpool, UK (2)

**Aims:** This study aims to determine which delivery technique is superior in terms of target coverage, organs at risk (OAR) sparing and treatment efficiency. Ultimately, the aim is to produce a robust SABR planning solution for patients presenting with spinal metastases.
Methods: Treatment planning was carried out on 15 patients with 16 treatment sites with a prescription of 27Gy in 3 fractions; using Pinnacle V9.8 treatment planning system (TPS). The Varian Novalis Tx 6MV SRS beam model was used to produce 7 beam static IMRT and 1, 2 and 3 arc VMAT plans. The Elekta Agility FFF beam model was used to produce Flattening filter free (FFF) VMAT plans. Dosimetric analysis was performed in terms of the following dosimetric indices; conformity index (CI), target volume coverage (TVC) and gradient index (GI). OAR doses, volume receiving low doses (V30%), plan monitor units (MU) and estimated beam delivery times were assessed and compared for all plans.

Results: VMAT plans (1, 2 and 3 arc) were more conformal, had better TVC and better dose fall off outside the target and had less volumes receiving low dose than IMRT plans (statistical significance of $p < 0.05$). OAR doses were lower with VMAT (1, 2 and 3 arc); however there was no statistical significance in the difference. All dosimetric indices improved when using more than 1 arc for VMAT but there was only a small improvement in TVC and GI when using 3 arcs instead of 2. OAR doses remained similar and within tolerance for all VMAT plans. FFF VMAT plans showed the same trends as non-FFF however, 1arc FFF VMAT plans were worse across all dosimetric indices compared to IMRT (statistically significant). FFF VMAT plans were similar in conformity but slightly poorer in TVC and GI when compared to non-FFF (statistically significant); OAR doses remained similar and within tolerance. FFF VMAT delivery is more efficient than non-FFF; 54%, 24% and 7% quicker estimated beam delivery times for 1, 2 and 3 arcs respectively.

Conclusion: Based on this planning study; VMAT appears to be a better treatment delivery technique than 7 beam static IMRT for SABR spine metastases, in terms of target coverage, OAR sparing and treatment efficiency. 2arc VMAT produces better plans than 1 arc, but not significantly better than 3arcs. FFF drastically reduces estimated treatment delivery times for 1 and 2 arc VMAT.

Using Cone Beam CT Data to Assess Delivered Dose to the Heart throughout Breast Radiotherapy
Niccole Dunkerley (1)
The University of Surrey, Guildford, UK (1) They Royal Marsden Hospital, Sutton, Sutton, UK (2)

Introduction: Deep Inspiration Breath-hold Radiotherapy is a technique which can significantly reduce cardiac dose for Breast cancer treatments; however, it is not widely implemented in departments in the UK. The purpose of this study was to investigate if Cone Beam CT images taken during Breath-Hold Radiotherapy treatment can be used to estimate the heart dose received in comparison to the predicted heart dose, and therefore, provide further evidence for the benefits of this technique and patient outcome.

Methodology: Data collected from 13 patients during the UK HeartSpare Study was utilised in this investigation. The study was randomised so that patients received one technique, either Active Breathing Control (ABC) breath-hold or voluntary breath-hold (VBH), for fractions 1-7 and the other technique for fractions 8-15. All patients received 40 Gy in 15 fractions. CBCT images were acquired immediately before treatment. The CBCT scans were exported from the X-ray Volume Imaging system onto the Pinnacle treatment planning system and the heart was then contoured on the CBCT scans and analysed. A phantom experiment was completed to investigate the effect of movement during imaging.

Results: There was no statistically significant difference between mean heart doses or the heart contour volumes from ABC and VBH treatments ($p=0.801$, $p=0.336$ respectively). The phantom experiment showed artefacts from movement in the images similar to those seen in the patient CBCT images.

Conclusion: The investigation found the quality of the CBCT images determines the ability to contour the heart outline and therefore the ability to assess the amount of dose the heart received throughout the treatment period. The CBCT images show a statistically insignificant difference between the predicted and the received dose, showing the breath-hold technique to be successful at reducing dose to the heart and improving patient outcome. There was also no statistically significant difference between the ABC and VBH techniques, showing VBH to be a cheaper, reliable option to the ABC technique.
Establishing National DRLs for the use of CT in Nuclear Medicine Examinations

Iball G
Medical Physics, Leeds Teaching Hospitals NHS Trust - on behalf of the IPEM CT doses in Nuclear Medicine Working Party

Background. The use of CT in Nuclear Medicine (NM) has increased markedly in the last decade. Whilst the UK has had Diagnostic Reference Levels (DRLs) for diagnostic CT and radio-isotope examinations for many years, there are currently no such DRLs for the use of CT in NM. Moreover, there is a general lack of international guidance in this area.

Methods. The IPEM CT doses in NM working party has undertaken a national survey of CT doses in both SPECT and PET imaging, covering three PET-CT and seven SPECT-CT examinations. Standard protocol and patient specific data was acquired for each of these examinations for a range of CT purposes. All data was included in the analysis, however, for DRL generation a minimum of ten data sets was required for given examination and CT purpose combination.

Results. PET-CT data was obtained from 35 systems, covering 32 centres, whilst SPECT-CT data was obtained from 50 systems in 44 centres. The most common examinations were: half-body PET-CT and cardiac, parathyroid, octreotide and bone SPECT-CT. Typical (median) doses for half-body PET-CT varied by a factor of 4 between centres for the same CT purpose, whilst for SPECT-CT the dose variation for a given examination/CT purpose combination was as high as a factor of 14. Where there were sufficient datasets, suggested National DRLs and achievable doses have been proposed and these will be presented. The effect of the use of CT Automatic Exposure Control and CT iterative reconstruction was also investigated.

Discussion. Results of this study form the first major national survey of CT doses in Nuclear Medicine and will be used as a benchmarking tool for NM departments in the UK and internationally.

Conclusion. Suggested National DRLs for SPECT-CT and PET-CT have been developed which should be used as a tool for ongoing optimisation of CT in NM examinations.

Key references.

A strategy for the determination of suitable reference doses for paediatric investigations, serving also as a tool for optimisation and supporting ISAS accreditation

Mike Holubinka (1)
Great Ormond Street Hospital, London, UK (1)

Introduction: The recently published EPiDRL guidance (draft) sets out a methodology for establishing local, national and European DRLs for paediatric imaging. DRLs provide stakeholders with useful data with which to evaluate the effectiveness of dose control. National bodies have an interest in DRLs for the purpose of regulation and quantifying risks to populations from the use of X-rays. The challenge of acquiring sufficient dose data to determine paediatric DRLs for all but the largest institutions should not be under-estimated.
**Method:** Study dose data (>5000 studies) have been reviewed for a newly installed Siemens Force CT and compared with retrospective data for the Siemens Definition that it replaced. Data analysis is based on data drawn from RIS, PACS and direct modality transfer of Radiation Dose Structured Reports (RSDR) to dose management and extraction software. Direct comparisons have also been made using anthropomorphic phantoms, representing newborn, 1yr, 5yr and 10yr olds.

**Results:** DRL data was readily established for common studies having a frequency >>1 per week. Patient weight could be extracted from RIS, and combined with RSDR data for calculation by EPiDRL groupings. Data redundancy rates could be high where input errors occurred. Insufficient data was available to define ISAS reference doses for the range of required studies for the EPiDRL ranges. Cross Sectional Area provided an useful surrogate for weight for head scans. 50% reductions are demonstrable utilising dose saving features.

**Conclusions:** DRLs are of limited value and sluggish to deliver prompt information to demonstrate the effect of technique change for optimisation, or for providing useful information for reference data as part of accreditation schemes, e.g ISAS. Determining dose to anthropomorphic phantoms proved highly effective for introducing new equipment, establishing ISAS reference doses and for evaluating changes where baselines exist. Comprehensive detailed dose data audit coupled with patient by patient image review enables both review of technique (or protocol dose) for optimisation and patient dose metrics for local DRL review. The DRL methodology alone does not effectively support on-going protocol refinement, but does provide useful data for broad reassurance audit.

**Using an Image Quality parameter for routine assessment of AEC performance in DR systems**

Patrick Monnelly (1)  Patrick Kenny (1)
Mater Misericordiae University Hospital, Dublin, Ireland (1)

We describe the use of Signal to Noise Ratio (SNR) as a metric for routine performance testing of the automatic exposure control (AEC) devices. AEC testing represents a significant component of digital radiology (DR) quality assurance (QA) testing. IPEM report 32 part VII recognises the weakness of both detector dose index (DDI) and detector air kerma (DAK) as AEC test parameters. However, both of these parameters are still currently recommended for AEC DR assessment. Having investigated several image quality metrics as AEC test parameters a DR AEC QA protocol was developed using signal-to-noise ratio as the test parameter. This oral presentation will describe how SNR is used to assess kV reproducibility, repeatability, chamber balance and attenuator reproducibility. We describe the efficiency of the method in reducing the room time required for testing. We also present the results of a survey of over twenty DR AEC systems using this protocol as well as determine provisional remedial and suspension levels for this technique.

**Typical doses and dose conversion coefficients for whole body CT in major trauma**

Lorna Sweetman (1)
Christie Medical Physics & Engineering, Manchester, UK (1)

**Background**
Whole body CT (WBCT) scans covering the head, neck, thorax, abdomen and pelvis are a standard part of the clinical pathway for severely injured patients1. While some have challenged the need for WBCT in all major trauma situations2, it is usually accepted that the justification decision will be straightforward due to the significant benefit to the patients. However, local experience has indicated that not all practitioners are familiar with the typical doses involved nor would they be able to estimate the effective dose given the dose-length product (DLP) for a WBCT scan.

**Method**
Data from 442 adult patient scans were collected from four hospitals for eight combinations of major trauma WBCT protocols and scanners (GE, Philips and Siemens). Certain datasets included a detailed breakdown of CTDI and DLP by body region and patient demographics.

**Results**
The average DLP was determined for each protocol and scanner. The mean of the scanner/protocol mean DLPs was 2534 mGy.cm (range 1740 – 3113 mGy.cm). The range for individual DLPs was 512 – 7471 mGy.cm and was generally normally distributed within each dataset. Effective doses were also calculated for each scan where DLP data were available by body region. The mean effective dose across all scanners and protocols was 30 mSv (range 12.4 – 69.2 mSv), with an average effective dose to DLP ratio of 0.01.


Experiences of performance assessment and optimisation of automatic exposure control for direct digital radiography units
Daniel Shaw (1) Carolyn Legate (1) Elizabeth Britland (1)
Christie Medical Physics and Engineering, Manchester, UK (1)

Automatic exposure control (AEC) is often used in planar X-ray imaging. It has endured advances in imaging technology such as computed radiography and direct digital radiography (DDR) with their different performance characteristics and therefore evolving clinical imaging protocols such as high kV chest imaging. It is important that commissioning and quality assurance (QA) procedures reflect clinical use due to their influence on image quality and patient dose. A year ago we reviewed our existing procedures and refinements were made including extending the range of kVs assessed. At commissioning we introduced the use of the detector dose index (DDI) to establish consistent levels of image quality for kV and thickness compensations. For routine QA the changes streamlined the measurements and the equipment required whilst maintaining a comprehensive overview of AEC performance. This presentation is a review of the experience gained during the year since the implementation of the changes: the practical issues raised, investigations made, and data amassed over this period.

In general the refinements have been found to be successful. Issues included:
- Many retrofitted rooms have required AEC recalibration, mostly due to the extended kV range now in use.
- DDI may not be calculated using the central portion of the image and typical PMMA phantoms are not sufficiently large to produce a uniform flood image.
- It has not always been straightforward to successfully recalibrate the AEC when kV compensation is found to be poor. A particular issue with retrofitted units.
- Further investigation of relationship between DDI and signal to noise ratio (SNR) is required and their relationship to beam quality (both hard and soft beams).

References
Quality Assurance

**A comprehensive electronic QA system for Truebeam linear accelerator dosimetry built on Sun Nuclear Systems’ ATLAS, QA3 and IC Profiler**

David Carnegie (1)  Gary Barfield (1)  Mohamed Metwaly (1)
United Lincolnshire Hospitals Trust, Lincoln, UK (1)

With the recent instalment of two (soon to be three) Varian Truebeam linear accelerators in the department it was necessary to review and update our QA system to maintain and exceed legislative requirements and professional guidance.

Chief among this was a drive to abandon pen-and-paper methods in favour of an entirely electronic method of recording, reporting and analysing dosimetric data. Using ATLAS allows one to schedule and track QA tasks and then measure and analyse the information gathered using a single interface. The data is stored in a central server which can be accessed by the application from any terminal with the client software.

Each day a series of DICOM loaded machine instructions are executed on the LINAC and measured by the QA3 device mounted to the gantry. On a daily basis output, flatness, symmetry, dose rate linearity, field size and field shift are measured for square and wedged fields at varying gantry and collimator angles. Dose rate is varied by performing a different arc each day for each of the photon energies allowing an indirect check of the gantry mechanics as well.

The dose difference between the daily check device and the latest Farmer chamber output (weekly) are compared every time an output measurement is made. This has identified when Farmer chambers have malfunctioned.

After commissioning the IC Profiler, it was found that the measurements were in agreement with water tank data to within <1%. Therefore on a monthly basis, beam profiles (flatness and symmetry) are measured with the IC Profiler array in two dimensions, the measurements from which are directly compared to water tank measurements. The Profiler is also compared with the QA3 to ensure agreement with the Profiler and to allow the ability to spot “drifts” in equipment calibrations.

ATLAS functions as a task manager as well allowing advanced scheduling of machine down time to fit around clinical need. All data is stored automatically in the system via the test builder module where it can be accessed, analysed and easily trended.

**Characterisation of a two-dimensional liquid-filled ion chamber detector arrays using flattened and un-flattened beams for small fields, small MUs and high dose-rates.**

Conor K McGarry (1,2) Prabakar Sukumar (1) Candcice McCallum (1) Alan R Hounsell (1,2)
Radiotherapy Physics, Northern Ireland Cancer Centre, Belfast Health and Social Care Trust, Belfast,Northern Ireland, UK (1) Centre for Cancer Research and Cell Biology, Queen’s University, Belfast,Northern Ireland, UK (2)

The MU linearity, field size, dose rate, dose per pulse (DPP) response and dynamic conformal arc treatment accuracy of the PTW 1000SRS array with Octavius 4D phantom has been characterized for both flattened and flattening filter free (FFF) beams. The 1000SRS array was assessed at 6MV, 6FFF and 10FFF using a Varian TrueBeam STx linac. To assess the effect of cross calibration dose rate, clinical plans with different dose rates were also delivered and analysed. The measurements from the array were compared with a pinpoint ionisation chamber (IC), a microdiamond IC and with EBT3 Gafchromic film. Measured dose profiles and FWHMs were compared with film measurements. Verification of FFF VMAT clinical plans were assessed using gamma analysis with 3%/3mm and 2%/2mm tolerances (10% threshold). Output factors agreed with film measurements to within 4.5% for fields between 0.5cm and 1cm and within 2.7% for field sizes between 1.5cm and 10cm and were highly correlated with the microdiamond
Implementing and using SNCmachine - Automated TG-142 Solution
Nicola Mullins (1) Mohamed Metwaly (1)
Lincoln County Hospital, Lincoln, UK (1)

Our department has been embarking on a large development with the installation of three Varian Truebeams, Eclipse treatment planning and ARIA record and verify. We planned to update our Quality Assurance program to help improve its effectiveness in identifying problems before they become an issue clinically. To achieve this various software solutions were investigated and purchased.

One of these solutions was SNCmachine, a browser-based software that provides analysis of QA tasks, such as those described in AAPM TG -142. The software will allow the user to analyse data using a variety of radiotherapy inputs kV, MV, integrated MV, CBCT and trajectory files. We can then determine Hounsfield units, noise, contrast, uniformity, resolution, distortion to name but just a few.

Commissioning was initiated by importing baseline images from QA patients within ARIA. A DICOM daemon automatically imports data when a QA patient is treated. To test the tasks, erroneous images were created and imported into the software. For example, the picket fence test plan was sent with varying errors in MLC positions of up to 3mm. The software determined the positioning of these gaps within 0.3mm leaf gap error. Similar erroneous images and files were used to evaluate all the tasks within the software.

The ability to set up the automatic transfer and testing of these tasks allowed for an increase in frequency with which the tests can be done. This then can improve the efficiency of the QA program to identify faults with kV and MV imaging, along with the ability to check the VMAT and DMLC delivery more effectively.

Evidence-based reduction in quality control of Elekta cone-beam CT imaging systems
Geoff Budgell (1) James Beck (1) Phill Cooper (1) Nicki McGrath (1) Imran Patel (1) Bruce Perrin (1)
Alistair Pooler (1)
CMPE, The Christie NHS Foundation Trust, Manchester, UK (1)

Aims Cone-beam CT (CBCT) was first installed at our Institute in 2003. Since then the CBCT QC burden has significantly increased with all our clinical linacs now CBCT-enabled. The aim of this work was to review our CBCT QC results, compare our methods with recently published recommendations [1,2] and determine whether our QC frequencies, tolerances and methods could be revised to reduce our total QC burden.

Methods CBCT QC results from 9 Elekta linacs over 2 years were plotted and the results examined for reproducibility and consistency between linacs. The main checks examined were monthly image quality and kV/MV isocentre checks for three different fields of view. Test frequencies & tolerances were also compared with the AAPM recommendations [1,2].

Results Many of our QC tolerances were adjusted – some relaxed & some tightened – in line with the measured results. E.g. spatial resolution tolerance was previously ≥6 line pairs/cm whilst AAPM [1] recommended ≥5 lp/cm. Normal QC results lay within 6-8 lp/cm for SFOV & 5-8 lp/cm for MFOV & LFOV. Hence we retained ≥6 lp/cm for SFOV and reduced the tolerance to ≥5 lp/cm for MFOV & LFOV. Excellent
agreement was found between kV/ MV isocentres but 0.5mm systematic offsets were found in laser set-up in the longitudinal & vertical directions leading to improvements in our laser set-up and QC. Excellent reproducibility of QC data enabled reduction in the frequency at which many of tests are performed without compromising safety. CBCT QC time was reduced by around two-thirds and streamlined sufficiently to allow some tests to be completed during morning run-ups.

**Conclusion** Careful analysis of QC data enables evidence-based reduction of the total QC burden while maintaining safe practice.

**References.**
Development of a RapidPlan™ model for use in the treatment of gynaecological tumours
Nicola Laverick (1), Melissa Leitch (1)
Beatson West of Scotland Cancer Centre, Glasgow, UK (1)

RapidPlan™ (Varian Medical Systems, Inc.) is a knowledge based treatment planning tool that can be used to estimate dose-volume histograms based upon the relative geometry of the organs at risk and the target volume. RapidPlan™ can then generate optimisation objectives based upon DVH data and the knowledge database of previous plans. This project aimed to build a RapidPlan™ model to be used in the optimisation of treatments for gynaecological tumours treated with RapidArc™. A secondary objective was to determine the effect of introducing plans from older versions of the planning system into a RapidPlan model.

Two models were built and trained using previously optimised treatment plans. One model contained plans originally planned with various versions of the optimisation and dose calculation algorithms and the second was restricted to plans using only the most recent optimisation (PO 13.6.23) and dose calculation algorithm (AAA 13.6.23). Both models were used to generate optimisation objectives for the OARs, with fixed objectives set for the PTV. The OARs specified in both models were bladder, bowel, left and right femoral heads and rectum.

Ten patients not included in the training of the models were used to verify the models. For each patient, both models were used to estimate DVHs and generate optimisation objectives. The resultant plans were then compared to each other and the original clinical plan in terms of PTV coverage and doses to the organs at risk.

Preliminary results indicate that the plans created using the RapidPlan™ models often have reduced OAR doses in comparison to the clinical plans, especially for the bladder and bowel. However, the PTV coverage in the plans created using the RapidPlan™ models is slightly reduced compared to the clinical plans, though this rarely results in a plan being clinically unacceptable. The second model, trained using a more restricted set of plans appeared on average to achieve lower bowel doses.

Global and Sector based dosimetric comparison of plugged vs plug-free needles in permanent prostate brachytherapy
Louise Sarri (1), Cathryn Crockett (2) A.B. Mohamed Yoosuf (1) Geraldine Workman (1) Darren M. Mitchell (2) Suneil Jain (3,2)
Medical Physics, Belfast Health and Social Care Trust, Northern Ireland Cancer Centre, Belfast, UK (1)
Department of Clinical Oncology, Belfast Health and Social Care Trust, Northern Ireland Cancer Centre, Belfast, UK (2) Queen's University, Belfast, UK (3)

Aims and Introduction
The goal of permanent prostate brachytherapy is to achieve adequate tumour and gland coverage with minimal toxicity. Previous studies have identified relative underdosing at the anterior prostate base. One potential cause for this is the effect of the deadspace created by the bio-absorbable plug in plugged needles. Plug-free needles have the potential of improving dose to this area by removing the dead-space created by the plug. We wished to compare the post implant CT global and multi-sector dosimetry of patients treated using plugged and plug-free needles.

Materials and Methods
58 consecutive cases were identified with Group 1 (n=28) treated with plugged needles and Group 2 (n=30) treated using plug-free needles. Dosimetric analysis was performed for the whole prostate and 12 individual sectors [1], including minimum dose to 90% of the prostate or sector (D90), and dose to 0.1 cm³ of the rectum (D0.1cc), as well as the number of needles per unit volume (N/V) and seed loss.
**Results**

Global dosimetry was similar for both groups, but fewer needles were required per unit volume in Group 2 (0.58±0.10 cm\(^{-3}\) vs 0.66±0.15 cm\(^{-3}\); p<0.05). Seed loss was significantly reduced in Group 2 (p<0.05). Furthermore, sector analysis indicated improvements in D90 in a number of sectors of the prostate (p<0.05), except for the anterior gland. The rectal D0.1cc was higher in Group 2 than Group 1 (114% vs 100%, p<0.02) but well within recommended tolerances [2].

**Conclusions**

Our results indicate that plug-free needles have the potential to improve implant quality via better spatial dose distribution within the prostate using fewer needles and reducing the number of seeds lost.

**References**


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**Using a Monte Carlo code to calculate in a patient-specific manner the dose distribution delivered by an HDR Ir-192 source**

Dina Roshd (1,2) Mark McJury (3,2) Gerry Lowe (1)

Mount Vernon Cancer Centre, Northwood, UK (1) The Open University, Milton Keynes, UK (2) Beatson WoS Cancer Centre, Glasgow, UK (3)

In brachytherapy, most treatment planning systems make a surprising approximation: when they calculate a dose distribution, they approximate a patient as an infinite expanse of water. They thus ignore any effects that scattering and heterogeneity may have on the dose delivered. The aim of this work was to carry out dose calculations in a patient-specific manner.

The particular brachytherapy source considered was the high-dose-rate (HDR) Ir-192 GammaMed Plus source (Varian Medical Systems, Palo Alto, CA), which is currently in use at the Mount Vernon Cancer Centre. The method used to perform the calculations was the Monte Carlo method. Specifically, the Monte Carlo code used was the Algebra2 code, which has been developed by the research group of Professor Luc Beaulieu at Laval University (Quebec City, Canada).

The original Algebra2 code was adapted so that it could model the GammaMed Plus source. To test the new model, the energy-weighted spectrum, the radial dose function and the anisotropy function of the source were all calculated and found in agreement with consensus datasets.

The code was then used to study a model of a scalp treatment. In such a treatment the dose delivered to the scalp has the potential to be affected by both scattering and heterogeneity, as an HDR source is in proximity of both air above the scalp and skull bone beneath it. Preliminary results suggest that (1) with the treatment shell used at the Mount Vernon Cancer Centre, the catheter-air interface reduces the scalp dose by ~1.5% (compared to the dose calculated for an infinite expanse of water), (2) the presence of skull bone increases the scalp dose by ~0.5%, and (3) the addition of a layer of bolus on top of the treatment shell increases the scalp dose by a further ~1%. Together these results may be of clinical significance, as in current practice, the scalp dose calculated by a treatment planning system is scaled down to account for loss of scatter, and the use of an additional layer of bolus is not systematic.

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**Investigating the effect of lead apron thickness on staff protection in interventional radiology**

Matthew Marzetti (1) Siobhan McVey (1) David Sutton (1)

NHS Tayside, Dundee, UK (1)

Interventional radiologists are required by IRR 99 regulation 8(1) to wear personal protective equipment in order to keep their personal doses as low as reasonably achievable (ALARA). Lead aprons with the equivalent of 0.25 mm or 0.35 mm of lead are routinely worn to provide the required protection, however very little research has been done into the thickness of lead required.
This investigation uses data from a Monte Carlo N-particle code to simulate the x-ray scatter fluence per unit workload received by an operator standing 1 m from the patient, at different operating potentials. The simulated x-rays were passed through various thicknesses of lead using the IPEM spectrum processor before being converted to air kerma, effective dose and Hp(10) per unit workload. This was then combined with radiologist workload data from Ninewells Hospital and Medical School to obtain an estimate of each radiologists received dose.

Ninewells Hospital currently has a 2 mSv per year local dose limit. If a member of staff exceeds this limit an investigation is required. The results of the simulation indicate that 0.35 mm of lead equivalent provides enough protection to avoid exceeding this limit if the radiologists workload is less than 8400 Gy cm\(^2\), provided procedures are carried out at 85 kV. If the radiologists annual workload is less than 4100 Gy cm\(^2\) then only 0.25 mm of lead are needed. The radiologists with the highest workloads in NHS Tayside currently exceed 8400 Gy cm\(^2\) and wear 0.35 mm jackets, however no local limits have been breached during the year. The simulated doses for each radiologist were compared to doses measured on the radiologists personal dose badge. It was found that doses calculated by the simulation were up to two orders of magnitude greater than those measured on the personal dosemeters. A similar comparison was done on collar badges, which are worn above the lead apron and good agreement was found for the simulated and recorded doses in this instance. The significant underestimation of doses may be due to dosemeters being worn below the level of the lead skirt on the side of table and so receiving significantly more shielding than the wearers torso.
**Tuesday 13th September 2016, 16.00 – 17.30**

**Radiation Protection**

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**Revision of the Medical & Dental Guidance Notes**

John Saunderson¹, (William Mairs², Philip Mayles³, Lisa Rowley⁴, Mark Worrall⁵)

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²RPSIG representative. Christie NHS Foundation Trust, Manchester, UK

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**Background**

In 2002 the Institute of Physics & Engineering published the “Medical and Dental Guidance Notes - A good practice guide on all aspects of ionising radiation protection in the clinical environment” as a replacement of previous Government guidance. In the 14 years since then, the big yellow book has provided invaluable assistance to MPEs, RPAs, RPSs, and RWAs in ensuring the safe use of ionising radiation in healthcare, for both staff and patients. However, in that time there have been changes in legislation, new techniques and practices, and more published work and guidance. In 2018, UK legislation will change further with the transposition into UK law of the 2013 Euratom “Basic Safety Standards for protection against the dangers arising from exposure to ionising radiation”. While a large proportion of the advice in the Guidance Notes is still current, there are an increasing number of gaps and out of date references.

**Revision**

In response to this need, a new revision of the Guidance Notes is currently being prepared by a working party formed by IPEM’s Diagnostic Radiology, Nuclear Medicine, Radiation Protection, and Radiotherapy Special Interests Groups. The working party aims to publishing the new edition as early in 2018 as practicable, once the new regulations have been finalised.

**Consultation**

A good deal of work and updating has already been undertaken in consultation with the regulators. The working party has recently sought further input from the medical and dental radiation user community in general (both individuals and institutions) on changes, additions, deletions, etc. that they would like to be considered for the new edition, and further comments are invited.

**Key references.**

- Allisy-Roberts, P. (Ed), Medical and Dental Guidance Notes - A good practice guide on all aspects of ionising radiation protection in the clinical environment, IPEM, 2002

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**Radiation Protection Self-Assessment**

Catherine Taylor (1), Lorna Sweetman (1)

The Christie NHS Foundation Trust, Manchester, UK (1)

Christie Medical Physics and Engineering (CMPE) is a Health and Safety Executive (HSE) recognised Radiation Protection Adviser (RPA) body for 13 acute NHS trusts, as well as breast screening centres and private hospitals. As part of the RPA and Medical Physics Expert support provided to our customers, a radiation protection self-assessment tool has been devised.

The purpose of the tool is to assist employers in taking ownership of radiation protection by recognising the common management tools and processes that apply across departments and modalities. It is also expected to aid recognition of the elements of day-to-day working that contribute to an organisation’s culture and how these express the importance of radiation safety.
The tool is divided into three parts, based on the levels of radiation safety self-assessment described in Report 162 of the National Council on Radiation Protection and Measurements (NCRP). The first and second parts are process level assessments of compliance with, respectively, the Ionising Radiations Regulations 1999 and the Ionising Radiation (Medical Exposure) Regulations 2000. These consist of 10 questions each, and can be completed in less than 30 minutes.

The third part is a programme level assessment, considering the department’s culture to the extent that it exhibits the traits of a healthy safety culture described by the US Institute of Nuclear Power Operations (INPO). It consists of fifteen good practice statements, against which users assess themselves on a five point scale. Each statement is accompanied by prompt questions, to provide evidence for the choice of response.

The tool has been piloted at one of the trusts supported by CMPE, and the data gathered so far is presented.

2. Traits of a Healthy Nuclear Safety Culture, INPO, 2013

A study on patient skin doses in cerebral embolisation using radiochromic films
Chrysoula Theodorakou (1)
The Christie NHS Foundation Trust, Manchester, UK (1)

Purpose
Patient skin doses during neurointerventional procedures may reach the thresholds for radiation-induced skin injuries. This study investigates and compares the irradiated areas and skin doses received by patients undergoing cerebral embolisation using Gafchromic self-developed dosimetry films for two neurointerventional suites.

Methods and Materials
The dose-area product (DAP), fluoroscopy time, total number of images and the cumulative air kerma (CAK) were collected for both suites. The patient peak skin dose (PESD) and irradiated areas for the posterior-anterior (PA) and lateral (LAT) planes were measured using the Gafchromic RTQA-2 dosimetry films.

Results
Preliminary results indicate differences in DAP, fluoroscopy time and CAK between the two neurointerventional suites. However, the patient peak skin doses are similar for both PA and LAT planes. The relationship between PESD, DAP and CAK are explored in this study.

Conclusions
This study utilized radiochromic films to measure the patient skin doses for two neurointerventional suites. PESD, DAP, CAK, fluoroscopy time and number of images are presented and discussed. This study has also investigated the relationship between PESD and exposure parameters for both suites.

How interventional cardiologists feel about radiation protection tools
Will Mairs (1)
Christie Medical Physics & Engineering (CMPE), Manchester, UK (1)

Anecdotal evidence suggests that staff frequently complain about using radiation protection tools for their personal protection.

Twenty interventional cardiologists with experience of using ceiling suspended eye shields, lead aprons, lead glasses or over glasses, leg protectors and lead gloves were surveyed on their feelings about these tools. All staff worked within a single department and were at various stages in their careers. A scale of 1
to 5 was provided for the staff to score their feelings where 1 was ‘intolerable’ and 5 was ‘not a burden’. The staff were also asked about their perception of personal monitoring on a scale of 1 to 5 where 1 was ‘an unnecessary burden’ and 5 was ‘a necessary part of my job’.

Results show that the interventional cardiologists generally tolerate some protection tools more than others. Starting with the most tolerated protection tool, the order of preference was ceiling suspended shields (93.8% of those with experience gave a score of ≥3), lead aprons (73.7%), lead gloves (70.0%), lead glasses or over-glasses (62.5%) and leg protectors (61.1%). Where staff elaborated on their reason for scoring as they did, various issues with the protection items were highlighted. A common theme was the weight of lead aprons and lead glasses. Lead glasses also ‘steamed up’ and may not have been compatible with prescription glasses. Lead gloves were said to affect tactile feedback. Ceiling shields affected vision for some when sterile covers were in place. Interestingly, some staff stated that if there were larger stocks of lead glasses and leg protectors available, they would be interested in trying these during clinical practice.

All staff gave a score of ≥3 in regards to their perception of personal monitoring which is reassuring for this staff group given that they are some of the most exposed in the medical sector.

Radiation Protection Considerations for Proton Therapy Centre Design
Mark Hardy (1)
The Christie NHS Foundation Trust, Manchester, UK (1)

Background
High energy proton therapy is an entirely new treatment modality in the UK. Consequently, there is no precedence of shielding design to comply with UK legislation. The design must be tailored to the individual centre as there may be significant local variations in footprint, use of equipment, use of surrounding areas and operational staffing requirements. In addition, the NHS proton therapy centres are likely to be in use for decades so should be designed that the latest technology and treatment techniques can be used to their full potential. Only if this is accounted for can the facility support maximising the effectiveness of patient treatments and providing best value for money to the NHS for decades to come. Here, the radiation protection considerations for the design of the Christie Proton Therapy Centre are discussed.

Method
A two stage approach has been used to ensure an optimal design for the Christie Proton Therapy Centre:

1. Establish specific requirements and establish reasonable assumptions regarding usage of the centre, including uncertainties and future use
2. Monte-Carlo modelling of the centre based on detailed design of the equipment and the building

Results
Table 1 shows the annual dose rates for specific staff groups as predicted by the Monte-Carlo modelling.

<table>
<thead>
<tr>
<th>Staff group</th>
<th>Estimate (mSv/yr)</th>
<th>Worst dose with uncertainty (mSv/yr)</th>
<th>Predicted future dose (mSv/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer</td>
<td>0.9</td>
<td>1.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Radiographer GR1</td>
<td>0.9</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Radiographer GR2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 2 – Results of the Monte Carlo modelling of the final design of the Christie Proton Therapy Centre
Discussion
The predicted dose rates for the proposed design of the Christie Proton Therapy Centre are within the design constraints set out by the trust in order to comply with IRR99 and local requirements, even with uncertainties taken into account. However, when possible future use is taken into account, annual doses for engineers and GR1 radiographers are higher than the trust’s requirement, meaning they are too high for pregnant staff to continue with their role for 100% of the time. However, in the gantry rooms other than GR1, doses are low enough that pregnant staff can work without restriction. Therefore if these potential future annual doses are realised in practice, careful allocation of pregnant staff could be used to maintain their personal dose below 1mSv over the term of the pregnancy.

Conclusion
Usage predictions have been made to enable radiation protection modelling to be carried out for the proposed design of the Christie Proton Therapy Centre. Monte-Carlo modelling has been used together with these predictions to estimate annual doses to key staff within the facility. The modelling results predict that the proposed design provides the shielding required to keep staff doses below the trusts requirements for current intended use. It predicts that for potential future use personal doses to all staff including pregnant staff can be kept below the relevant requirements.
<table>
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<tr>
<th>Evaluating the influence of $^{18}$F-FDG PET data on the target volume delineation of non-small cell lung cancers</th>
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<tbody>
<tr>
<td>James Ross (1,2)</td>
</tr>
<tr>
<td>University Hospitals of North Midlands NHS Trust, Stoke-on-Trent, Staffordshire, UK (1) University College London, London, UK (2)</td>
</tr>
</tbody>
</table>

**Background:** Although $^{18}$F-FDG PET-CT staging scans are routinely performed as part of the non-small cell lung cancer (NSCLC) patient pathway, the use of the PET data to assist in the delineation of target volumes for external beam radiotherapy treatment planning is not clinically well-established. The aim of this investigation was to assess how the presence of PET data impacted the generation of GTVs using manual and thresholding techniques.

**Method:** Ten radically-treated patients with NSCLC were retrospectively selected for this study. Two radiation oncologists were asked to independently generate GTVs ($CT_1$ and $CT_2$) on the CT components of the same PET-CT staging images, whilst a PET radiologist was asked to produce GTVs ($PET-CT_{man}$) according to both PET and CT data. Contrast CT images, acquired separately to PET-CT staging images, were available on a separate monitor to both staff groups. Additionally, a single-value threshold approach was explored whereby data representing at least 45% of SUV$_{max}$ was visualised to represent GTVs ($PET_{45}$). For each GTV pair the volumetric difference and a conformity index, the quotient of GTV overlap and the sum of their two volumes, were calculated.

**Results:** The mean GTV volumes were calculated as 82.87 cm$^3$ ($CT_1$), 58.27 cm$^3$ ($CT_2$), 42.82 cm$^3$ ($PET-CT_{man}$), and 12.83 cm$^3$ ($PET_{45}$). For manual delineation with PET data visualised mean percentage differences and evidence against similarities with respect to $CT_1$ and $CT_2$ volumes were -32% ($p = 0.02$) and -13% ($p = 0.06$); for $PET_{45}$ the results were -81% ($p = 0.01$) and -76% ($p < 0.001$). The mean percentage difference between the $CT_1$ and $CT_2$ volumes was -25% ($p = 0.02$). Mean conformity indices between the GTVs of $PET-CT_{man}$ and $CT_1$ and $CT_2$ were 0.40 and 0.50 respectively; for $PET_{45}$ the results were 0.17 and 0.24. Between the $CT_1$ and $CT_2$ volumes the conformity index was 0.59. For patients with potential nodal involvement the use of PET data through a manual approach led to the detection of three additional nodes for patient 3, five and three additional nodes compared to $CT_1$ and $CT_2$ for patient 4, and one additional node for patient 6. No additional nodes were detected with $PET_{45}$.

**Conclusions:** The results from this study indicate that the introduction of $^{18}$F-FDG PET data to CT images for target volume delineation in radiotherapy treatment planning for NSCLC patients may, on average, reduce GTVs and consequently reduce irradiated volumes. There was compelling evidence to suggest that by applying a 45% threshold to the PET data, one might significantly underestimate the GTV in comparison to manually derived GTVs. Clinically, manual GTV delineation with PET data visualised improved the sensitivity to the detection of nodal involvement: additional nodes were delineated in 33% of cases. However, it was reported that the introduction of PET data generally did not provide useful information for tumours surrounded by lung tissue, particularly when the depicted tumour was blurred by respiratory motion. Moreover, due to the relatively large spatial resolution of PET, thoracic wall invasion, where potentially present, could not be confirmed or excluded.

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<table>
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<tr>
<th>Robust optimisation in breast planning using intensity modulated radiotherapy</th>
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<tr>
<td>Kevin Young (1)</td>
</tr>
<tr>
<td>UHCW, Coventry, UK (1)</td>
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</table>

Conventional 3D CRT of breast utilises an extension of fluence anteriorly of the breast (commonly known as ‘flash’) to accommodate breast motion due to respiration.

With the introduction of intensity modulated planning techniques a flash margin can be generated by extension of beam segments anteriorly or the introduction of virtual bolus in the treatment plan so that
fluence optimisation can occur on an extended PTV. The two afore mentioned methods of introducing flash into intensity modulated breast plans lead to inherent inaccuracies in the planning process.

It is proposed that an alternative method of flash introduction be used that involves ‘robust optimisation’ i.e. the optimisation of a plan such that it is ‘robust’ against defined set up error including respiratory motion. The robust optimisation works by optimising a plan such that the clinical objectives are met for all the set up errors under consideration.

A range of intensity modulated breast plans are produced with both the use of virtual bolus and robust optimisation with CTV-PTV margins and set up errors determined by locally acquired data and values from the literature. The aim of this study is to compare quantitatively the dose distributions resultant from the two techniques and draw conclusions on the applicability of robust optimisation for breast planning.

Verification of plan robustness against set up error when using robust optimisation is performed by using the ‘dose perturbation’ feature that is within the treatment planning system with the perturbations equal in magnitude to set up errors and ensuring the clinical dose constraints remain met.

All the plans produced for this study were produced in RayStation v4.5.1 (RaySearch Laboratories). The clinical goals for this study are drawn from the Fast Forward (ICR) clinical trial guidelines and were applied to both plans produced using virtual bolus and the robust optimisation technique.

An initial study on a limited number of patients shows that robust optimisation is a comparable technique to PTV expansion in virtual bolus in terms of clinical goal achievement taking respiratory motion into account. For the virtual bolus planning case the breast PTV was expanded 2cm anteriorly into virtual bolus and a similar set up error was used for the robust optimisation where 2cm is the flash margin used routinely locally in breast planning. All plans were prescribed to 40.05Gy in 15 fractions to the median of the PTV (expanded PTV in the case of virtual bolus use).

The mean achieved dose volume values are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Virtual Bolus Plans</th>
<th>Robust Optimisation Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV V(38.04Gy)</td>
<td>95.98%</td>
<td>92.58%</td>
</tr>
<tr>
<td>V(42.05Gy)</td>
<td>2.18%</td>
<td>2.99%</td>
</tr>
<tr>
<td>V(42.85Gy)</td>
<td>0.07%</td>
<td>0.685%</td>
</tr>
<tr>
<td>Max Dose</td>
<td>43.45Gy</td>
<td>44.54Gy</td>
</tr>
<tr>
<td>Heart V(10Gy)</td>
<td>0.035%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Heart V(2Gy)</td>
<td>11.92%</td>
<td>11.905%</td>
</tr>
<tr>
<td>Contra Lat Lung (12Gy)</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Ips Lat Lung (12Gy)</td>
<td>10.79%</td>
<td>10.855%</td>
</tr>
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</table>

A comparison of parotid doses achieved with different radiotherapy planning techniques within the De-ESCALaTE HPV trial
Anne Gasnier (1)
The Royal Marsden, London, UK (1)

Background: the De-ESCALaTE HPV trial (CCR3737) is a randomised multi-centre trial investigating the potential reduction in toxicity from using radiotherapy and Cetuximab to treat HPV-positive oropharyngeal SCC compared to standard chemoradiotherapy (Cisplatin). Prior to opening for patient recruitment, 2 benchmark cases are planned by each participating centre: a lateralised and a non-lateralised case. 95% of the planning PTV should be covered by 95% of the prescription dose (radical PTV: 70Gy/35# and elective PTV: 50Gy/25# when planned conformally, 56Gy/35# otherwise). Dose to the parotids is minimised in order to reduce salivary toxicity, without compromising the PTV coverage. The aim is to achieve a mean dose to the contralateral (CL) parotid lower than 26Gy for non-lateralised cases, and lower than 14Gy for lateralised cases. However, higher doses to the parotids may be accepted in cases when
the overlap between the PTVs and parotids is important.

**Methods:** the dose to the CL and IL (ipsilateral) parotids achieved when using 4 different radiotherapy planning techniques (conformal, IMRT, VMAT and Tomotherapy) were compared for the two planning exercises.

**Results:** Benchmark cases were submitted by 33 centres.
1) For the lateralised case, the average doses to the parotids were:
   - CL parotid (Gy): 10.0 (conformal), 11.2 (IMRT), 9.2 (VMAT), 6.1 (Tomotherapy)
   - IL parotid (Gy): 70.0 (conformal), 67.4 (IMRT), 65.1 (VMAT), 67.8 (Tomotherapy)
2) For the non-lateralised case, the average doses to the parotids were:
   - CL parotid (Gy): 57.5 (IMRT), 54.0 (VMAT), 53.7 (Tomotherapy)
   - IL parotid (Gy): 55.3 (IMRT), 50.9 (VMAT), 57.0 (Tomotherapy)
   No non-lateralised case was planned conformally.

**Conclusion & Discussion:** A lower dose to the parotids was achieved when planning with VMAT compared to IMRT. It must be noted that the local CTV-PTV margin was used (ranging from 3mm to 5mm, 4mm on average), which impacted the dose distribution and doses to the parotids. Also, the doses to the parotids for the non-lateralised benchmark case were high due to the important overlap of the parotids and planning PTVs in this complex case.

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**Radiotherapy margins for multiple targets in prostate cancer**

William Beasley presenting (1) Marcel van Herk (1) Laila Zadelhof (2)
University of Manchester, Manchester, UK (1) Hogeschool Inholland, Haarlem, The Netherlands (2)

**Introduction:** Margin recipes for radiotherapy are derived such that the probability of a single target receiving sufficient cumulative dose (e.g. 95%) exceeds a threshold value (e.g. 90%) over a full course of treatment. Margins for multiple independently or partially correlated moving targets are less well established. Here a margin recipe for a treatment of prostate cancer, with prostate, seminal vesicles and lymph node regions as partly independently moving targets is derived.

**Method:** First, the motion of prostate, seminal vesicles and lymph node was quantified using repeat CT data from 19 patients using local rigid registration of 7 templates between planning and each follow up CTs (~10 per patient). Correlation of the motion was calculated by shifting the displacement of each region to zero mean per patient and next calculating the correlation of all ~290 displacement components in x, y and z for the 7 regions (21 x 21 correlation matrix). Random and systematic errors were evaluated conventionally. Based on the results a correlation model was defined. Next, a simulation was run that detected how often correlated regions would be outside a given error threshold to define the correct factor in the margin calculation. Finally, the effect of overlapping dose or joined-up distributions between targets was taking into account by changing the dimensionality of the considered motion per target.

**Results/Conclusion:** Based on a correction strategy on bony anatomy, lymph node errors were small (~1 mm SD), while prostate and seminal vesicle errors were larger (2mm SD). The AP and SI movements of neighbouring structures were moderately correlated ($0.25 < R < 0.45$). Using this motion model, the simulation shows a required margin factor of $3.2\Sigma + 0.7\sigma$. Due to the dose overlap this margin reduced to $3\Sigma + 0.7\sigma$. Adequate lymph node margins are therefore 3, 4, 4 mm (LR, SI, AP), while for prostate and seminal vesicles they are 3, 7, 7 mm, not taking delineation uncertainty into account. We conclude that in prostate radiotherapy with nodes, margin requirements are slightly bigger than in prostate cancer only due to the partly independent nature of the motion.
Designing and Constructing a Mechanical Viewfinder Accessory for Improving Fluoroscopic Palatal Investigations in Children
Thomas Taylor (1)
Oxford University Hospitals NHS Foundation Trust, Oxford, UK (1)

This project was undertaken as part of the STP rotation module for Medical Device Design and Development. A viewfinder accessory was designed following a request from the Consultant Cleft & Plastic Surgeon at the Oxford Spires Cleft Centre, in order to assist with the diagnostic procedure used for children presenting with symptoms of velopharyngeal insufficiency (VFD). During the clinic, lateral fluoroscopic imagery is taken in order to visualise the movement of the soft palate during speech. The footage produced can be crucial in both diagnosing the patient and for surgical treatment planning. In order to obtain accurate information, it is essential that the patient remains still, in an upright profile position, which is often extremely difficult (or often not possible) to maintain for the required length of time with younger children, who may be distracted or frightened by the procedure, leading to delays in clinic time as well as unnecessary radiation exposure for staff and patients. To address this problem, a mechanical rig was designed and manufactured, consisting of a brightly coloured, rigid metal frame, along with a Tyco viewfinder through which the patient can view and describe cartoon images, and a microphone clip in order to record the sounds produced during speech. The viewfinder accessory has now been used within the clinic for 9 months, assisting both the speech and language therapists and the consultant by producing exceptionally clear images of the target area, as well as allowing a reduction in the overall x-ray exposure time for these young patients. Quantification of these results to demonstrate improved patient outcomes is currently in progress, with the intention of submitting for publication.

The following presentation details my experiences as a trainee clinical scientist in designing and constructing a medical device accessory, following the appropriate regulations, standards and guidelines, in order to produce a simple, safe solution which has been seen to provide real benefits to both patients and clinical staff.

Energy Efficient Stabiliser Prototype for a Self-Propelled Wheelchair
Megan Bolton (1,2)
NHS Tayside, Dundee, UK (1) NHS Lothian, Edinburgh, UK (2)

Background: An individual confined to a wheelchair often desires the ability to remain active and independent therefore use a self-propelled wheelchair when able. However not all people are capable of self-propulsion or only manage to self-propel short distances before fatigue. The aim was to design a product to make a basic manual wheelchair more efficient, safely and within the NHS budget.

Design Description: A single wheel that rotates 360° attached centrally on a bar between the two anti-tip positions extending posteriorly. The wheel is attached to a pivot that is controlled by the resistance of a spring and will move over kerbs. A central location would help stabilise the chair. The device is removable if required.

Methods: Initial validation tests were performed. Weight distribution tests were performed under three different rear wheel positions. Pushing efficiency was investigated by implementing a smart wheel. The smart wheel recorded: the number of pushes over 10m, the force of each push, velocity and push mechanical efficacy.

Results/ Discussion: The weight distribution tests demonstrated that in the most forward position, the load was greatest through the rear wheel compared to the other positions. The maximum load recorded through the device was 64.5 N which is significantly less than the maximum load of the device which suggests it is safe to use.
The smart wheel data highlighted that the forward position was too extreme, making the wheelchair unstable resulting in more energy to maintain balance. The middle position illustrated the most efficient setup and resulted in less force needed and the lowest number of pushes required to travel 10 m. This was the most efficient configuration for the user.

Conclusion: This prototype demonstrates a great potential for making a basic manual wheelchair more efficient for patients with a simple inexpensive adaption. Preliminary tests indicate the device is safe and effective. Further tests are required which will ultimately lead to a final design and product. This prototype indicates that there are cost effective methods the NHS can implement to improve the quality of life for wheelchair users.

Design and verification of a wheelchair cushion designed specifically for paediatric use
Maighread Ireland (1), Laura Finney (2)
Dept of Medical Physics and Clinical Engineering, Royal Liverpool University Hospital, Liverpool, UK (1)
Leckey Design, Lisburn, Northern Ireland, UK (2)

Background: A literature review has highlighted the danger of extrapolating adult data for use in the design of paediatric support services\(^1,2\). Paediatric body dimensions, biomechanical properties and daily activities are different to adults; therefore for design purposes a child cannot be considered as a scaled-down adult. This study involved the design and verification of a paediatric wheelchair cushion, based specifically on paediatric requirements and dimensions.

Method: Requirements specification was devised from questionnaire feedback from multiple occupational therapists and clinical scientists working in seating services, along with feedback from paediatric commercial sales. A wooden rigid cushion loading indentor (RCLI) was manufactured according to ISO 16840-2:2007\(^3\), to objectively compare design prototypes. The RCLI has been proven to differentiate wheelchair cushion performance\(^4\). Anthropometric data\(^5\) was used to alter the dimensions specified in ISO16840-2, to approximate the anatomy of a 10-year old child. XSENSOR\(^\circledR\) pressure map readings were also used to assess prototypes, and ISO 16840-9:2015-Clinical interface pressure mapping guidelines were followed.

Results: Feedback highlighted the need for adjustable-deep contouring in paediatric seating. Prototypes devised from the specification were tested for load deflection and hysteresis. Hysteresis at 100N and 300N were computed for each prototype, and load deflection plotted. This provided information on seat cushion resilience and impact damping. Pressure map readings provided information on pressure distribution.

Discussion/Conclusion: Questionnaire feedback highlighted the difference in pressure factors between adults and paediatrics, an important consideration during design. The paediatric RCLI allowed objective decisions to be made during the design process, increasing safety, quality and reliability of the design. This type of evidence may inform and advance clinical effectiveness of cushion selection. Future work would involve carrying out further tests specified in ISO 16840-2:2007.

References

3. ISO 16840-2:2007-Determination of physical and mechanical characteristics of devices intended to manage tissue integrity-Seat cushions.


Low dose CT reconstructed with a range of ASIR % for attenuation correction and localisation of I-123 SPECT reconstructions
Nicola Laverick (1), Rebecca Gillen (1) Nick Weir (1) Sandy Small (1)
NHS Lothian, Edinburgh, UK (1)

Hybrid imaging systems have become popular as they can provide attenuation correction and improve anatomical localization of structures. However, the addition of a CT scan increases the radiation dose to the patient and is of particular concern in patients who are undergoing multiple scans as part of their treatment. The use of iterative reconstruction has been shown to produce CT images of a comparable noise level using lower dose (1).

This project aimed to use CT data sets acquired using a range of doses and varying amount of adaptive statistical iterative reconstruction (ASIR) to investigate the effect on SPECT phantom images. Image quality of the CT data sets was also assessed.

Syringes of a range of volumes filled with a solution of I-123-sodium iodide were placed inside a Jaszczak phantom and the remainder of the phantom was filled with water. SPECT images were acquired on a GE Discovery 670, with and without the addition of “arms” of tissue equivalent material and Teflon, using a clinical mIBG protocol. CT scans of differing CTDI were acquired and reconstructed with 0%, 50% and 100% ASIR. The SPECT images were reconstructed using each CT data set for attenuation correction. The counts from ROIs over each syringe on each of these reconstructed images were compared.

This investigation showed that reducing the CTDI of the CT scan had no significant impact on the pixel values of the SPECT scan when used for attenuation correction. The percentage of ASIR used in the CT reconstruction had no discernible effect on the pixel values.


Uptake in the small and large bowel during 18F-FDG PET Imaging
Margo-Rose Macnab (1)
NHS Grampian, Aberdeen, UK (1)

18F-fluorodeoxyglucose (FDG) is the most commonly used ligand in positron emission tomography (PET). Physiological bowel uptake is seen frequently and can affect the interpretation of images, but the cause of this uptake is currently unclear. Possible mechanisms for uptake may be: individual difference in glycolic activity of the gut micro-organisms, stimulated glycolic activity of the gut micro-organisms brought about by the presence of cancer, transport from a primary tumor via the GI tract into the bowel or some systemic activation of glucose consumption in the bowel.

We reviewed PET images from 1162 consecutive patients between May 2014 and September 2015 at Aberdeen Royal Infirmary. We visually rated these for the intestinal uptake, excluding any uptake in primary tumours, and classified uptake into diffuse, patchy, segmental and focal. The rating was compared
for different indications, diabetic and non-diabetic patient groups and different patient parameters, such as age, height and weight.

Patients taking medication for diabetes (most commonly metformin) were found to have a significantly larger uptake than both other diabetic and non-diabetic patients. After removal of this medicated group, oesophageal and lung cancer patients showed significantly greater gut uptake when compared to the other types of cancer patients referred. Patients with Non-Hodgkin’s lymphoma, Hodgkin’s lymphoma, head and neck cancer and melanoma exhibited significantly lower uptake. The height of the patient appeared to have no effect on bowel uptake rating, whereas the weight and age of the patient showed positive correlation with uptake, but with small values of $R^2$.

This study indicates that there is a significant difference between the uptake in different patient groups, which would suggest that the type of cancer plays a role in the gut uptake mechanism. Further work to determine this mechanism is required.
The unprecedented precision of modern radiotherapy may lead to overconfidence in the accuracy of the total treatment chain. While for a brain metastasis tumor delineation based on MRI is highly accurate; target volume definition in general, however, remains difficult and is now by far the limiting factor in the accuracy. These limits we may have to learn from our clinical mistakes. For instance, a group in Brussels found an almost 50% recurrence rate after introducing marker-based image guidance for low risk prostate cancer with a too small margin. Apart from this clear example of geometrical miss (unfortunately very few are published), there is little or no evidence that the precision of radiotherapy affects outcome. The only indirect evidence is by retrospective analysis of clinical trials, correlating outcome to secondary factors that in retrospect are known to affect precision.

A major step to improve the accuracy of to address its weakest link: make sure that target volume definition is consistent and according to protocol. Then of course, pathology studies can help to improve knowledge of GTV and CTV delineation. Unfortunately, pathology investigations are generally impossible for the actual patient groups undergoing radiotherapy.

For this reason, data mining approaches may help to correlate e.g., local dose variations with tumour control and/or complications. It is fair to say that radiotherapy is one the most quantitative and exact medical treatments around. Its plans are created on fused images from multiple modalities, dose calculation is highly accurate, and during treatment 3D and 4D imaging are employed to minimize the geometrical uncertainties. However, if you ask two doctors to indicate the borders of the tumor, or to define dose limits for an organ at risk there is a large probability that they will disagree by much larger amounts. This means that currently the question is not so much how to treat, but where to treat. Therefore there is a continuous drive to improve imaging techniques, but there is also a big need to learn from past treatments and capture information from individual patient outcomes. While in Amsterdam and now in Manchester, we have been setting up systems to do just that. The idea is to correlate dose delivered to patients with their outcome. We apply deformable image registration to map the anatomy of individual patients to a template patient and then statistical tests are used to define regions in the patient where dose correlates with clinical outcome. So far we have identified in prostate cancer patients regions where a higher dose results in prolonged survival, indicating a shortcoming of the tumor definition. In lung cancer, we identified a region where a higher dose correlates with a poorer outcome, indicating a shortcoming of the organ at risk definition. To allow this kind of studies, the technical infrastructure of a department needs to be appropriate and clinical data needs to be recorded consistently. Particularly the latter aspect needs improvement in many centers.

I conclude that there are still uncertainties in modern radiotherapy that need to be covered by safety margins. The most important uncertainties relate to imaging and biology that are not corrected by IGRT. Physicists and computer scientists in the hospital have an important role to reduce these uncertainties using big data techniques.
### Clinical Neuroimaging Analysis in Dementia

**Robin Holmes, NIHR/HEE Post-Doctoral Research Fellow, Medical Physics – University Hospitals Bristol NHS Foundation Trust**

**Introduction.** NICE guidelines recommend the use of structural and functional imaging in the assessment of suspected dementia; consequently large numbers of scans are carried out across the UK costing the NHS approximately £50-100M annually. Interpretation of neuroimaging relies on the identification of areas of the brain where structure or function is significantly different to normal. Neuroimaging analysis studies have demonstrated that changes in the brain can be detected many years before clinical onset of dementia and that particular dementias can be recognised from characteristic patterns of atrophy and/or impaired function. Consequently the technique of anatomic standardization and comparison of patients with controls and/or other patient groups is increasingly used in research and, to a much lesser extent, in clinical practice. The aim of this image analysis is to allow a positive identification of neurodegenerative disease, at an earlier stage and with increased confidence than visual inspection alone.

**Work to date.** Control scans have been obtained from online databases and normal appearing scans x-ray CT of patients have been selected. Several thousand patient cases, including clinical history and neuroimaging, is being collected both prospectively and retrospectively across several centres. Software to segment images, detect abnormalities and overlay results is under assessment. An initial prototype uses matlab and Statistical Parametric Mapping (SPM); this will be replaced with software based on 3d slicer and/or OsiriX. Novel phantoms which mimic the appearance of the brain when scanned are being used to ensure that the brain images acquired by different scanners are similar.

**Conclusions –** This project has demonstrated that freely available code can be used to create clinically useful software. Detection of atrophy in individual clinical CT scans has been achieved for what may be the first time. The same techniques will be applied to stroke, hydrocephalus, movement disorders and epilepsy. The software and clinical images will be made freely available to the NHS at the end of the project. The design and open nature of the project will encourage further collaboration and extensions including machine learning.

### Automatic Bone Marrow Segmentation for PETCT Imaging in Multiple Myeloma

**Patrick Leydon (1), Martin O’Connell (2) Derek Greene (1) Kathleen Curran (1)**

**University College Dublin, Dublin, Ireland (1) The Mater Private Hospital, Dublin, Ireland (2)**

**Introduction:** Multiple myeloma (MM) is a malignant hematologic disorder characterized by bone marrow infiltration with neoplastic plasma cells. Approximately 10% of all hematologic cancers are related to MM. Whole-body 18F-FDG PETCT is an extremely useful imaging tool for the assessment of patients with MM. The novel approach developed in this research automatically segments bone marrow regions of interest on both the PET and CT datasets.

**Method:** Firstly, affine linear transforms are applied to the PET dataset and it is aligned to the CT images. Next, a binary mask is created based on a pixel threshold value of cortical bone. A series of image processing steps are performed to remove noise and fill gaps that correspond to bone marrow locations. This process results in a binary mask relating to bone marrow only which can then be applied to the registered PET dataset.
Conclusion: The proposed method offers a fully automated and completely objective approach for segmentation of anatomical regions relating to bone marrow. With further development, this method could be used to evaluate clinical images in order to develop a database of PETCT images against which quantitative statistical comparisons between patients with normal bone marrow metabolism and those with myeloma can be made, establishing a baseline against which future scans may be referenced. In cases where the suspicion of myeloma exists, the tools could be used to support the diagnosis of the disease, and may be useful in staging of the disease in cases positive for myeloma.

PRRT Patient Specific Dosimetry: Variation in Organ and Tumour Dose Demonstrates Limitations of Fixed Administered Activity Regimes
Emma Page (1) Jill Tipping (1) David Hamilton (1)
The Christie NHS Foundation Trust, Manchester, UK (1)

Aims
To report variation in mean absorbed dose from serial post therapy SPECT-CT images for organs, tumours and total body for 10 patients treated with $^{177}$Lu or $^{90}$Y Dotatate at the Christie.

Methods
Following each $^{177}$Lu administration 4 SPECT – CT were acquired to assess dose to kidneys, spleen and tumours and 6 blood samples were acquired to determine red marrow self-dose. Total body activity was estimated from 6 external dose rate measurements. Patient specific organ and tumour masses were estimated from pre-therapy diagnostic CT. Organ and tumour doses were calculated using OLINDA/EXM. Additionally the ability of doses and excretion kinetics in earlier administrations to predict doses in later administrations was tested.

Results Summary
Initial results show variation in kidney, spleen and tumour doses among patients as 0.45 - 1.00, 1.26 – 1.82, and 5.86 – 18.62 mGy/MBq respectively.

Conclusions
The variation in mGy per MBq among patients administered fixed activity, demonstrates the requirement for patient specific dosimetry regimes by revealing the failure to achieve maximisation of mean tumour dose and standardisation of upper limits to normal tissue dose.
In the UK one in two people are diagnosed with cancer during their lifetimes and of those who survive 41% can attribute their cure to a treatment including radiotherapy. After surgery, treatments including radiotherapy are the most effective cure for cancer in the UK. Radiotherapy is also very cost effective, accounting for less than 10% of the total cost of cancer care in the UK. Proton beam therapy (PBT) is a new type of advanced radiotherapy, which offers the potential of precisely delivering a targeted dose of radiation to the tumour whilst sparing the surrounding healthy tissues. PBT offers huge potential, particularly for paediatric cancers and cancers close to critical structures such as head and neck and CNS, which are difficult to treat by more conventional means. Whilst PBT has enormous potential, there are still clinical, scientific and technological challenges that be overcome.

Unlike, X-ray radiotherapy, protons deliver their dose in a well-defined Bragg peak. By modulating the energy and position of the Bragg peak the dose can be painted over the tumour volume. Thus, in theory, PBT allows more dose to be delivered to the tumour whilst sparing the healthy tissue surrounding it. At present all clinical treatments with protons assume a constant relative biological effectiveness (RBE) throughout the tumour of 1.1, i.e., the same dose of protons delivers 1.1 times more biological effect than photons. However, this simplification doesn’t take into account the unique molecular and cellular responses of protons and how this changes with the linear energy transfer (LET) that varies with depth. In this presentation we give an overview of proton radiobiology and the way in which it differs to that for photons. We will also discuss new developments in the field and exciting new opportunities that may exist.

Higher yields of DNA Double Strand Breaks (DSBs) are generally accepted to be the method by which Proton Beam Therapy (PBT) leads to higher cell killing than X-ray therapy, quantified by the Relative Biological Effectiveness (RBE). The RBE of protons is conventionally taken as 1.1 relative to X-rays, although a large range is seen experimentally. A better understanding of the mechanisms leading to higher RBE of protons is needed, particularly for dose planning in PBT. Initial investigation of proton RBE will start from track structure simulations, characterising interactions with a DNA target.

Modelling the DNA target is usually done at a compaction level of the so-called chromatin '30 nm fibre', the exact structure of which is still unknown. The fibre is formed by a geometrical arrangement of nucleosomes, where nucleosomes are DNA supercoiled around the histone core. Two main classes of chromatin arrangement have been suggested, the 'solenoid' and 'two-start' model. Conventionally simulations will take one of these models to score DSB induction.

This work compares the differences between the ‘solenoid’ and ‘two-start’ models through nanodosimetric parameters, making use of ‘Geant4-DNA’, an extension to the ‘Geant4’ Monte-Carlo toolkit, to track low energy secondary electrons. The DNA double helix is modelled at the resolution of ‘backbone’ and ‘base’ volumes. The backbone volumes are set up to score energy depositions from primary protons and any secondaries. Volumes with a ‘hit’, that is energy deposited above a minimum threshold, are scored according to a clustering algorithm. The algorithm checks for hits on opposite strands that are within 10
base pairs, if these criteria are met a DSB is assumed to have been induced. The number of clusters is equal to the number of DSBs, and the size of the cluster is equal to the complexity of the DSB.

Initial results show little difference between average cluster size and cumulative probability of a proton causing a DSB between the solenoid model and the two-start model. Although, slight divergence of DSB probability is seen at higher LET between the models.

This work shows that the chromatin model chosen for Monte-Carlo simulation will have little effect on the final calculated DSB yield.

Towards the Development of Repair Simulation in the Biological stage of Geant4-DNA
John Warmenhoven (1) Nicholas Henthorn (1) Marios Sotiropoulos (1) Karen Kirkby (1,2) Michael Merchant (1,2)
Institute of Cancer Sciences, Manchester Academic Health Science Centre, University of Manchester, Manchester, UK (1) The Christie NHS Foundation Trust, Manchester, UK (2)

Double Strand Breaks (DSBs) are some of the most cytotoxic events a cell can undergo. Improper repair of such breaks can negatively impact important cellular processes and potentially lead to cancer. A myriad of cancer susceptibility disorders are linked to mutation or suppression of repair protein genes, the correct functioning of this system is instrumental in cancer prevention. The capacity for DSBs to induce cell death can also be utilised in cancer treatment by targeting the tumour with ionising radiation that damages it's genetic material. Increasing our understanding of these processes through modelling will provide a tool for understanding proton relative biological effectiveness (RBE), a critical parameter for treatment planning. Experimental measurement of RBE show a large variance due to dependencies on variables such as LET and tissue type.

A mechanistic model of repair is in development to predict various biological end points that will be validated through comparison with experiments. Current, often closed source, approaches to this problem utilise ordinary differential equations or first order kinetic approximations along a linear succession of reactions[1]. This approach fits the experimental data in a limited set of circumstances and large variances are observed dependent on the particular set of model parameters used. This project will develop a more comprehensive model using the open source Geant4-DNA[2] environment as an input to a more biologically correct iterative molecular reaction based model. The parameters used in the model will be set from the literature and validated through experimental verification.

Fear? – It makes you think! – Medical Devices and Risk Management
Paul Robbins, Papworth Hospital NHS Foundation Trust

Fear - Risk and Risk Management – mainly in the form of Flight or Fight has been around since the start of life on earth. To understand Risk we need to understand Fear and how and why we need control it. As the country’s health care system repositions in response to changes in the Economy and Demands of Scale flight is no longer an option. Lord Carter has made it plain that we need not necessarily to work harder - although that helps - but smarter. We need to understand what we are doing and what we can do to tease out every penny of our budgets to obtain the maximum value from our equipment estate.

Looking at the risks associated with equipment and equipment support operations, responding to these in an effective way provides both tools and a mechanism to allow us to be proactive. Risk Management in equipment support operations is not about doing nothing, nor is it about ignoring the support advice provided by the Equipment Manufacturer. It is about doing the right interventions at the right times with respect to the local perception of device risk.

Through a couple of case studies this presentation will discuss the fear of risk, look at tools for managing that fear and review how these can be applied to day to day operations to ensure that we maximise opportunities for a productive environment.

Adapting a commercial procurement model for use in the NHS - 3 Gateways to success in medical device purchasing
Nicola Cawthorne (1) Benjamin Hilliam (1) Richard Axell (1) Thomas Stone (1) Paul White (1) Max McClements (1)
Addenbrookes Hospital, Cambridge, UK (1)

Background: Purchasing Medical Devices within the NHS follows strict procurement regulations to ensure the appropriate use of public money, compliance with CQC guidance and European law. Efficient and effective procurement processes within large healthcare organisations are complex. A common problem in these processes is a lack of stakeholder engagement and buy-in; this can result in a lack of accountability in procurement decisions, and constitutes both a clinical and financial risk.

This work investigated the feasibility of adapting a commercial process for the procurement of major works to fit the requirements of medical device procurement.

Method: The Trust medical devices procurement process was transposed onto a commercial major works process. Stage gates were used to ensure all projects follow a standardised project management and procurement process. A gateway document was used to summarise each stage and could only be approved by a single organisational management group. Gateway 1 defined the

Figure 1 The Staged Gateway Medical Device Procurement Process
strategy and action plan to complete the project to budget. Gateway 2 included selecting the appropriate supply chain and stakeholder management. Gateway 3 reviewed the project after completion; determining the success of the project and if any processes employed required review. Gateways could only be approved in numerical order and the project could be terminated at any gateway.

Results: Figure 1 shows the 3-staged gateway process developed for medical device procurement projects within the Trust. Gateway 1 ensures an approved business case, risk analysis and identifies appropriate stake holders. We then decided to split the requirements for commercial Gateway 2 into two parts to form our Gateways 2 and 3. Gateway 2 includes a device specification, evaluation method, approval of funding and a procurement strategy identified from the Trusts standing financial instructions. Gateway 3 included the evaluation of supplier responses through methods detailed in Gateway 2 and agreement from all stakeholders to award the contract. To implement this process the terms of reference of the Medical Devices Management Group were updated to include overall responsibility for approving gateway documents. In addition, the procurement information on the trust intranet was reviewed and streamlined ensuring one cohesive message about medical device procurement was presented to all staff. The system has been in place for 5 months and one framework agreement has been completed using this methodology.

Conclusion: We developed and used a staged gateway process to streamline all medical device purchases within the Trust. Further work is required to improve this process and encourage engagement of clinical stakeholders.

Considerations to the Implementation of In-house Passive RFID audit for Medical Devices
Stephen Hunt, University Hospitals of Leicester NHS Trust, Leicester, Leicestershire, UK

Passive Radio Frequency Identification (RFID) has created emerging applications for the identification, and thus audit of items in areas such as supply chain, cargo transportation and baggage handling. Amongst the number of Passive RFID tagging systems available, the ultra-high frequency (UHF) 860 – 960MHz band has attracted interest due to its low cost, physical size, and increased interrogation range, compared to other passive tagging solutions.

However, to realise these benefits for the audit of medical devices in the clinical environment, requires prior consideration to the anticipated outcomes of its use with regard to the yield that can be captured into an inventory. Amassing tagged items requires a trolley based tag interrogation system to be ‘walked’ around the ward setting. To obtain an acceptable yield, ‘line of sight’ access to the RFID tag that is unobstructed by metallic objects is desirable, and thus necessitates careful attention to realise a design that can be used successfully in this busy environment. Furthermore, regard to Radio Frequency (RF) exposure to individuals and ‘patient connected’ medical equipment within the tag interrogator antenna RF field, is an essential design requirement.

An in-house system is currently under development at the University Hospitals of Leicester for such use by Medical Physics, Clinical Engineering. The design incorporates a commercial UHF tag interrogator and associated software development kit (CAENRFID, Italy, type ‘WA941MEOXAAA’) to meet the above requirements, utilising the ‘EPC Class 1 Gen 2’ protocol. A bespoke set of PC applications have been developed allowing medical devices registered in the trusts ‘equipment management database’ to be easily ‘paired’ to RFID tags by their barcode, RFID interrogated and also linked to a medical equipment library database. Currently, an ‘interrogator trolley’ is under test to determine the yield that can be realised based on the physical position of the tag on the equipment item and the placement of tagged equipment around metallic objects in a ‘test’ ward setting.
Wednesday 14th September 2016, 11.00 – 12.30

Engineering

Real-world monitoring of rehabilitation technologies
Laurence Kenney, University of Salford

Considerable efforts have gone into the development of new technologies to assist functional movement over recent years, leading to a large number of novel devices entering the market. Examples of these devices include multifunctional prosthetic hands, inertial sensor-controlled functional electrical stimulations for foot drop and active lower limb prostheses. The cost of such devices is typically many times higher than the equivalent earlier generation, yet the rate at which the new devices are coming onto the market appears to be far outstripping the ability of researchers to thoroughly evaluate their efficacy and cost-effectiveness.

Obvious metrics of performance of an assistive device are how frequently and in what manner a device is used in everyday life. Although modern technologies offer the capability to record such data, there are few publications reporting on this.

The presentation will introduce work carried out by the Rehabilitation Technologies and Biomedical Engineering group at the University of Salford on the real world monitoring of a number of devices, including walking frames and upper limb prostheses. The talk will describe metrics which can be derived from sensors to characterise the use of these devices, and discuss possible applications of these data for device evaluation studies and to inform future research avenues.

A Flexible Control System of Functional Electrical Stimulation (FES) for Upper Limb Rehabilitation
Mingxu Sun (1), David Howard (1), Laurence Kenney (1), Christine Smith (2), Helen Luckie (1), Karen Waring (1)
University of Salford, Salford, UK (1) Sheffield Hallam University, Sheffield, UK (2)

Background. Highly intensive FES-supported practice of functional tasks, under voluntary control, is showing promise to promote recovery of upper limb function following stroke [2, 3]. However, the ability to deliver this type of therapy in clinical settings is limited by available tools [1, 4]. Development of flexible systems, which support the user in the creation of task and patient-specific FES controllers has received relatively limited attention [8]. In this study, a flexible FES controller and associated graphical user interface is described, which allow therapists to set up FES controllers specific to both task and patient-specific impairment patterns. The graphical user interface (GUI) has been designed to be used by therapists with little or no programming skills.

Methods. A FSM controller is usually composed of a set of states, input signals, output functions, and state transition conditions [7]. In this particular case, each “state” corresponds to one movement phase and the state’s “output functions” implements the ramping of muscle stimulation(s) towards their respective targets (note the target may be zero) and then holding them at those targets. The set of possible “input signals” for the FSM controller are button status, clock time and angle data for different body segments (e.g. upper arm, forearm) via accelerometer units attached to them [6]. The “state transition conditions” implement the conditions for exiting each movement phase. Each of the parameters listed above are defined by the therapist, depending on the chosen task and the patient’s pattern of impairment, using the setup GUI.

Following ethical approvals, 12 participants (mean age = 67.25, range 41 – 88; mean years since diagnosis 5, range 1 week – 28 years; mean Fugl-Meyer Upper Extremity score = 36.5, range from 8 - 65) with upper limb impairments following stroke were recruited to test this system in either laboratory (lab) or in two hospital settings [5]. In total, seven different functional tasks, tailored to suit the impairment levels of the particular patients were used across the study. Therapists setup the state machines using the GUI, and the controllers were either created from scratch or were pre-existing state machines, adapted to suit each patient. The seven tasks were “Sweeping coins into contralateral hand”, “Pushing up from chair”, “Placing block on shelf” and “Picking up tray”, “Picking up mobile phone”, “Pouring from bottle to glass” and “Opening door”.
**Results.** All participants successfully completed at least one task. On average 2.75 different functional tasks (range 1 - 6) were used for each recruited stroke patient.

**Conclusion.** The testing demonstrated that the FSM FES controller could be set up by therapists with a range of patients, practicing a range of practical tasks. Further work to improve the usability and functionality of the software is ongoing in an NIHR-funded study.

**Key references.**

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**Impact of varying training components for an ensemble neural network system of estimating prosthetic socket pressure distribution**

Philip Davenport (1), Siamak Noroozi (1) Philip Sewell (1) Saeed Zahedi (2)
Bournemouth University, Poole, Dorset, UK (1) Chas A Blatchfords, Ltd, Basingstoke, Hampshire, UK (2)

Existing methods of measuring the pressure distribution within prosthetic sockets suffer from interference with the interface under examination [1]. An inverse-problem solution – relating the external strains on the socket with the internal pressures using a neural network – has shown promise in mitigating these issues [2]. However the optimisation of the neural network training procedure has not been examined in detail for this application.

Ensemble averaging has long been proposed as a mechanism for improving network performance [3]. Individual networks’ estimates of load distribution are expected to vary between over- and under-estimation of particular values depending on factors such as the initial network weights and the order of training cases. Therefore, by evaluating the response of multiple networks and finding the average of their estimates, a better overall model of the pressure-strain relationship can be made.

Neural network literature suggests that performance is improved by including varying network designs within the ensemble [4]. In this work, this was achieved by several methods – by varying the architecture of the networks in terms of hidden neurons and through altering the method of noise injection.

The impact of these changes was evaluated systematically using a separate measurement file and calculating the sum of errors between the known loads and each ensemble. Preliminary results confirm the expected improvement in performance from the use of ensembles, and given the low computational cost their use within this application is recommended.

[2] Sewell et al. (2012), 54 (1), Artificial Intelligence in Medicine p29
Visual impairment in dementia is likely under-recognised, leading to a lack of appreciation of how it may contribute to key features of dementia: a reduced autonomy and ability to carry out activities of daily living. Careful management of the visual environment, including provision of visual cues, may therefore improve functional independence.

A controlled environment was created to simulate representative aspects of a domestic environment. Participants were asked to perform a series of tasks involving walking along corridors with turns, navigating through a room to an open door, and reaching for objects. Lighting levels could be controlled, and static and dynamic visual cues were used to assess whether these would help identify targets. Task performance was assessed by the use of inertial measurement units (IMUs) attached to each shoe. Each IMU contained tri-axial accelerometers, gyroscopes and magnetometers; position within the environment as well as spatio-temporal parameters of gait were calculated from IMU data. In addition, a portable eye-tracking system was used to record eye fixations and saccades. Three groups were studied: i) people with typical Alzheimer’s disease (tAD); ii) people with Posterior Cortical Atrophy (PCA), an atypical presentation of Alzheimer’s primarily effecting visual processing; iii) age-and gender-matched controls.

Both dementia groups walked slower than controls, with greater variation in step time and step length. Hesitant steps were particularly apparent on routes which contained turns. Changing ambient light levels from 190 lux to 20 lux had a small effect on performance, but floor-level running LED lights had an adverse effect of performance in the PCA group. Attaching a visual cue to a door handle improved performance in navigating to an open door, and reduced path tortuosity when walking towards the door.

Using IMUs, we have been able to identify hesitant, and perhaps confused, behaviour when dementia subjects are asked to perform everyday tasks of navigation and object finding. This behaviour may arise due to deficits locating destinations and objects in visual space or making navigational decisions. Such information might provide empirical insights into design of dementia-friendly environments.
Radiotherapy planning Optimisation: creating the perfect plan or providing the optimal treatment?
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Faculty of Science and Engineering, University of Hull, Hull, UK
Faculty of Health and Wellbeing, Sheffield-Hallam University, Sheffield, UK

Radiotherapy has continually evolved in its history and recently we might argue that it has gone through revolutionary changes with the implementation of IMRT at the end of the last century and in the last decade with IGRT. As ever it is likely the impact of the continuing increase, and cost reduction, of computing power that allows us to generate treatment plans more rapidly; providing more options to consider when planning radiotherapy.

The really important and very exciting revolution, is that we are close to, or starting to be able to respond in real time to the response of the patient to the treatment we administer. Traditionally, in radiotherapy, we have striven to ‘keep the treatment on course’ by recalculating Monitor Units to correct the dose to isocentre in the event of minor changes or pause the treatment to recompute and restart it in response to more significant changes. As we move forwards we need to absorb the benefits that emergent technology, from within and without our field, offers and promises. Once we have embraced these opportunities and learnt to adapt, arguably ingrained philosophies, we may be able to develop radiotherapy that is consistent with the goals of ‘personalised medicine’. At this stage it is timely to re-examine what ‘optimisation of the treatment plan’ actually means.

This presentation will hopefully challenge some of our traditional approaches in radiotherapy and encourage debate about the ‘art of the possible’. We will review changes to clinical practice in some of the departments that have adopted MRI-guided radiotherapy and explore where this may develop with its expansion; we will also review the potential for molecular imaging using PET to contribute to treatment planning and the ‘adaptive radiotherapy’ paradigm via determination of biological target volumes, stratification of patients to treatment via measurement of hypoxia and measurement of biological parameters that guide treatment planning. A major limitation of PET to date has been the accessibility of non-18F-FDG radiotracers, and we outline the current ‘dose-on-demand’ paradigm soon to be instituted in our department.

A major unmet need in modern radiotherapy is an understanding of the tumour biology that underpins individual patient response, and thus we will also explore the several techniques that may be employed at the clinical/preclinical interface to inform this. Chief amongst these are methods for the long-term culture of patient-derived material in an environment that reflects that of the original tumour, and where the effects of combination targeted/chemo/radiotherapy can be assessed at the molecular, biochemical and ‘organ’ level using genomic/proteomic/radionomic approaches.

In summary, advances in the delivery of radiotherapy have made traditional treatment planning approaches obsolete and should challenge us to develop new strategies for finding the most optimal treatment plan for patients which may be personalised rather than based on population average needs.

How do we know when a VMAT/IMRT plan is optimised correctly? Through Independent Estimation of Expected OAR doses
Ian Seedhouse (1), Craig Edwards (1) Philip Tudhope (1) Andrew Moloney (1)
University Hospitals of North Midlands, Staffordshire, UK (1)

The completion of VMAT planning is one based on experience and time constraints. But when is a plan optimal? And what is optimal?
This project has developed, for 74Gy VMAT Prostate plans, in-house bespoke software which independently estimates relative OAR volumes, for specific doses, $V_D$: Bladder $V_{74Gy}$, $V_{69Gy}$, $V_{50Gy}$ and Rectum $V_{70Gy}$, $V_{65Gy}$, $V_{60Gy}$, $V_{50Gy}$. The information is then used to determine how optimal the plan is as regards OAR doses.

Written using MATLAB source code, the software calculates the average fall-off of dose across the OAR, through modelling the OAR as a series of partial shell structures. The model was calibrated using 24 patients and was initially used to audit 74 clinical plans.

Comparison of model $V_D$ with that achieved by the clinical plan showed good agreement 1.5±1.5% (mean±1SD) (Rectum $V_{50Gy}$=2.0±2.6%) demonstrating consistency of planning outcomes and validating the model. During the audit a difference of ±5% between modelled and clinical plan $V_D$, was used as a threshold to warrant further investigation. Of the 74 patients, 9 required further investigation. In 5 of these cases it was possible to produce a more optimal plan and reduce OAR doses. For the remaining, these were not examples of poor optimisation but were examples of either: a) The plan had been optimised using a novel technique; or b) The optimisation of the plan had been skewed in order to meet a particular objective.

In conclusion, what the project has achieved is the development of an in-house software solution which will, identify cases where it will be difficult to meet planning constraints prior to planning; and draw attention to cases which are unusual or don’t conform to what is typically achieved at UHNM. Since the audit, the program has been implemented clinically and is now used routinely within the department. Further development will see the program introduced to additional clinical sites.

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**Evaluation of a knowledge based optimisation model for VMAT of pancreatic carcinoma**

Peter Houston (1)
Beatson West of Scotland Cancer Centre, Glasgow, UK (1)

**Purpose:**
To evaluate the performance of a knowledge based optimisation model for volumetric modulated arc therapy (VMAT) applied to pancreatic carcinoma patients.

**Method:**
Seventy patients previously treated with VMAT were selected to train a knowledge based optimisation model (RapidPlan v13.6.23). All 70 clinical plans were replanned to produce a more optimal set of plans for model inclusion. The model was analysed and any outliers which adversely affected the goodness of fit were removed. The final model contained 52 patients.

The model was validated against a further 15 patients, comparing model generated plans to clinical plans, created by experienced treatment planners.

**Results:**
PTV conformity was improved in 11 of 15 plans, 4 plans displayed no significant difference in Conformity Index (CI), mean $C_{Model}=0.9$ (SD=0.01), $C_{Clinical}=0.8$ (SD=0.1). On average Homogeneity Index (HI) was similar between plans although model generated plans displayed less deviation, mean $HI_{Model}=6.8$ (SD=0.6), $HI_{Clinical}=7.0$ (SD=1.9).

On average, mean dose and D1cc to OARs (kidneys, liver and spinal cord) are lower in model generated plans.

**Conclusion:**
Overall, the model generated plans are of higher quality and are at least comparable to the clinical plans. The model generated plans also displayed less variation than the clinical plans, presenting a robust and consistent planning solution for pancreas VMAT.
A workflow for automated error detection in contour propagation for adaptive radiotherapy
William Beasley (1,2) Alan McWilliam (2) Nicholas Slevin (2,3) Ranald Mackay (1,2) Marcel van Herk (2) Christie Medical Physics and Engineering, The Christie NHS Foundation Trust, Manchester, UK (1) The University of Manchester, Manchester, UK (2) Department of Clinical Oncology, The Christie NHS Foundation Trust, Manchester, UK (3)

Introduction: Automatic segmentation of on-treatment images, through propagation of contours from a planning CT (pCT), is an essential component of adaptive radiotherapy (ART). Initial validation of automatic segmentation algorithms is essential, but cannot guarantee absence of propagation failures in routine clinical use. We present here a workflow for automatic quality control (QC) of contour propagation performance on an individual patient basis.

Method: For the automated QC workflow, contours on pCT are propagated onto the CBCT on day 1 (CBCT1) and are manually reviewed. At treatment fraction n, contours are propagated onto CBCTn; it is these contours on which QC is performed. For this, these structures are propagated back onto CBCT1, and compared with the structures already reviewed on CBCT1. From the concordance of these structures on CBCT1, ‘consistency metrics’ can be defined, which are used to detect propagation failures on CBCTn. The workflow was tested on weekly CBCT images for ten head and neck patients, on which the parotids had been outlined by a single clinician. Additional noise was added to the CBCT images to reduce propagation performance, and a commercial automatic segmentation algorithm (ADMIRE, Elekta AB, Stockholm, Sweden) was used to propagate contours from the pCT onto these noisy CBCT images. The true accuracy of the propagations was measured by comparison with the manual contours, and the uncertainty metrics were measured as described above. A logistic regression model was trained to predict propagation failures (defined as propagations with a true accuracy significantly different to baseline performance) using the uncertainty metrics. The model was evaluated with 3-fold cross-validated ROC analysis.

Results/Conclusion: The area under the curve was 0.90, indicating that the presented workflow is capable of identifying contouring errors with reasonable accuracy. Further work is required to validate the model using different sources of error, but this method shows promise as a useful component of an ART workflow, enabling automatic detection of contours that require manual review and contour editing.

Approaching automation in breast radiotherapy planning – from partial to total
Robert Adam Mitchell (1) Philip Wai (1) The Royal Marsden NHS Foundation Trust and The Institute of Cancer Research, Sutton, Surrey, UK (1)

Background: Planning times increase when using a step-and-shoot technique for breast radiotherapy [1]; this is offset by dose homogeneity improvements and decreased toxicity [2-3]. This study reports on a partial automation method and an approach allowing total automation to reduce planning times whilst maintaining plan quality.

Methods: SWO: MLC positions are derived from pre-specified isodose levels using Pinnacle3’s autoblock tool; segment weightings are calculated using segment weight optimisation (SWO). A 40 patient retrospective planning study was conducted. DMPO: Non-automatable information is entered via an interface. A field-based breast PTV is then created. The planning technique is based on that described by Purdie et. al and utilises DMPO [4]; plan modulation is heavily restricted. Ten patients were replanned.

Results: SWO: Reductions in median planning times of up to 45% were observed. There were no statistically significant, clinically relevant differences between the clinical and scripted plans. DMPO: Median planning time was reduced by 62%. A trend towards plan standardisation is suggested by reductions in variations of mean PTV dose and appreciable decreases in high dose metrics (D2%, V105%, V103%).

Discussion: The disadvantage of the SWO approach is that the scripts contain pauses to allow mandatory manual adjustments by the planner. The current DMPO method also contains pauses in the scripting workflow; such breaks could be removed as planners gain familiarity with the technique. Approaching complete automation emphasises the need for robust extra checks at the end of the planning process.
**Conclusion**: Planning time reductions in breast radiotherapy can be achieved through the utilisation of either partial or total automation techniques without compromising plan quality. Whilst it is inevitable that such non-commercial methods will be superseded by more sophisticated commercial ones [4], viable efficiencies can be attained using non-commercial approaches until it is financially feasible to implement commercial solutions.

We all know the thrill of coding – of creating something, of seeing it work. We all remember the excitement of typing in those few lines of text, hitting “Go” and seeing our name appear on the screen. Repeatedly. It didn’t matter that the font was wrong. It didn’t matter that the text was upside down. It didn’t matter that we hadn’t worked out how to stop the program from running so had to switch the machine off. We’d created it with nothing more than our brainpower and a bit of typing. Admittedly, it wasn’t quite in the “let there be light” category of creating stuff with just a few words, but we’d done it. And it was fun. Software was the new Rock n Roll.

And then we remembered that we were scientists and got introduced to structure, to methods, to paradigms, to standards, to regimes. And suddenly it wasn’t so much fun anymore. Software was in danger of becoming formulaic pop.

This talk is about why such things as methodologies matter in a healthcare context and gives some pointers as to ways in which to incorporate them, without losing the joy of creativity. In so doing, it aims to provide some simple ideas that don’t make coding harder, that don’t interrupt the creative flow, but instead add to the quality and especially to the maintainability of the code. If you like, they’re simple habits that improve your working life and will feel odd if you don’t do them – like checking whether a guitar is in tune before playing that killer riff.

Experiences in reducing treatment and application downtime and providing accurate data whilst upgrading an Oncology Information System

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Background Over the last two years the authors have attempted to reduce downtime affecting radiotherapy treatment through proactive management and monitoring of the network and servers providing an Aria Oncology Information System. Data from Aria are provided in the form of reports and web pages, some essential to the operation of the department, and fed to electronic plan approval and in vivo dosimetry applications written within Radiotherapy Physics. In November 2015 the Aria system was upgraded from version 10 to 13.6 with a change of database from Sybase SQL Server to Microsoft SQL Server and an upgrade of operating systems.

Methods Work included: changing the backup system, arranging for increased redundancy, improving Windows Update management, adding scheduled reboots of Citrix servers, extending the “Nagios” monitoring system, filtering Windows event logs, and automating shut down of non-critical servers during air conditioning faults. In advance of the upgrade, a test installation version of Aria 13.6 was made available by Varian on a workstation; and reports, web pages and in-house software were updated to work with this.

Results Downtime due to backups overlapping with treatment time has been eliminated. Non-essential servers shut down as planned during a recent air conditioning failure, but the failure of a network switch on another weekend meant that treatment was not available and email alerts did not reach their intended recipients. Time constraints during the upgrade weekend meant Citrix servers were put in to use without patches and crashed several times in the week afterwards. Treatment data is recorded differently in Aria 13.6 than in Aria 10 in a way which was not indicated by the test workstation. Post-upgrade fixes to address this, and the extent of other required changes, delayed the availability of new versions of some of the reports and in-house applications. This in turn affected data quality due to lack of checks on the RTDS data set.

Treatment data is recorded differently in Aria 13.6 than in Aria 10 in a way which was not indicated by the test workstation. Post-upgrade fixes to address this, and the extent of other required changes, delayed the
availability of new versions of some of the reports and in-house applications. This in turn affected data quality due to lack of checks on the RTDS data set.

**Discussion.** The treatment data-related changes required additional work in the days after the upgrade, as did additional user support and problem solving from the loss of proactive monitoring and management. In the three months since the upgrade the service has mostly returned to a similar level of availability as before.

**Conclusion.** Oncology Information System upgrades continue to present a challenge to the smooth operation of a radiotherapy service.

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**Applications for 3D printing in radiotherapy**

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The aim is to determine if 3D printing can be applied to radiotherapy to generate bolus and HDR skin applicators. This involved establishing the water equivalence of the printing materials for kV, MV and Electrons and formulating the design process.

The Tango Plus™ (Stratsays) 3D printer material was compared to WT1 solid water for 300KV photons, and WTe for 8,10 and 12MeV electron energies. Depth dose curves were obtained by placing increasing thickness of solid water above the chamber. The process was repeated with the Tango Plus™ material and the results compared. The substitution method was used to establish the water equivalence of the material at MV photon energies. There was good agreement between measurements made in the Tango Plus™ material compared to WT1, WTe and using the substitution method for all energies results were within 3%.

Bolus was printed for an IMRT nose patient. The required bolus was outlined in Monaco (Elekta) treatment planning software and exported as a DICOM-RT structure. The structure was imported into TomoMask (New Bourne solutions) where it was converted into a STL file ready for printing. The benefit of this method was that the dose distribution within the patient could be modelled and the optimal bolus size printed. This bolus indexed well with the shell, matched with the outlined structure on the CT images and was used clinically on the patient.

HDR skin applicators have also been printed based on the optimal plan. A plan is generated in Oncentra Brachy (Elekta) where catheters and dwell positions are placed around the patient that will deliver the optimal dose to the PTV. The dwell position co-ordinates can then be exported into a MatLab script which creates a cylindrical surface around the line of dwell positions. These cylinders are exported as a STL and imported into the Mimics software along with the CT images. By extruding the patient surface and subtracting the cylinders it is possible to print an applicator that will deliver the optimal dose distribution based on the plan generated.

3D printing has many possible applications in radiotherapy and has been used for both bolus and HDR skin applicators.

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**MERLIN - an in-house software project for multi-criteria dosimetric evaluation of conformal, IMRT and Arc radiotherapy**

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**Introduction.** We have developed **MERLIN**, a client-server Dicom application for comprehensive multi-criteria dose analysis of external beam radiotherapy. The main use of this in-house project is to replace the time-consuming patient specific QA measurements for IMRT and VMAT plans, to act as independent MU check software in conformal RT and to verify the integrity of a Dicom plan transfer towards the record and verify system. A second aim of **Merlin** is to validate planning algorithms by refined comparison of computed
dose with imported dose measurements, using a set of built-in mathematical tools.

**Method.** For independent dose checks, we have developed a GPU-based *Dose Engine* (DE) for heterogeneous media, with lateral electron transport. For dose comparisons, a *Maths Module* is able to analyse any pair of dose grids sourcing from planning systems (TPS), dose measurement systems (e.g. OmniPro), or locally computed. The algorithms implemented are local/global gamma 2D/3D, DTA 2D/3D, as well as local/global relative difference. A powerful feature in Merlin is using filter masks for dose analysis, like a dose value/gradient range, pixel-based density value/gradient range or region-of-interest mask (RT structures). This allows refined analysis like the pass rate in bone or lung tissue, at tissue-air interface, in a specific structure combination or in build-up region, to name a few.

**Results.** Our DE computing times are < 2 seconds for a 4-beam setup on a NV Quadro 5000 GPU, about 3.5 seconds for a 7-field IMRT and < 30 seconds for a full prostate VMAT plan. The DE - water tank agreement is about 99% global gamma pass (2%/2mm), while with Elekta Monaco 5 Monte Carlo plans is ~98% local gamma (3%/3mm) for VMAT and >96% for head & neck IMRT. We compared Monaco v3 vs. v5 doses, passing above 98%.

**Conclusion.** *Merlin* is an accurate substitute for machine-based patient specific QA, while performing independent MU check and plan transfer validation as well. Its parametric math tools allow for multi-criteria dose analysis, suitable for validating third party algorithms and beam models, or comparing planning systems against each other or measurements.

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**Development of a virtual reality application for the benefit of nystagmus sufferers**

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Nystagmus is an eye movement disorder in which the sufferer experiences repetitive involuntary eye motion. It has been estimated to affect 0.24% of the population in the UK. Nystagmus is broadly classified into two groups: Infantile (present at birth or within the first 6 months of life) and acquired (developed later in life). Patients with infantile nystagmus commonly adapt to the erratic eye motion during early neural development; nevertheless, it adversely affects quality of vision (e.g. visual acuity). However, acquired nystagmus patients rarely adapt and perceive the world as constantly in motion. Acquired nystagmus is often completely incapacitating, typically resulting in nausea, vertigo, loss of balance and inability of the sufferer to effectively interact with the world around them. Patients with acquired nystagmus currently have few opportunities for relief and no reliable treatment options. They can feel imprisoned by their condition and hence opportunities to communicate their experiences can help to remove their sense of helplessness and isolation.

We address this problem by innovative application of virtual reality technology to allow acquired nystagmus sufferers to communicate the debilitating nature of their condition. Virtual reality technology refers to headsets capable of immersing the wearer in a virtual environment by providing stereoscopic vision and head tracking (examples are the Oculus Rift and Google Cardboard). Here we present a virtual reality application developed to effectively demonstrate how a nystagmus patient perceives the world around them. In the application, eye tracking data from a real nystagmus patient has been replicated within the virtual reality environment for an authentic experience.

With the publication of the application across multiple platforms (Windows (desktop), Android, iOS) we raise awareness of the condition, provide an educational tool and offer nystagmus sufferers a medium to discuss the condition with those around them.
Science without Borders. Risk of Microshock in Operating Theatres
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The lowest threshold of perception of the human body to an electric shock is around 0.5 mA at mains frequencies. Such events are called macroshocks. By contrast, a microshock is a term used when tiny electrical currents (around 50 uA) cause cardiac fibrillation when applied directly to the heart muscle but would otherwise go unnoticed in the human body. In the operating room, the patient is particularly vulnerable to both macro and microshocks due to the fact that they have their skin resistance deliberately lowered, they come into contact with a large number of devices simultaneously and they are often under anaesthesia thus unable to pull free from sources of electrocution. Electrical contact with the heart muscle is very likely through pacing leads and intracardiac temperature/pressure lines. A team in south Brazil developed a novel device for detecting leakage currents inside the operating room called Protegemed. The device works by inserting small toroids in the electrical supply to measure phase and differential currents in each socket. If the differential current exceeds a pre-determined threshold, an event is triggered which sends information via a microprocessor to the hospital information system. The Clinical Biomedical Engineering team monitor these events remotely via the hospital network.

Last year, I obtained a grant from the Brazilian Ministry of Education under the Science without Borders programme to visit the University and Hospital in Brazil and conduct research using this technology. During my trip I conducted a number of experiments on the device simulating situations which may lead to an electrical hazard inside the operating room even if it was supplied via an isolating transformer. These situations include breakdown of insulation in one or more piece of equipment, loss of protective earth and accidental patient contact with earth via the operator. The experiments were conducted under controlled environment in the University's laboratories with the aid of physical simulators and computer simulation using pspice. We also installed and tested a number of devices in the local Hospital. Over the next few years we hope to strengthen these collaborative links with more planned visits and exchange PhD students. We hope that these activities will lead to more research opportunities, International commercialisation and safer environment for patients worldwide.

Developing D-flow applications for measuring parameters and visualising geometry of spine of patients with scoliosis
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The knowledge of geometry of spine is very useful when treating various diseases of the spine such as scoliosis. Clinicians usually use two dimensional parameters that defines geometry of spine of a patient. However the nature of the geometry of the spine is three-dimensional hence it requires knowledge of three dimensional parameters in order to treat it properly. Some of the imaging techniques that are commonly used include radiology, computed tomography, ultrasound, nuclear imaging and magnetic resonance imaging (MRI). The main limitation of radiography, the mostly used common imaging technique, is that it is two dimensional while spine geometry of scoliosis is three dimensional. Besides many of the imaging techniques are not user friendly since they are complicated, associated with harmful radiation and not easy to use. Thus the main aim of this project was to develop user friendly D-flow based applications that can calculate and visualise three dimensional shape of the spine using motion capture system in order to provide 3D parameters and visual feedback in real time to the clinician. Hence three D-flow based applications namely; pointing wand calibration, marker dependent and marker independent applications, were developed during the project. The applications were then tested by visualising geometry of skeleton and S- shaped cable attached to the skeleton. The marker dependent application was tested by attaching passive Infrared markers to the skeleton ad thereafter labelling them in a particular sequence using a pointing wand and fidget. Besides for the marker independent no marker was attached to the skeleton and the geometry of the
spine was obtained by pointing the wand at each anatomical land mark of vertebrae and pressing button of
deficit to capture coordinates of that position. The coordinates of the labelled points were used to calculate
different parameters and reconstruct a visualisation of the spine. The numerical results of parameters such
as angles from both applications were recorded, analysed and compared to manual measurements using
statistical software Minitab. Consequently there was no statistical difference between values of parameters
from both developed visualising applications. In conclusion all applications could accurately visualise the
geometry of spine and calculate the 3D parameters for defining curvature of the spine.

The RiPod: A home-use uroflowmeter suitable for redistributed manufacturing
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Introduction. Traditional manufacturing methods for medical devices require sourcing, moulding, and
assembly processes that occur often in different countries, and then require storage in both central
warehouses and end-point distribution centres. Redistributed manufacturing aims to disrupt the traditional
model by manufacturing and assembling the device closer to the end user [1]. The Flowtaker [2] is a single-
patient home-use urine flowmeter to help the diagnosis of gentlemen with urinary problems, which we
developed employing the traditional manufacturing model. We have completely re-designed this device by
integrating sensing, electronics and power elements. The simplified plastic parts can be manufactured using
consumer 3D printing technology. This new design (“The RiPod”), is suitable for assembly by the layperson.
In this study, we characterised the performance of The RiPod against the original Flowtaker.

Methods. Calibrated weights were added to each unloaded device in 100g increments up to 1000g. This
experiment was performed a total of 6 times for each device. As per practice with the Flowtaker, the 0g and
1000g measurements of the first experiment were used as calibration points. Performance of each device
was assessed by Bland-Altman plot analysis, and quantified by the mean difference and the coefficient of
repeatability.

Results. For the Flowtaker, the mean difference was 0.5g and the coefficient of repeatability was 1.3g. For
the RiPod, the mean difference was 1.5g and the coefficient of repeatability was 4.2g. In both cases, the
Bland-Altman plot did not show any linear trend. The errors are lower than 10g, and therefore not
considered clinically significant.

Conclusion. In this project, we have developed a prototype uroflowmeter suitable for redistributed
manufacturing. These preliminary results show that the performance of this new technology is lower than the
original design, but is still within what is considered clinically acceptable.

References
[Accessed 03 March 16]

The Beta PCA+ Handset: Widening access to self-administered pain relief
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Background: Patient controlled analgesia (PCA) is the gold standard for intravenous pain relief during post-
operative care. A PCA pump delivers a background dose of anaesthesia in addition to boluses of pain relief
that are administered by the patient pressing a switch on the pump handset. PCA aims to ensure an
effective level of analgesia while minimising dose-related side effects. The Pain Team at our Trust identified up to 20% of patients are excluded from using PCA as they are unable to press the switch to activate the pump. We aimed to design an adaptation to the handset (Beta PCA+) to enable greater access to PCA. This project was made possible by funding from an IPEM Innovation and Research Award in 2012.

**Methods:** To facilitate the design process, the Beta PCA+ device was developed using a Healthcare Design Toolkit. This process seeks to explore needs, create concepts and then evaluate them in a rapid iterative cycle. Key stakeholders were identified including patients and ward, pain team and medical equipment library staff. Needs were explored through design workshops, stakeholder meetings, regulatory analysis and observations. Requirements were captured from the perspective of each stakeholder and the service pathway was mapped to understand the use context. Concepts were generated in creative workshops, then early prototypes were made to establish concept viability and inspire iterations. FAST analysis and FMEA risk analysis methods were used throughout the design process. The Beta PCA+ was prototyped and manufactured using a variety of processes including filament deposit manufacture, CNC machining and selective laser sintering (SLS). A service evaluation was then undertaken to evaluate the Beta PCA+ device.

**Results:** The Healthcare Design Toolkit was effective for capturing key design information, defining the requirements specification and generating creative design concepts. Sixty-four requirements were identified including the need to: reliably deliver pain relief as requested; maintain the pump’s functional and safety features; be suitable for patients with fragile skin and be cleaned and tracked according to existing processes. A mechanical mounted lever concept was selected due to its simplicity: it is an accessory to the original handset and does not involve modification to the PCA pump. The Beta PCA+ device was designed in SolidWorks and then 3D printed using SLS method (Figure 1). A service evaluation is currently underway and six patients identified by the Pain Team, who were physically unable to operate the standard PCA handset, have successfully used the Beta PCA+ to control their own pain relief.

**Conclusion:** A Healthcare Design Toolkit was used to facilitate in-house innovation in an NHS Trust to enable more patients to access PCA pain relief. Rapid prototyping methods were used to develop a deeper understanding of need and develop a product suitable for Beta testing. The Beta PCA+ handset has been successfully used in a service evaluation to deliver PCA to patients who would previously have been excluded from this treatment pathway.
### In vivo portal dosimetry: from plan QA to patient QA

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Portal dosimetry is increasingly used for dosimetric plan QA and machine QA, especially now several commercial solutions are becoming available such as IViewDose (Elekta), Varian Portal Dosimetry, EpiGray (Dosisoft) and Dosimetry Check (MathResolutions). Most of these solutions also support in vivo dosimetry, introducing patient related information into the QA results. Therefore, in vivo portal dosimetry (IVPD) is not only a tool for plan QA but also for patient treatment QA. While cone beam CT (CBCT) guided IGRT procedures focus on the correct location of the target, anatomical or setup changes can also have dosimetric impact, detectable by IVPD. Furthermore, IVPD is a valuable tool for detecting anatomical changes on treatment units without CBCT.

In this lecture, results will be presented from 10 years of clinical experience with IVPD and the role of IVPD in the QA program of the NKI will be discussed. Furthermore, recent developments such as pre-treatment dose verification in patient anatomy will be presented.

### Investigate the dosimetric effect for IBA in-vivo detector - Dolphin

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**Introduction:** Transmission-type detectors were great for in-vivo dosimetry. Simple strategy using a constant tray factor for Dolphin (IBA Dosimetry, GhmBH, Germany) in the treatment planning system (TPS) beam model to account for the change of beam characteristic is studied.

**Methods:** Tray factors for 6MV and 10MV were estimated by measuring the central chamber of dose ratios of the OCTAVIUS 2D array (PTW, Freiburg, Germany) with and without the Dolphin in the beam path. The tray factors were manually adjusted in 0.1 steps to obtain the optimal values in various standard fields. Three-phase investigations were made: (1) 3 6MV head-and-neck (HN) and 4 10MV prostate were created in Pinnacle v9.10 (Philips Medical Systems). These plans were then delivered at Elekta Agility Linac with and without Dolphin in the beam path and data were collected by the 4D Octavius 1500 detector to obtain 3D reconstructed dose distribution. After applying the factors, 3D Y analysis in Verisoft 6.1 with 3%/3mm/local-dose passing criteria and 10% dose suppression were made. (2) New beam models with modified outputs were created and used to recalculate the plans. These reference plans were compared to the Dolphin-mounted reconstructed 3D dose. (3) In the last phase, six TLD-700 chips stuck onto the surface at the eye level of a head phantom were used for every HN case and irradiated with and without Dolphin.

**Results:** Optimal tray factors of 0.91 and 0.925 were found for 6MV and 10MV respectively. After applying these factors to the un-attenuated measurements, 3D Y passing rates were 99.1±0.1% and 98.3±0.5% for HN and prostate cases respectively. In the second phase analysis, 95.6±1.4% and 95.6±4.4% 3D Y passing rates were achieved. As for TLDs measurements, 11.5±4.5% in average increased surface dose was found.

**Conclusion:** A single tray factor for a specific beam quality is adequate to account for the effect of the transmission detector in high to medium dose regions (down to 20% of the maximum dose). However, special awareness should be made to the increased surface dose which is not reflected in the electron contamination component in the TPS beam model and in the phantom measurements by solely using a single tray factor.
Commissioning and Evaluation of Dosisoft's MU2net and Epigray applications
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An independent monitor unit calculation system, MU2net, and an EPID based in-vivo treatment verification system, Epigray, were commissioned to work alongside Eclipse TPS (version 11) for treatments on a newly installed Varian Truebeam linear accelerator (STx versions 2 and 2.5).

MU2net uses TMR data, normalised to 10cm deep, to calculate doses or MU’s to a point in the treatment field. Plans were generated in Eclipse TPS including open, wedge, MLC and IMRT fields for beam energies 6MV and 10MV. Central axis and off axis point doses were compared with both the TPS and measured water tank data (except IMRT, which were compared with TPS data only). Open fields showed results less than 1% from the measured data with the exception of rectangular fields which were within 1.8%. However MLC fields showed discrepancies of up to 2.7%, while wedge fields showed a wider variation of differences ranging from -1.1% up to 3.1% for off axis points. On the other hand, IMRT plans for prostate and head & neck were generally less than the set tolerance of 5%, while some outliers had differences of greater than 5% for the IMRT head & neck cases. This is due to the difficulty in choosing a reference point suitable for each beam and ensuring it is in the direct beam for the minimum recommended 25% of the total field. Ongoing work will see the commissioning of MU2net for RapidArc beams.

Epigray software compares ratios of TMRs with EPID signal to predict dose delivered to a point or more in a treatment field. Commissioning of the system is carried out for 6MV and 10MV beam energies for 2 Varian Truebeam accelerators for conformal, IMRT and Rapidarc treatment delivery. The commissioning data are being compared with both Eclipse and ion chamber data. Experience with Epigray so far has been limited but commissioning work will help to gain knowledge, experience and hopefully confidence with the system. Correspondence with Dosisoft is continuous at this stage to ensure the beam data is correct and gives the most accurate results. A positive outcome of the Epigray system would be less pre-treatment patient specific QA.

Modelling the Integral Quality Monitor (IQM) within a Treatment Planning System (TPS)
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**Aims**
The IQM is a wedge-shaped transmission ion chamber mounted below the front face of a linac head, designed to automatically verify beam deliveries during clinical use. The aim of this investigation was to determine the required modifications to our Philips PinnacleTM 9.8 TPS models to incorporate the effects of the IQM being present in the radiation beam during treatment.

**Methods**
Measurements were made with the IQM attached to an Elekta Versa HD linac fitted with the Agility MLC. Measurements were taken of transmission, PDDs, profiles and output factors at 6MV, 6MV FFF & 10MV, with and without the IQM. The data was compared with our standard clinical models on Pinnacle 9.8. In addition, treatments planned using current clinical TPS models at all three energies were corrected for transmission through the IQM and delivered to the Delta4 device. These were compared to uncorrected plans delivered without the IQM.

**Results**
Transmission on the central axis of 0.946, 0.946 and 0.959 was measured for 6MV, 6MV FFF & 10MV respectively. Output factors with and without the IQM agreed to within ±0.3% for field sizes 3x3 - 30x30cm² for all energies. PDDs with and without the IQM agreed to within ±0.5% beyond Dmax for field sizes 3x3 to 30x30cm². Below Dmax agreement was within 1.2mm. Profiles measured with and without the IQM (at Dmax, 5, 10 and 20cm deep) showed excellent agreement (0.5% in the flattened area or 1mm at field edges) for field sizes 5x5 - 20x20 cm² for all energies. Similar results were seen for 30x30 cm² fields at 6MV FFF & 10MV. However, larger differences (up to 1.4% in the flattened area or 1mm at field edges) were seen for 6MV, the differences increasing with off-axis distance. Delta4 measurements gave good agreement between plans delivered without the IQM and plans delivered through the IQM with a simple transmission correction applied.
**Conclusion** The presence of the IQM device has minimal effect on TPS models up to a field size of 30x30 cm². However a systematic correction of 4-5% to the prescribed monitor units is required to correct for the attenuation of the device.
Practical management of Optical Radiation in the Medical Sector – an illuminating insight into the forthcoming IPEM guide  
Colin Swift, The Christie NHS Foundation Trust, Manchester

Artificial optical radiation has extensive uses throughout the medical sector, ranging from trivial uses such as general lighting, and optical indicators, through to phototherapy sources and lasers. Often the safety aspects of these sources is overlooked or not fully understood- sometimes both. As such the IPEM sought to produce a practical guide for implementation of the Control of Artificial Optical Radiation at Work Regulations and assessment of the potential hazards of non-ionising electromagnetic sources in general of a wavelength range from 100nm to 1mm. This talk will serve as an introduction to the guide as well as detailing what needs to be done to assist individuals in the assessment of the hazards presented by a not-trivial source of artificial Optical Radiation.

Differences in Minimal Erythemal Dose (MED) results explained by temperature variation in handheld testers  
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Background
A study by Otman et al. in 2006 recommended the semiautomated Durham Erythema MED tester as a validated alternative to traditional MED testing which could overcome practical obstacles associated with MED testing. Their results demonstrated an MED that was, on average, 88% of the traditional template MED test method. Subsequently a study in 2014 by Lynch et al. found the handheld MED was, on average, 67% of the traditional MED. There is a discrepancy between these two results.

Objective
The aim of this study was to carry out a technical investigation into enclosed handheld Durham erythema test devices after our own clinical trial demonstrated statistically different MED results to the traditional template method.

Methods
The MED produced by the Durham Erythema tester was compared to the traditional template method in thirty-two patients. Following this study time dependent lamp temperature and surface output measurements were recorded and compared. Ratios between successive apertures were examined and aperture transmission percentages were calculated.

Results
The Durham Erythema tester MED was, on average, 57% of the traditional MED. A non-uniform lamp output from the Durham Erythema tester was discovered and linked to temperature variation within the closed device. This resulted in transmitted irradiance percentages that were different from the 1.26 progression quoted by the manufacturer. When the corrected transmitted percentages were used the Durham Erythema MED was 82% of the traditional MED.

Conclusion
Temperature variation affects the transmitted irradiance percentages. Our findings explain the differences in published literature. The first aperture is affected most by temperature variation. By discarding the first aperture a 1.26 progression can be assumed.
Making the most of the sun: optimising treatment times for daylight PDT across the UK
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Background: Daylight photodynamic therapy (dPDT) is a treatment modality useful for virtually pain-free treatment of superficial skin lesions. It would be useful if there was UK data indicating which times during the year patients could be expected to receive an effective light dose.

Objectives: To determine, by analyses of lux data from several UK sites, which times of the year the minimum threshold PpIX effective dose is achieved, i.e. when dPDT can be effectively carried out.

Methods: Lux readings from several sites across the UK were analysed. These lux values were converted to PpIX effective dose using an equation derived from analysis of daylight spectral irradiance. The measured PpIX effective dose was then compared against a threshold value to determine which times of the year dPDT can take place at each UK location. Where effective dose was sufficient but outside temperature would prevent dPDT an analysis of the dose received inside a conservatory was performed.

Results: The results of this analysis indicate times of the year when dPDT can be performed with confidence that the minimum threshold dose will be reached. The analysis also allows determines effective dose received in a conservatory, allowing treatment to take place even on cold days.

Conclusions: Using the derived equation and measured lux values, it is possible to estimate the PpIX effective light dose that a patient may receive during dPDT treatment. This data can be used to inform centres throughout the UK what times of the year are most appropriate for dPDT.

Patient UVA dosimetry using EBT3 Gafchromic film
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This study explores the use of Gafchromic EBT3 film (Ashland, USA) as a patient UVA dosimeter. Although EBT3 has been designed by its manufacturers as a tool for radiotherapy dosimetry, Butson et al\(^1\) have shown the film can be used to quantify solar UV dose. The film is minimally inconvenient for the patient as it can be easily affixed to the skin and allows simultaneous measurements at many sites. Absorption peaks of the film are located in the visible red region meaning a visual change in film colour will be observed upon exposure to UVA radiation. Scanning of the film using an Epson V800 scanner and analysis of the images using ImageJ and Microsoft Excel then provides UVA dosimetry information. A UVA exposure response curve for the film was obtained by comparing the pixel intensity in the red channel of the scanned film to measurements with a calibrated UVA radiometer to provide an acceptable level of accuracy. A useful range of \(\sim 0.2-30 \text{ J/cm}^2\) was observed. Our patient dosimetry is based on the Scottish Photonet Designated Patient Irradiance (DPI) method. The objective of this study was to compare the mean calculated irradiance incident on patients during treatments with the irradiance measured at 7 anatomical locations for 15 patients of average size. A further objective is to investigate the influence of patient size on the incident irradiances by carrying out measurements on 15 patients of varying body habitus.

The use of EBT3 may facilitate more optimum treatment delivery and evaluation of dose particularly in the more UV sensitive areas of skin.

Background: The Designated Patient Irradiance (DPI) is used in UV phototherapy treatments to determine treatment time in order that a patient receives the required dose of UV exposure. There are two methods for obtaining the DPI for a phototherapy cabin; direct and indirect. The direct method involves entering the cabin and acquiring measurements of irradiance at different positions on the body. The disadvantage is exposure of staff to high levels of UV radiation, requiring personal protective measures that have the potential to fail. For the indirect method, measurements of irradiance are made at various positions within the cabin without an individual present, meaning there is very little UV exposure for staff. To convert an indirect measurement into a DPI, a correction factor (CF) is required. The CF is taken as the ratio of direct-to-indirect measurements (DIR). At our Photobiology Unit direct and indirect measurements have been made annually and quarterly, respectively, on all cabins across NHS Tayside.

Aim: In line with the Artificial Optical Radiation Regulations, it is important to ensure individuals are not unnecessarily exposed to UV radiation. This research aims to determine if, using published measurement techniques, global DIRs can be advised, removing the need for direct measurement of cabin irradiance.

Method: Historical DIR data for eight Phototherapy cabins across NHS Tayside was collated and statistical methods used to assess the significance of several factors on the calculated DIR. Factors considered were cabin geometry, meter type and year.

Results: Initial findings show that the DIR has not varied significantly over the past 15 years. There are however, significant variations in DIR between cabins of different geometries and the type of meter used for measurement.

Conclusion: By following published measurement techniques it is possible to use global DIRs which remove the need for a staff member to expose themselves to UV radiation.
Rapid pacing induced ischemia causes right ventricular dysfunction during transcatheater aortic valve implantation

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Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK (1) Anglia Ruskin University, Chelmsford, UK (2) Papworth Hospital NHS Foundation Trust, Papworth Everard, UK (3)

**Background:** Transcatheter Aortic Valve Implantation (TAVI) is now an established keyhole procedure for inoperable patients who have stiffened aortic valves. To implant the device Rapid Pacing (RP) is used to stabilise the aortic valve while the balloon is inflated. Prior to device implantation a RP Test Capture (RPTC) is routinely performed to ensure adequate aortic valve stabilisation. We hypothesized that RP induced ischemic Right Ventricular (RV) dysfunction would mask any potential improvements post-TAVI.

**Method:** Twenty-Two patients with a median age of 77 years (range 68 to 93) patients had RV conductance catheter assessment pre-TAVI, post-RPTC and post-TAVI. Prior to RPTC measurements a median number of 37 RP beats (IQR 22 to 43) were delivered compared to 157 RP beats (IQR 110 to 252) prior to post-TAVI measurements. Pressure Volume loops were recorded at steady state (all time points) and during inferior vena cava balloon occlusion (pre-TAVI and post-TAVI). Load-dependent (all time points) and load-independent (pre-TAVI and post-TAVI) indices of RV contractility were compared.

**Results:** Table 1 shows that RV diastolic dysfunction was evident after RPTC prior to valve implantation (Tau p < 0.0001; EDP p < 0.0001) and was still apparent after valve deployment (Tau p < 0.001; EDP p < 0.001). Load-independent indices showed RV systolic contractility was reduced post-TAVI (Ees p < 0.03; PRSW p < 0.01) and This suggested ventriculoarterial uncoupling Post-TAVI (p < 0.02).

**Conclusion:** These finding showed that a short burst of RP caused significant RV diastolic dysfunction before the aortic valve was implanted. Further work must be completed to look at ways to modify the clinical procedure and help prevent this damage in the future.

**Table 1 RV Haemodynamic Data**

<table>
<thead>
<tr>
<th>RV Function</th>
<th>Pre-TAVI</th>
<th>Post-RPTC</th>
<th>Post-TAVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number RP Beats, n</td>
<td>-</td>
<td>$26.7 \pm 11.4$</td>
<td>$159.5 \pm 92.6$</td>
</tr>
<tr>
<td>RP Rate, BPM</td>
<td>-</td>
<td>$197.7 \pm 15.6$</td>
<td>$200.9 \pm 17.7$</td>
</tr>
<tr>
<td>Time Constant of Diastolic Relaxation (Tau), ms</td>
<td>$58.0 \pm 15.5$</td>
<td>$77.9 \pm 33.2$</td>
<td>$80.1 \pm 24.4$</td>
</tr>
<tr>
<td>End-Diastolic Pressure (Ped), mmHg</td>
<td>$8.5 \pm 5.8$</td>
<td>$11.6 \pm 6.1$</td>
<td>$11.7 \pm 5.9$</td>
</tr>
<tr>
<td>Effective Arterial Elastance (Ea), mmHg/ml</td>
<td>$0.38 \pm 0.15$</td>
<td>$0.65 \pm 0.48$</td>
<td>$0.40 \pm 0.18$</td>
</tr>
<tr>
<td>End-Systolic Elastance (Ees), mmHg/ml</td>
<td>$0.39 \pm 0.18$</td>
<td>-</td>
<td>$0.30 \pm 0.17$</td>
</tr>
<tr>
<td>Ventriculoarterial Coupling Ratio (Ees/Ea)</td>
<td>$1.10 \pm 0.40$</td>
<td>-</td>
<td>$0.80 \pm 0.37$</td>
</tr>
<tr>
<td>Preload Recruitable Stroke Work (PRSW)</td>
<td>$21.0 \pm 10.5$</td>
<td>-</td>
<td>$14.7 \pm 8.4$</td>
</tr>
</tbody>
</table>

Values are mean±SD. * indicates p < 0.05 for pre-TAVI vs. post-RPTC; † indicates p < 0.05 for post-RPTC vs. post-TAVI; ‡ indicates p < 0.05 for pre-TAVI vs. post-TAVI.

Using physiological measurement techniques to facilitate Europe’s first DCD heart transplant

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Stephen Large (3) Paul White (1,2)  
Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK (1) Anglia Ruskin University, Chelmsford, UK (2) Papworth Hospital NHS Foundation Trust, Papworth Everard, UK (3)

**Background:** The demand for hearts for transplantation has never been greater. Over the last decade abdominal and lung transplant programmes have turned to the Donation after Circulatory Death (DCD) donor in an attempt to increase organ supply. In circulatory death the donor is declared dead 5 minutes after the heart has stopped beating (mechanical asystole). However, the inability to assess heart function following circulatory death has prevented the routine adoption of DCD heart transplantation. Here, we report
a novel method that was used to define functional acceptability criteria for DCD hearts for transplantation.

**Method:** Following next of kin consent seven adult donors with a median age of 28 years (range 21 to 51) were recruited. After excluding the cerebral circulation, a mechanical support circuit was used to provide Normothermic Regional Perfusion (NRP) and restore function to the arrested DCD heart within the donor. After weaning from mechanical support, DCD hearts were functionally assessed using conductance catheterisation, right heart catheterisation and echocardiography. During the research phase, hearts were then transferred to the TransMedics Organ Care System (OCS) and an evaluation of function was performed with the conductance catheter in a modified working heart mode. Data collected during the research phase was then used to define functional acceptability criteria for DCD hearts. This ensured only hearts with acceptable function were selected for clinical transplantation.

**Results:** During the research phase one donor was excluded due to an incomplete data set. Table 1 shows that Donor Hearts 1 and 4 are unsuitable for transplantation as the conductance catheter derived contractility \((dP/dt \text{ max, } dP/dt \text{ min, } \text{Tau, } Ees/Ea)\) was poor and this correlated with inadequate cardiac indexes \((< 2.5 \text{ L/min/m}^2)\) and filling pressures exceeding 12 mmHg. Therefore, we defined the clinical acceptability criteria for DCD donor hearts as: cardiac index \(\geq 2.5 \text{ L/min/m}^2\); central venous pressure \(\leq 12 \text{ mmHg}\); pulmonary capillary wedge pressure \(\leq 12 \text{ mmHg}\); and left ventricular echocardiographic ejection fraction \(\geq 50\%). Donor hearts 5 and 6 were transplanted in the clinical phase with 100% survival and no episodes of rejection (total 698 days, range 330-368).

**Conclusion:** NRP allows rapid reperfusion and functional assessment of the DCD heart. The conductance technique was successfully used to define functional acceptability criteria from routine clinical measurements. This ensured only DCD hearts with sufficient function were selected for transplantation and resulted in Europe's first successful DCD heart transplant on 1st March 2015. We are now the global leader in DCD heart transplantation having performed the largest series of successful DCD heart transplants in the world.

**Table 1. Donor Demographics, Timings and Functional Assessment**

<table>
<thead>
<tr>
<th>Donor</th>
<th>Demographics</th>
<th>Research Phase</th>
<th>Clinical Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age - yrs</td>
<td>1   2</td>
<td>3   4</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>28  21</td>
<td>45  28</td>
</tr>
<tr>
<td>2</td>
<td>185</td>
<td>168 156</td>
<td>177 172</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>85  55</td>
<td>96  75</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height - cm</td>
<td>185 168 156</td>
<td>177 172</td>
</tr>
<tr>
<td></td>
<td>Weight - kg</td>
<td>80  85  55</td>
<td>96  75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timings</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WLST to Death - min</td>
<td>22 12 10 14</td>
<td>54 13</td>
</tr>
<tr>
<td></td>
<td>FWIT to NRP - min</td>
<td>21 20 12 19</td>
<td>17 12</td>
</tr>
<tr>
<td></td>
<td>NRP Duration - min</td>
<td>113 114 82 60</td>
<td>52 52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Functional Assessment After Weaning from NRP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cardiac Output – L/min</td>
<td>4 5.2 4.6 4.5</td>
<td>6.0 5.6</td>
</tr>
<tr>
<td></td>
<td>Cardiac Index – L/min/m²</td>
<td>2.2 2.7 3.0 2.1</td>
<td>3.2 2.8</td>
</tr>
<tr>
<td></td>
<td>CVP - mmHg</td>
<td>4  8  6  16</td>
<td>10  6</td>
</tr>
<tr>
<td></td>
<td>PCWP - mmHg</td>
<td>9 9 14 14</td>
<td>12 9</td>
</tr>
<tr>
<td></td>
<td>MAP - mmHg</td>
<td>31 51 70 50</td>
<td>85 79</td>
</tr>
<tr>
<td></td>
<td>LV EF - %</td>
<td>- - - -</td>
<td>58 66</td>
</tr>
<tr>
<td></td>
<td>dP/dt max – mmHg/s</td>
<td>949 1497 1230</td>
<td>1007 -</td>
</tr>
<tr>
<td></td>
<td>Tau - ms</td>
<td>86.8 30.8 49.1</td>
<td>50.2 -</td>
</tr>
<tr>
<td></td>
<td>Ees/Ea</td>
<td>0.34 1.12 1.21</td>
<td>0.66 -</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Functional Assessment in Working Mode on Modified TransMedics OCS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dP/dt max – mmHg/s</td>
<td>559 1442 1322</td>
<td>719 -</td>
</tr>
<tr>
<td></td>
<td>Tau - ms</td>
<td>48.0 59.6 46.9</td>
<td>46.9 -</td>
</tr>
<tr>
<td></td>
<td>Ees/Ea</td>
<td>0.49 1.24 0.98</td>
<td>0.64 -</td>
</tr>
</tbody>
</table>

WLST - Withdrawal of Life Sustaining Therapy; FWIT – Functional Warm Ischemic Time; NRP – Normothermic Regional Perfusion; CVP – Central Venous Pressure; PCWP – Pulmonary Capillary Wedge Pressure; MAP – Mean Arterial Pressure; LV EF – Left Ventricular Ejection Fraction; dP/dt max – Maximum Rate of Isovolumic Contraction; dP/dt min – Maximum Rate of Isovolumic Relaxation; Tau – Time Constant of Diastolic Relaxation; Ees/Ea – Ventrículoarterial-Coupling Ratio.
On the Role of Computational Modelling and Inflammation Imaging in the Prediction of Abdominal Aortic Aneurysm Rupture Risk: A 2 Year Longitudinal Study

Peter Hoskins (1), Noel Conlisk (1) Rachael Forsythe (1,2) Lyam Hollis (1) Barry Doyle (1,3) Calum Gray (2) Scott Semple (1,2) Tom MacGilivrey (2) David Newby (1,2)
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Introduction:
Abdominal aortic aneurysm (AAA) repair is based on maximum diameter > 55mm and/or rate of AAA expansion > 10mm/year. However many smaller AAAs rupture, while some AAAs with larger diameters never rupture. Geometrical properties of the aneurysm, peak wall stress (PWS) estimated using finite element analysis (FEA), and clinical markers of inflammation (e.g. MRI – USPIO) have all separately shown their potential for improved rupture risk prediction. Therefore, it is desirable to understand what link may exist between these different methods, with the aim of providing a more comprehensive assessment of rupture risk.

Method:
50 patients (43 male and 7 female) from the MA^3RS clinical trial (McBride 2015) were selected for analysis, the mean patient age was 73 years (59yrs – 87yrs). Each patient had a CT scan at baseline and 24 months. At baseline patients had MRI pre- and post-infusion of USPIOs and USPIO uptake was calculated. Wall stress for both the baseline and 24 month time points was calculated using a processing chain with CT as the input data. 3D reconstruction and meshing was performed using commercial software (VASCOPS GmbH, Sweden), and FE analysis using Abaqus (Dassault Systemes, USA).

Results:
A total of 100 aneurysms have been analysed (50 at baseline and 50 at 24 months).
Baseline comparisons of wall stress from FE and USPIO uptake performed on each patient showed that focal USPIO uptake around the lumen was co-located with elevated stress in 39 of 50 patients. However, 11 out of 50 patients showed no co-location in this region. Focal USPIO uptake away from the lumen behind thrombus was associated with low wall stress in 49 of 50 patients. Interestingly, in 21 of 50 patients where the thrombus was thin or missing, high USPIO uptake was associated with high wall stress.
At baseline, the average maximum AAA diameter was 52mm (± 6.05), mean PWS was 0.194 MPa (± 0.405), mean rupture risk was 0.44362 (± 0.121), and mean total AAA volume was 143.4 cm^3 (± 56.96). At follow up, maximum diameter had increase on average by 8%, PWS by 9%, rupture risk by 10% and total volume by up to 22%. Interestingly not all individual aneurysms increased in dimensions over the course of the study, some in fact showed a decrease in volume of up to 17% at the 24 month time point.

Discussion:
Comparative results from the present study suggest a co-location of stress and USPIO uptake in regions where the thrombus is thin or where the wall is devoid of thrombus entirely, but no co-location in focal regions of inflammation behind thick thrombus.
The results from geometrical analyses show that, though diameter and stress both increase with time, a more representative measure of risk may be total AAA volume.
Interestingly in a handful of cases diameter, PWS, rupture risk and total AAA volume were observed to decrease. As AAAs are not treated medically, this may potentially reflect further remodelling of the vessel following treatment for co-existing conditions such as hypertension, or in response to medically advised lifestyle changes.

Ongoing work:
A more comprehensive geometric analysis is underway and will be presented at the meeting, correlations with other markers of inflammation derived from PET imaging (18F-NaF PET-CT) conducted on the same cohort at 24 months will also be explored.

Brachytherapy

**Approaches for treatment verification and in vivo dosimetry in brachytherapy**
Dr Josh Mason, Leeds Cancer Centre, LTH NHS Trust, Leeds, UK

UK RCR guidelines recommend that in vivo dosimetry is performed for most radiotherapy patients at the start of treatment. In brachytherapy there are risks of treatment errors due to large per-fraction doses, use of manual procedures and mechanical equipment failures. However in vivo dosimetry is rarely performed in brachytherapy. Reasons for this include lack of suitable dosimeters, difficulty in accessing the treatment site, the high dose gradients within brachytherapy implants, energy dependence of dosimeters in the kV photon energy range used for most brachytherapy treatments, and lack of investment in solutions by manufacturers.

This presentation will explore these issues and review different approaches for treatment verification and in vivo dosimetry in brachytherapy including development of dosimeters, methods for real-time monitoring of treatments and alternatives to direct dose measurement such as electromagnetic reconstruction and source tracking using external detectors. Clinical studies will be reviewed including our own experience of real-time in vivo dosimetry in HDR prostate brachytherapy.

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**The impact of contrast on the volume calibration accuracy for ultrasound systems used for guided prostate brachytherapy treatment planning**
Andrea J Doyle (1,3), Jacinta E Browne (2,3)
FOCAS, Dublin Institute of Technology, Dublin 8, Ireland (1) Dublin Institute of Technology, Dublin, Ireland (2) Centre of Industrial Engineering Optics, FOCAS, Dublin Institute of Technology, Dublin, Ireland (3)

**Background.**
Prostate cancer is the most diagnosed invasive cancer in men in Ireland at 35.1%. [1] Ultrasound guided brachytherapy for prostate cancer was introduced in 2007 in Ireland [2] and has since been accepted in a number of treatment centres, largely due to its benefits for patient recovery, dose localisation and conformity.[3] The success of the procedure is based on the correct dose estimation and concise implantation of the brachytherapy seeds in the prostate. The ability to delineate the prostate from surrounding tissue; the contrast resolution, is vital in this procedure and the ability of the user to define the prostate is fundamental to the procedure. [3] This study will create a series of volume phantoms with varying contrasts of -2dB, -3dB and -4dB difference from background tissue mimicking material as well as an anechoic target, to assess the impact of varying contrast on volume calculations used in prostate brachytherapy treatment planning.

**Methods.**
A range of volume ultrasound prostate brachytherapy calibration phantoms were constructed with tissue mimicking material with acoustic properties similar to prostate tissue. These volume phantoms were produced and moulded (Figure 1) in order to construct four different test phantoms with prostate volumes composed of tissue mimic which produced different contrast levels to the back tissue mimicking material. The volume of the prostate insert was measured before it was incorporated into the background material of the phantom. Each of the four phantoms contained a simplistic prostate volume representing three different contrasts, -2, -3 and -4dB and an anechoic volume [4]

**Results.**

[Figure 1: Prostate Volume Tissue Mimic Mould]
The constructed volume phantoms were used to evaluate the accuracy of the volume estimation with the different volume phantoms of varying contrast, for a group of oncologist using a range of ultrasound systems across a number of hospital sites. The impact of the contrast relative to the background tissue mimicking material and the accuracy of the volume estimation for the group of oncologists was evaluated and will be presented. The effect of ultrasound scanner instrument optimisation was also investigated to determine the impact of volume delineation and therefore volume estimation accuracy. Furthermore, the role of such volume calibration phantoms for treatment planning will be determined by constructing a range of varying volume phantoms with a backscatter value of -3dB.

Discussion.
The lower -2 dB contrast volume provided the greatest difficulty for edge delineation and therefore had the greatest impact on volume estimation.

Conclusion.
This study presents a simple but challenging approach to determining the volume calibration accuracy for ultrasound systems used for guided prostate brachytherapy treatment planning.

Key references.

QUBIC - an in-house software development for brachytherapy treatment plan verification
Virgiliu Craciun (1)
University Hospitals Southampton NHS Foundation Trust, Southampton, UK (1)

QUBIC (Quick Utility for Brachy Inserts Check) is an in-house DICOM-compatible, client-server, Brachytherapy application, built to serve three main purposes: independent dose check, plan visualization and plan check. QUBIC can be run on all our desktop PCs, being in clinical use in our department for HDR treatment checks.

The Dose Engine uses the TG-43 formalism. It computes the dose at reference points, defined in the TPS or locally, based on user’s date/time schedule. It accounts for source decay and (if applicable) applicator transmission, source encapsulation and channel shielding. The dose agreement with our Nucletron Oncentra GYN TPS is typically ~ 0.1%.

The Plan Visualization feature is supported by a full 2D/3D/stereoscopic graphics engine providing a set of viewing tools sufficient for a proper plan review outside TPS environment, on any of our office PCs or workstations. Along with imported CT images and structures, items like catheters, dwell locations and dose distributions are included as review features. The display is customizable in terms of scene composition and viewing parameters.

The Plan Check feature is a distinctive module of this application. From review of the market, we believe that this feature is not available in current commercial applications. Typically, checking a RT plan is a task performed by a human operator against a clinical protocol, however, many of the sub-tasks that form the whole plan checking process can be implemented algorithmically in software. The algorithms have been developed in-house, ranging all the way from simple tasks to complex heuristic analysis. This module provides a wide range of protocol checking options: CT Image set parameters, structure set morphology; radiation source parameters; applicators and catheters set-up geometry, registration and shielding; dose grid and distribution; and imported plan parameters’ consistency and conformance. The applicators’ spatial registration can be automatic or manual, using commissioned models. The results can be exported as ASCII or PDF report. A summary of work to date will be presented.
Commissioning of microMOSFETs for HDR brachytherapy in-vivo dosimetry
Aaron Huckle (1) Gerry Lowe (1) Peter Hoskin (1)
Mount Vernon Cancer Centre, Northwood, Middlesex., UK (1)

In vivo dosimetry (IVD) for Ir-192 high dose rate (HDR) brachytherapy has been investigated by different centres with the aim to establish accurate and consistent equipment and methodology, to quantify organ at risk (OAR) doses and target volume doses for dose verification purposes.

Historically, positional setup errors and dose uncertainties in high dose gradients, as well as the practical aspects of manufacturing detectors small enough to fit inside a HDR catheter, have hindered the advancement of IVD within HDR brachytherapy. These setup challenges create uncertainty in measured dose close to the source, where small changes in distance result in large dose deviations.

Our department recently purchased the mobileMOSFET system (Best Medical, Canada) and we have developed a phantom to facilitate reproducible measurements at fixed distances from the Ir-192 source. Working towards implementing IVD clinically within the brachytherapy department, we performed repeat measurements to characterise the microMOSFETs in terms of reproducibility, linearity, energy response and detector deadtime.

The energy response was found to be within ±3% and linearity within 2%. The reproducibility of repeat measurements varied from 1% - 4% depending on the temporal resolution of the detector. The energy response of the detector varies significantly at lower energies so separate calibration factors are required depending on the source to detector distance.

We have been able to characterise the response of the microMOSFETs for HDR IVD and produce distance dependent calibration factors. Our aim is to use the detectors for dose verification purposes and identifying treatment errors such as incorrect catheter attachment to the HDR afterloader.
Motion Management

Motion management in radiotherapy: from planning CT to image guidance
Marcel van Herk, University of Manchester

In the past 25 years, the technology of external beam radiotherapy has improved tremendously. Due to the development of advanced diagnostic imaging, tumor localization has greatly improved. The recognition of the presence of internal organ motion has lead to development of image guidance systems based on 2D, 3D or 4D imaging systems integrated with the treatment machines, first based on CT and soon based on MR. The achievable localization accuracy is so high, that invasive fixation is no longer needed. For treatment of tumor in the brain, for instance, localization of the skull with 3D image guidance is accurate to well within one mm. The main factors that affect the accuracy of treatment after image guidance has been implemented are: uncertainties in target volume definition, the quality of the surrogate (if any) used to localize the tumor, intrafraction movement, and movement that is too complex to be corrected by the image guidance solution (e.g., deformations).

The treatment process starts with the planning CT and it is essential that this CT is representative for the situation during all fractions of treatment. Periodic or random organ motion affects the quality of the planning CT. In case periodic organ motion is faster than the acquisition speed of the scanner (e.g. respiration), correlated imaging is used to create a movie loop of the motion. A derivate based on averaging, motion encompassing, or motion compensation is then used to base the treatment plan upon. In case the motion is slower, adaptive radiotherapy is often used to update the model to better fit the ‘average’ anatomy. Another form of adaptive radiotherapy is to create a library of plans, where the best fitting one is selected as part of the image guidance process.

With better imaging (e.g. MR on the treatment machine), the trend is to move towards an online planning process to compensate for changes in the anatomy. However, this process is currently too time consuming for large scale implementation. Finally, research groups are working on gating and tracking approaches that are of interest for large and exceptional motion. However, generally available imaging is of insufficient speed or quality to currently perform such procedures without using implanted markers.

Dosimetric analysis of oesophagus plans using 3D-CT versus 4D-CT planning scans within the UK NeoSCOPE trial
Adam Selby (1) Caitlin Bowden (1) Sarah Gwynne (1) Richard Webster (2) Gareth Jones (2)
Singleton Hospital, Swansea, UK (1) Velindre Cancer Centre, Cardiff, UK (2)

Dose escalation in oesophageal cancer is limited by doses to organs at risk (OAR). Planning target volumes (PTV) delineated using 4D-CT are often smaller than 3D volumes using population-based margins. We undertook a dosimetric analysis of 3D versus 4D PTVs generated as per the NeoScope protocol with regard to doses to OARs.

The dataset for this study were 20 quality assured 4D cases, treated within the UK NeoSCOPE trial (neoadjuvant chemoradiotherapy for oesophageal cancer). Corresponding 3D volumes were also created using standardised PTV margins. A 3D conformal plan was created for both PTVs. The doses received by the OAR in each case were calculated, with particular focus on the heart.

To date, 12 cases have been analysed. Mean 3DPTV was 536.2cc and 4DPTV 423.3cc (mean difference -112.9, 95% CI -52.04 to -173.8, p=0.0018). Mean V25Gy dose to the heart was 59.7% and 53.5% for 3DPTV and 4DPTV respectively (mean difference -6.18, 95% CI -4.044 to -8.318, p=<0.0001). The V40Gy mean heart dose was 12.4% and 9.9% for 3DPTV and 4DPTV respectively (mean difference -2.4, 95% CI -0.85 to -4.0, p=0.0061). The mean V30Gy to the liver was 14.5% and 12.4% for 3DPTV and 4DPTV respectively (mean difference -2.17, 95% CI -1.1 to -3.2, p=0.0008). The mean V20Gy lung dose was 14.9% and 11.4% for 3DPTV and 4DPTV respectively (mean difference -3.4, 95% CI -2.37 to -4.51, p=0.0008). Updated results to include the remaining 8 cases will be presented at the meeting.
This is a novel study analysing the dosimetric benefits of 4D-CT in oesophageal cancer. We have shown that doses to the lungs, liver and heart are reduced using 4D-CT and this may facilitate further dose escalation, whilst maintaining isotoxicity. This hypothesis will be investigated further in the upcoming UK SCOPE 2 trial.

A small centre’s experience of implementing deep inspiration breath hold (DIBH) for left sided breast patients
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Radiotherapy is often used as an adjuvant treatment for breast cancer and has been shown to reduce the risk of recurrence and increase overall survival. Despite the benefits there are concerns regarding cardiac morbidity and mortality which have been shown to correlate with mean heart dose. Various methods have been developed with the aim of reducing cardiac toxicity whilst maintaining the same radiation dose to the breast.

Our centre has recently implemented one of these techniques – deep inspiration breath hold (DIBH). The patient inspires to a specified threshold level and maintains this position during CT scanning and radiotherapy field delivery. The increased lung volume pushes the breast away from the heart, thus reducing the volume that falls within the irradiated volume.

This talk will detail the experiences of a small centre in the commissioning and implementation of DIBH. A particular focus will be given to the pitfalls and difficulties that were encountered and how they can be overcome. The dosimetric impact of DIBH on treatments plans will also be reviewed.

Availability of breath hold with hypo-fractionated radiotherapy
Robin Garcia (1) Véronique Bodez (1) Enric Jaegle (1) Aurélien Badey (1) Catherine Khamphan (1) Maria Elena Alayrach (1) Paul Martinez (1) Institut St. Catherine, Avignon, France (1)

Introduction :
Lung and liver radiotherapy is always complex due to respiratory movements. An hypo-fractionated radiotherapy needs efficient processes to optimize the treatment sessions. Different techniques and methods exist which have variable interests. Breath hold is one of the potential method as long as the patient can follow the instructions on the different beams or arcs durations.

Materials and Method :
The patients manage their breath hold with the use of the SDX/Dyn’R system. The preparation phase focusses on the ability to maintain long breath hold. The dosimetric planning optimizes the dose distribution with the use of multiple 3D conformal arcs or multiple arcs VMAT. The treatment is delivered with a TrueBeam/Varian accelerator. While the patient is managed with the SDX spirometer, the gating is obtained with the integrated RPM system. This help to get a Breath Hold CB-CT and to secure the delivery.

Results :
To optimize the ability to follow an important delivery, the breath hold method can benefit from the FFF beams High Doserate, the planning based on multiple arcs and the patient management. Depending on the anatomy site, the dose rate can decrease the session duration by two or four. The use of archtherapy, either conformal or intensity modulated, improves both the dose distribution and the timing. The patient himself contributes to optimize his own treatment following the instructions delivered during the preparation phase.
Conclusion:
If the patient and the techniques aspects can favor the use of the Breath Hold method, the radiotherapy process benefit from an easier situation. Indeed, no movement provide simple CT acquisition, simple planning and short and efficient treatment.

Image Guided Radiotherapy with Clarity®: Trans-perineal Ultrasound for Localisation in Prostate Radiotherapy

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Aim: To assess the accuracy and precision of trans-perineal ultrasound for prostate image guided radiotherapy (IGRT).

Background: Ultrasound imaging enables soft tissue visualisation which is beneficial in prostate radiotherapy where internal organ motion can be significant and independent of bony anatomy. Trans-perineal ultrasound with the Elekta Clarity® system can be used to assess interfractional and intrafractional prostate movement by matching daily images to a reference ultrasound image.

Method: Ultrasound imaging was performed for several months without applying the patient shifts to allow for training and assessment of the system. During this time online matches were made for 86 images of 17 prostate patients to assess prostate displacement. The matches were repeated offline by two radiographers with ultrasound experience and the average of their shifts was set as the ‘gold standard’. Online matches were compared to the gold standard to assess variability in a clinical situation. The gold standard was validated by repeat matches of 20 anonymised images by a specialist from Elekta®. Routine audit of the online matches against the gold standard have been taking place for all patients since applying the shifts clinically.

Results: 86% of pre-clinical online matches agree with the gold standard to within 3mm (σ = 2.9 mm). 97% of gold standard matches agreed with the Elekta specialist to within 3mm (σ = 1.1 mm). Ongoing audit of online clinical matches has shown 97% agreement with the gold standard to within 3mm (σ = 1.4 mm). The average prostate displacement identified by this technique is 4mm and displacements exceeding 10mm are common.

Discussion: The intra-observer variability of pre-clinical results indicate that online matching is initially challenging in a clinical situation. However, ongoing audit of clinical results has shown that staff training has improved precision, while demonstrating that soft tissue matching with trans-perineal ultrasound is an effective means of prostate IGRT.
At the Norfolk and Norwich University Hospital 74Gy in 37# is prescribed for VMAT Prostate treatments. A class solution for planning these patients is based upon a constant Gantry speed (GS) at 4.8deg/s. The use of the class solution means that individual patient QA is not required.

Based on the prospective findings of the CHHiP trial, the department wanted to implement a prescription of 60Gy/20#. The increased dose per fraction introduced Gantry Speed Modulation (GSM). A new class solution had to be developed and the dosimetric effect of GSM investigated to avoid the need for individual patient QA.

Three sets of plans, 2Gy/#, 3Gy/# with and without GSM were delivered on the PTW Octavius 2D-Array to compare local 3%/3mm gamma pass rates. Ion Chamber dose measurements were made at the centre of the phantom. For the ion chamber measurement the QUASAR phantom was used. To test how GSM affects the local gamma, plans for 10 patients were produced with increasing dose/# for the same plan and delivered to the 2D-Array.

Pass rates for local 3%/3 mm gamma criteria ranged from 94.7% to 98.8% for all patients’ plans with GSM. The pass rates were not significantly different for the plans with no GSM.

Dose measured was within 0.5% of the expected dose for all ion chamber measurements.

Local 2D gamma ranged from 94.2% to 97.7% pass-rate for all varying dose per fraction plans. Pass rates were therefore not affected by the introduction of GSM.

From this it was felt that individual patient QA was not required but a class solution was developed by limiting the amount of GSM within the plan and maintaining a consistent planning method.

A warning is shown on the 2100 Clinac if acceleration GSM exceeds 0.8 deg/s, even if the gamma pass rates are unaffected, therefore the GMS was limited to be less than 0.7 deg/s between consecutive points.

It was discovered that it is not possible to cut-out the GSM entirely, without compromising the quality of the plan. Planning guidelines were drawn up with the aim to limit the GSM. Any plan that sits within this constraint is still classed as “based on a Class Solution”.

Activities of EUTERP, the European Training and Education in Radiation Protection Foundation

The platform for European Training and Education in Radiation Protection (EUTERP), originally an initiative of the European Commission, was transformed into a legal entity as a Foundation under Dutch law in June 2010. The main objective of the Foundation is to encourage and support harmonization of education and training requirements for Radiation Protection Experts (RPEs), Radiation Protection Officers (RPOs) and radiation workers (RW), facilitating the mobility of these professionals. The EUTERP Foundation aims to facilitate information exchange between all stakeholders in education and training in radiation protection through the website www.euterp.eu, the publication of newsletters and the organization of workshops. EUTERP is also an active partner in the European Network on Education and Training in Radiological
Protection (ENETRAP). It contributes to the new formulation of guidance for the implementation of education and training of the RPE and RPO, in accordance with the revised European Council Directive 2013/59/EURATOM. In close collaboration with the association of the Heads of European Radiological protection Competent Authorities (HERCA), EUTERP strives towards a common understanding and approach in education and training of RPEs and RPOs whilst respecting the differences that exist in the different European Member States.

Dependence of Small Object Detectability on Subject Contrast in PET-CT Imaging using Regularisation, Resolution Recovery and Time of Flight Reconstruction Techniques

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PET examinations such as those that aim to assess activity in plaques or small lymphatic nodes are dependent on the ability of a system to identify small objects in a variety of different backgrounds. In this study we aimed to evaluate the lower limit of lesion detectability using a commercially available software package which implements several advanced reconstruction methods such as regularisation, resolution recovery and time of flight in order to produce images with higher resolution and signal to noise ratio than previous clinical scanners.

Detectability depends on a number of factors such as target size, activity and background, we aimed to evaluate performance over a range of target to background contrast ratios for a range of target sizes. Using a phantom the performance of these advanced methods was assessed and in particular the relationship between the detectability of small hot objects and the object to background contrast ratio.

This study highlights the challenges in imaging small objects with PET, in particular the influence of the partial volume effect on contrast and the need for sufficient subject contrast to benefit from the implementation of the latest advancements in reconstruction algorithms. Modern techniques in PET image reconstruction have been proven to improve image quality but the level of improvement is reduced as the target object becomes smaller and use of these techniques can result in the suppression of true activity instead of the enhancement of it.

Commissioning a new radiotherapy centre outside of the UK - point of view of an early career physicist

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Background
Leeds Cancer Centre (LCC) commissioned a new radiotherapy centre in Malta. The project included commissioning two new Versa HD linacs as well as the transfer of a Synergy linac and CT simulator from an existing radiotherapy service. This involved LCC staff working in another country as well as on the project in Leeds. Each aspect of the project was closely project managed to ensure that logistical issues were handled appropriately.

Aim
The aim of the sub-project was to commission an electron beam model for Monaco v5.1, for an Elekta VersaHD linac.

Method
As no Versa HD machines at LCC had electrons commissioned, all measurements needed to be made in Malta. During the commissioning of the linacs, measurements required to produce the beam models were taken. At a later date further measurements were taken that were used to validate the beam model using a large water tank as well as EBT film in a phantom. As the machines were already clinical for photon treatments at this point all these measurements were taken over a weekend. The consequence of failing to take the measurements correctly and this not being discovered until returning home was so great, a much higher level of preparation was required than for normal projects. 2 LCC physicists and 1 technician were
present with support from Maltese physicists.

Results
The required measurements were successfully taken in Malta in the short time period allocated and analysed at a later date in the UK.

Discussion
The detailed work instructions written in advance in the UK were essential to the success of this project. They were written to try and foresee all equipment issues and decisions that would be required by the staff present. Only early career physicists were present when the measurements were taken with phone support provided by more senior staff, however, this had its limitations. A concern with writing the work instructions in advance of any work taking place is that some useful information may be unintentionally missing. This provided a valuable learning opportunity to record all observations and decisions made.

The timeframe for collecting measurements had to be strictly adhered to as the machine needed to be returned to clinical use on the Monday following the measurements. Although an LCC technician was present, the equipment was maintained by a third party and these had limited weekend availability.

Conclusion
Early career UK clinical scientists can be involved in large international commissioning working with limited UK support providing the appropriate preparation is done in advance.

A novel method for X-ray field size measurements for flattening filter free (FFF) beams
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Aims
Due to the shape of the dose profile for flattening filter free (FFF) beams, the traditional field size definition of using 50% of the central axis dose is not applicable. Various methods have been proposed to provide a solution [1]. This work looks into the feasibility of a novel simple method for measuring the field size of an FFF beam, particularly for linacs without a flattened beam. This is to divide through the FFF beam profile by a larger FFF beam profile of the same energy and depth. This effectively flattens the profile meaning that traditional normalisation methods and field size definition is valid.

Methods
Profiles were acquired in water for a range of field sizes for both FFF and flattened (FF) beams. The FFF profiles were divided through by a large FFF profile and normalised to the central axis. The FFF field size was then calculated using traditional methods and compared to the FF field size. This was carried out on both an Elekta Agility and Varian Truebeam linac for a range of energies and depths.

Results
The results show that for both 6FFF and 10FFF the field size measured is within ±0.5mm of the FF field size at a range of measurement depths (d\text{max} to 20cm) and for field sizes ranging from 2cm to 30cm. This is similar to the variation seen in the field size measured for a 6MV and 10MV FF beam. At larger field sizes (up to 40cm) agreement within 1mm is obtained.

Conclusion
The proposed novel method appears suitable for measuring the field size of an FFF beam and provides a simple method for field size definition for FFF-only linacs.

References.
### Setting up a Medical Exposures Committee - our experience

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Requirements for optimisation and Medical Physics Expert input to imaging departments are likely to increase in the future due to UK implementation of EU legislation. National dose audits have previously shown wide variation in doses for radiological procedures, suggesting that there is much work to be done in this area. The recent introduction of dose management software allows access to large amounts of exposure data that can be useful for this task. However, in many cases there is no formal process to manage doses and image quality, and as a result efforts to improve these aspects are unsuccessful.

This talk will discuss our experience of setting up a Medical Exposures Committee, including obstacles and lessons learned, and aspects that are essential for establishing a successful dose team.

### Commissioning of Compass 4.0 for IMRT verification

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**Background:** Compass is a treatment planning verification tool capable of independent computation of delivered dose to a CT data set using beam parameters received from the TPS, as well as reconstruction of actual delivered dose to an ion chamber array.

In upgrading from Compass 3.0 to Compass 4.0 some software changes are expected to alter the reconstruction of measured fluence for field sizes larger than 20x20cm. Consequently before implementing clinically it is necessary to verify the performance compared to the previous version and to the treatment planning system.

**Method:** A selection of sample fields calculated using Pinnacle with equivalent squares ranging from 2cm to 30cm were modelled on a CT scan of a solid water block. 2mm cube ROIs were drawn at varied depths along CAX and transversely across the phantom at dmax and 10cm deep to extract PDDs and beam profiles.

Historic clinical patients for a range of standard IMRT sites (e.g. prostate, head & neck, and lung) were chosen and re-calculated in v4.0 for evaluation with respect to the original QC results. Additionally, plans for sites that have previously not been verifiable using Compass due to limitations in large field performance (e.g. anus, cervix, and prostate including nodal irradiation) were investigated.

**Results:** All ‘computed’ doses were identical between v3.0 and v4.0. For ‘reconstructed’ measurements, v3.0 and v4.0 were found to be in close agreement with each other for field sizes up to and including 10x10cm, with no difference in dose greater than 0.5% observed in the central region of the profiles.

Above field sizes of 15x15cm differences of up to 2% were observed between v3.0 and v4.0, with v4.0 agreeing more closely with Pinnacle compared to the previous version.

### Testing of a Liver-mimicking Phantom Using Magnetic Resonance Elastography (MRE)

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**Background:** Magnetic Resonance Elastography (MRE) is a non-invasive diagnostic tool for measuring liver stiffness that can be useful in diagnosis of conditions like fibrosis. Using a phase-sensitive pulse sequence and propagating mechanical shear waves MRE produces cross-sectional maps of tissue stiffness.

**Aim:** NHS Tayside has recently acquired specialist hardware and software to perform clinical MRE on a 3.0T Siemens Prisma-fit MR system. Before clinical implementation, validation of repeatability,
reproducibility and acquisition technique is required.

**Method:** A phantom constructed of gelatine to mimic the mechanical properties of soft tissue with grapes added to simulate stiffer lesions. MRE was performed by placing a Resoundant Active driver on top of the phantom which generates mechanical sine waves of 60.1Hz synchronised with image acquisition. A body matrix coil was secured around the phantom and the driver. Stiffness images were acquired using a 2D Gradient echo pulse sequence with TR/TE of 50/23.8ms, slice thickness of 5mm, field of view (FOV) of 256mm and acquisition matrix 128*128. To assess scan-scan repeatability ten consecutive acquisitions were performed. The effect of contact with the phantom was assessed by comparing ten measurements with the body matrix coil secured tightly and loosely. The generated stiffness images were manually segmented using ITK-SNAP (http://www.itksnap.org) to measure visible grape volume. Intra- and inter-observer repeatability was assessed using Bland-Altman and coefficients of repeatability (CoR), scan-to-scan variability measured using coefficients of variation (CoV) and paired t-test used to compare tight and loose coil.

**Results:** Intra-observer repeatability was calculated with an average stiffness volume of 390.1 mm$^3$ and CoR of 41.1mm$^3$. Inter-observer repeatability was lower at 323.7mm$^3$. Average scan-scan variability in stiffness volume CoV was 8.0%. The mean stiffness volume measured with the coil tightly secured was 648.6±24.5mm$^3$, which was significantly higher than that measured with coil loose 541.8±99.6mm$^3$ (p= 0.006, paired t-test).

**Conclusion:** Phantom experiments have demonstrated that MRE is a repeatable and reproducible technique for determining stiffness when performed with the body coil tightened appropriately. The next step for validating the technique for clinical use is to assess reproducibility in healthy volunteers.

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**The effect of weight loss in head and neck patients in the presence of a magnetic field**

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**Background:** Head and neck patients tend to experience weight loss during treatment. Adaptive radiotherapy for these patients focuses on an offline protocol where the patient is re-scanned and re-planned two-to-three weeks through treatment. The MR linac (Elekta, AB, Stockholm, Sweden) will provide excellent soft tissue contrast which may be desirable for this group of patients. However the electron return effect, caused by the Lorentz force may potentially result in an increased dose to superficial tissues, for example the parotid glands. This effect can be controlled in plan optimisation, however it is unknown whether the presence of a magnetic field makes it necessary to adapt the plan at an earlier stage or more frequently during treatment. The purpose of this abstract is to assess the suitability of the current off-line adaptive radiotherapy workflow for head and neck patients in the presence of a magnetic field.

**Method:** Ten patients treated with either 66Gy or 60Gy in 30 fractions, were selected from the clinical archive that had shown significant weight loss during treatment which required a repeat CT. Both the initial planning CT (pCT) and the repeat CT (rCT) were fully contoured. Two plans were optimised, at 0T and 1.5T using Monaco (Elekta AB Stockholm, Sweden) which met the departmental constraints for Target and OAR doses. These plans were copied to the rCT and re-calculated, allowing the segmentation and delivered MU to remain constant. The magnitude of the change in dose to the target and OARs due to weight loss was compared between the 0T and 1.5T plans. The difference between the dose distribution on the pCT was compared to the distribution on the rCT and how this was affected by the presence of the magnetic field.

**Results:** The analysis showed no statistical difference between the doses in the PTV and parotids in 0T or 1.5T fields. The percentage difference in the mean dose to the right parotid from pCT to rCT was 4.4±4.1% and 3.6±4.9% for 0T and 1.5T respectively and 6.4±3.3% and 5.2±3.4% for the left parotid.

**Conclusions:** This work shows that the dosimetric effect of weight loss is not significantly affected by the presence of a magnetic field. Therefore, current off-line strategies for adaptive planning for head and neck patients are valid for use on the MR linac.
Creation of fMRI Suitable Spectacle Frames
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Problem: STRADL, a large research study being carried out within NHS Tayside, uses functional MRI (fMRI) to assess the neural activations underlying reward selection and processing. During the fMRI exam, participants are required to follow a set of instructions on an LCD screen and respond. The participant views the screen via a mirror set-up on the head coil. Many volunteers will require refractive error correction in order to view the LCD screen, therefore a set of fMRI suitable spectacles are required. Participants are unable to wear their own personal spectacles due to the possibility of them introducing image distortion or containing ferromagnetic materials.

Approach: A set of MR Safe lenses and a portable focimeter were purchased. During my MR placement I designed and constructed a set of cardboard frames to hold these lenses based on advice from another local centre. I established how to use the focimeter and created a set of instructions for the research team to follow. Testing of multiple prototypes was performed which indicated that the resultant pair of frames should fit the purchased lenses, be comfortable to wear, fit within the head coil, allow the screen to be visualised and most importantly, be MR Safe.

Solution: Instructions on how to use the focimeter have been provided to the research team to allow them to measure the prescription in a volunteer's spectacles prior to the fMRI exam. Appropriate lenses can then be selected from the purchased lens set and inserted into a suitable set of frames. Three pairs of cardboard frames of different sizes have been created to allow a comfortable selection for the participant. Testing found that all pairs of frames fit comfortably within the head coil, and allowed the participant to clearly see the LCD screen at the back of the scanner.

Identifying sources of error in output measurements for handheld UVB treatment devices
Janine Crutchley (1)
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Introduction: We are involved in a large scale trial for investigating the efficacy of handheld UVB treatment devices in patients with Vitiligo supporting the trial team by measuring the output of the devices (both dummy and active) before they are sent to the trial participants.

Main: During one batch of output measurements, the output dropped below the ‘rolling’ average with some measurements recorded below the 20% ‘failure’ threshold. This has implications for devising an effective treatment plan for the trial participants.

A plan was devised to determine the source of the drop in output.

Conclusion: This poster will discuss the plan, summarise all the data collected and present the findings that determined the source of the drop in output.

NICE Medtech Innovation Briefings: Informing decisions about innovative technologies
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The National Institute for Health and Care Excellence (NICE) Medtech Innovation Briefings (MIBs) were commissioned by NHS England and introduced in 2014 in response to a need for a rapid, objective review of information about novel technologies. They are designed to support decision-making by clinicians.
managers, clinical engineering, policy developers, commissioners and procurement professionals, and may be of interest to patients and the public. MIBs are not formal NICE guidance.

A medical device or diagnostic test is eligible if CE-marked and available to the NHS, or if this is expected soon. It must be new or an innovative modification of an existing technology, with potential patient or system benefits, and not covered by another guidance-producing body.

Each briefing describes a medical technology and its place in the treatment pathway. Key points from published evidence are summarised, with critical review and a focus on clinical benefits and cost implications. Comments are invited from the manufacturer, specialist practitioners and representatives of patients or carers where appropriate. The production timeline is approximately 9 weeks.

Between February 2014 and May 2016, 61 MIBs were published, and another 15 were in development. As a novel, rapid evidence summary, technical challenges have been faced in the production of MIBs, and continuous learning has helped refine the process. Feedback from companies and users of the briefings suggest that they are of value and that they are being used beyond their target audience of the NHS in England.

Raising awareness of this valuable resource will reduce the need for local organisations to produce their own, similar reports. Ultimately this will save staff time, effort and resources, whilst encouraging the adoption of innovative technologies that benefit both health and social care systems and patients.

Optimising QA: A successful collaboration between medical physicists and radiographers
Muriel Dorthe (1) Elli-Noora Salo (1) Christina Stewart (1) Nick Weir (1)
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There is a legal requirement (IRR99) to perform regular QA testing. With competing resource demands, the Imaging Physics Section has been reviewing the frequency of the QA surveys they perform and has considered performing fixed radiographic surveys less frequently (for example changing from every 12 to every 24 months).

We carried out a risk assessment regarding a reduction in the frequency of level B (medical physics) QA testing. We reviewed the results of 80 surveys over the last 15 years across a range of 10 diagnostic rooms, where the most common types of installations were represented. Each parameter surveyed (AEC calibration, output linearity, DAP calibration, filtration) was evaluated with regards to the frequency and severity (impact) of the fail, both in terms of dose to patients and staff. This identified parameters which might pose a higher risk if tested less frequently.

Some of these parameters are included as part of Level A (Radiographer) QA testing either directly or indirectly. In order to mitigate the risk, it is crucial that these Level A tests are performed regularly and reliably. Barriers to this can be attributed to a lack of familiarity knowledge about how to perform the tests, the significance of the tests, staffing pressures, and a busy schedule.

In order to address some of these issues, the Imaging Physics section organised QA workshops specifically for radiographers which consisted of a general background presentation followed by a series of practical sessions demonstrating both how the tests are performed locally, and how to record the results.

These workshops have been well received and have contributed to improving not only the regularity of the QA tests, but also the communication between radiographers and the Imaging Physics Section, allowing for issues to be dealt with more quickly as they arise. The reduction in medical physics QA survey frequency can potentially free further resources for dose/image quality optimisation.
Modulation Transfer Function (MTF) Image Quality QA Testing (Digital Radiology Community) - A questionnaire Review
Richard Farley (1), Elizabeth Davies (1)
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Following the UK and Ireland Digital Radiology Users Group (DRUG) meeting in York 2015, the Trust decided to develop a quantitative image quality component as part of the Quality Assurance (QA) process. We created an online questionnaire advertised on the UK JISCMail Medical-Physics-Engineering mailbox to look at Modulation Transfer Function (MTF) testing in order to gauge the number of centres that performed these tests and their frequency. Questions included choice of edge phantom used and with what associated thickness, as well as the technique and software used to extract and process the MTF test images. In addition we asked to give reasons for not performing MTF testing, and if centres would be interested in developing MTF testing if support and guidance was available from the DRUG community.

Out of 68 centres, just over two thirds (47) carried out MTF testing. A variety of edge test phantoms were used, e.g. Tungsten, Copper and Steel, with thicknesses ranging from 1 – 5mm. Several software packages were used to process test images; the majority were IQworks and ImageJ based platforms, with only one third using in house developed software. Images were primarily extracted direct from modality, if this was not possible images were extracted via PACS. Generally the main tolerances used were based on IPEM Report 32 Part VII and NHSBSP 0604 v4, though other tolerances were also used. For centres not performing MTF testing, the main reasons given included lack of time to develop the knowledge and expertise in doing so, and lack of relevant equipment. However with available support, two thirds would be interested in developing MTF testing.

The conclusion from the questionnaire indicated that the majority of centres are performing MTF testing, where the centres that aren’t the majority of these would be interested in developing MTF testing with additional support available. The DRUG website will be used as a resource for helping centres to develop MTF testing. Future questionnaires are being planned for other quantitative image quality tests to gauge the number of centres performing such tests, those that aren’t and reasoning, as with this MTF questionnaire.

Investigating mechanical interactions between skin and fabrics
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Background. Understanding the mechanical interactions between skin and fabrics is fundamental to the fields of incontinence-associated dermatitis [1], cosmetics [5] and sports-related trauma [2]. It is believed that the coefficient of friction between skin and fabrics is a significant factor in the severity of skin abrasion. However, as dry-friction is not a well understood phenomenon, there is currently no universally accepted theory for solving two-body friction problems [4]. Furthermore, many investigations which use models to accurately determine the coefficient of friction are not executed with sufficient mathematical rigour [3].

Methods. Experiments have been conducted on a small cohort of human volunteers using an experimental protocol developed to generate sufficient experimental data to test models of friction. The subject's upper arm is placed in a restraining armrest and a grid of approximately 1cm-by-1cm is drawn on the skin across the area of interest. A long-thin strip of non-woven fabric is attached to a tensometer and draped over the subject’s upper arm with weights (40-200g) attached to the free end (see figure). The tensometer moves the fabric at a fixed speed and the applied force is recorded. A stereo photogrammatic scanner based in Medical Physics at University College Hospital then takes a sequence of 3D images of the area of interest in the unstressed and static configurations as well as during the tensometer movement. For numerical modelling of a fabric in contact with skin, we compare (i) a generalised capstan equation, (ii) a belt-friction model modified from [4] for Coulomb's law for static friction, and (iii) a shell-membrane model in frictional contact with an elastic foundation with friction imposed at the free boundary. The models are also validated against experimental data obtained from both human subjects as well as plaster-of-Paris bodies of revolution.
Results and Discussion. With the data obtained from the 3D stereo photogrammatic scanner images, we are able to accurately obtain the three-dimensional skin displacement of the upper arm and, from the tensometer, the tensions applied to the ends of the fabric at all times. In addition, one result observed is a strong positive correlation between the radius of the upper arm and the final tension (see figure). Such a result is predicted by the shell-membrane model but not by the others.

Conclusion. The experimental protocol developed by the authors provides the detailed skin displacement vector field, as well as applied force information, over the time of the experiment. This methodology provides valuable data for validation of computational models of friction generated by a fabric in contact with the skin. Furthermore, the work includes a thorough and critical examination of commonly-used theoretical models to determine the coefficient of friction.


Investigating radiotherapy breast tumour bed boosts
Graham Lockwood (1,2) Naomi Bulmer (1)
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This work will review the existing techniques used to provide breast radiotherapy boosts and evaluate alternative methods and potential improvements to practice. Breast radiotherapy boosts are delivered to the tumour bed following a course of whole breast radiotherapy. The current method in this centre is to use electron beams. The planning process involves using dose charts to decide on a beam energy to use and surgical clips to decide on the field size. Boost treatments are not currently planned on the treatment planning system (TPS), so this presents an opportunity to use the TPS to provide quantitative data on the treatment delivered and therefore propose whether improvements or changes to the technique can be made. The project aims to carry out a planning study to investigate the coverage of the tumour bed volume, along with OAR doses for previously delivered clinical plans. It is likely that currently chosen beam energies are not providing sufficient coverage at depth. It is also possible that if too high an energy is being used then OAR doses are being increased. This work will then go on to investigate alternative methods of delivering the boost and how these compare to the current technique.

Assessment of Volumetric Modulated Arc Therapy for the Treatment of Mediastinal Lymphoma
Catherine Macleod (1) Melissa Leitch (1) Catherine Hanna (1) Carrie Featherstone (1) Suzanne Smith (1)
Beatson West of Scotland Cancer Centre, NHS Greater Glasgow & Clyde, Glasgow, UK (1)

Systemic lymphomas are commonly found to involve the mediastinum. The young age of many patients and long-term survival rates after therapy mean it is vitally important to minimise the risk of radiation-induced long-term effects, such as second malignancies of the breast and lung, and cardiovascular disease.

A comparative planning study was conducted to assess how of the use of volumetric modulated arc therapy (VMAT) could improve in the conformity and homogeneity of the dose delivered to PTV while sparing normal
tissue, in contrast to the standard approach of using an anterior and posterior parallel opposed pair (APPA) planning technique.

Three retrospective radiotherapy plans (APPA, VMAT with one full arc (FA) and VMAT with two arcs and avoidance sectors over the lungs (FAAS)) were created for seven patients (four females, three males (median age of 24)) who had been treated for lymphoma with mediastinal involvement, and compared in terms of the dose delivered to the planning target volume (PTV) and organs at risk (OARs).

Due to the large variation in position, shape and volume of the PTV within the mediastinum, which is characteristic of the disease, the process of prescribing a standard planning protocol to the patient cohort is difficult. Both VMAT plans produced a significant (p<0.0167) improvement in conformity of the 95% dose distribution within the PTV and a significant reduction in V20Gy to lung and V15Gy to heart compared to the APPA plans. The addition of avoidance sectors did not demonstrate a significant difference to the dosimetric parameters compared to the full arc plan. However the FAAS plans did produce a significant reduction in mean dose to the heart compared to the APPA plans and improved in the heart and lung dose values in patients with an elongated PTV within the mediastinum.

These findings suggest that VMAT plans have potential to reduce long-term effects which may result from radiotherapy treatment of lymphoma with mediastinal involvement in comparison to the standard APPA approach.

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**Daylight PDT dosimetry using EBT3 Gafchromic film**

Michael Manley (1)  Paul Collins (2) Jackie McCavana (1)

Department of Medical Physics and Clinical Engineering, St. Vincent’s University, Dublin, Ireland (1) The Charles Centre, Department of Dermatology, Saint Vincent’s University, Dublin, Ireland (2)

The aim of this study was to investigate the use of Gafchromic film to quantify the radiant exposure received by patients undergoing topical daylight PDT to fields of actinic keratoses. Chun and Yu have shown the film can be used to quantify solar UV radiation. This work examines the use of Gafchromic EBT3 (Ashland, USA) as a patient dosimeter. Spectral radiometry measurements demonstrate that the ratio of UV radiation to that in the visible spectrum remains constant regardless of the quantity of cloud cover. The PpIX weighted effective radiation exposure the patient receives during treatment can therefore be quantified. A piece of film is taped to the skin, sited near the treatment area. Scanning of the film using an Epson V800 scanner and analysis of the images using ImageJ and Microsoft Excel then provides dosimetry information. An effective dose response curve was established for the film response by exposing pieces of film for varying duration on a clear sunny day. The pixel intensity of the scanned film in the red channel was calibrated against integrated area of PpIX weighted daylight spectra obtained from a compact double integrated spectroradiometer (DMc150-MDE, Bentham, UK). A random cohort of patients will be selected to assess the suitability of the technique. The film provides a quantitative dose measurement for patient treatments in the hospital environment or at home (as film can be posted back for analysis). Measurements will assist dermatologists in assessing the dose influence on treatment efficacy and patient compliance.


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**An Evaluation of SPICE in Terms of Accuracy for Clinical Use in Treatment Planning of Prostate Cancer**

Virginia Marin Anaya (1)  Sam Tudor (1) Marina Romanchikova (1) Rajesh Jena (1) Tony Geater (1) Simon Thomas (1)

Cambridge University Hospitals, Addenbrooke's Hospital, Cambridge, UK (1)

**Background:** Manual segmentation, although still treated as the gold standard, is tedious, time-consuming, and suffers from inter- and intra- observer variability. SPICE (Smart Probabilistic Image Contouring Engine) is an automated segmentation software, developed by Philips, that uses a set of algorithms for probabilistic segmentation of structures. The aim of this study is to evaluate SPICE performance for clinical use in...
Methods: 19 patients were selected to act as subjects. Quantitative evaluation of SPICE was performed by comparing the structures produced by SPICE with the manually-delineated structures by the oncologist using SHERRI (Surrey Heuristics Engine for Radiobiology, Radiotherapy and Imaging). The Conformity Index (CI), Mean Distance to Conformity (MDC (mm)) and Shift to the Centre of Mass (SCM (mm)) were used as quantification parameters.

Results: SPICE was found to outline the whole bone rather than the femoral heads only. The results for the right femur (CI=0.996±0.001, MDC=0.58±0.05, SCM=1.41±0.72) and the left femur (CI=0.996±0.001, MDC=0.55±0.03, SCM=0.85±0.53) show that SPICE can outline the bone very accurately. SPICE obtained good results for the bladder (CI=0.89±0.11, MDC=2.81±1.00, SCM=4.64±2.66), but poor results for the rectum (CI=0.69±0.16, MDC=8.80±14.09, SCM=6.07±4.50).

Conclusions: SPICE does not eliminate the need for a clinician to review the contours of structures, but has the potential to improve contouring consistency in treatment planning of prostate cancer.

Implementation of an Independent Radiation Detector Actively Monitoring Radiation Pulses During PDR (Pulse Dose Rate) Gynaecological Treatment

Tervinder Matharu (1)  Tim Allen (1) Dominika Oborska-Kumaszynska (1) Christina Stewart (2) Rose Cox (1) Erine Dalton (1)
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Background: A patient was to receive Gynaecological treatment consisting of 28 radiation pulses over 28 hours with a pulse period of 1:00 hour. On completion, the treatment record showed that only 27 pulses were delivered, pulse 12 was missing. Engineers log files were different to treatment record.

Actual treatment record:

<table>
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<th>#</th>
<th>Date</th>
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<th>Energy</th>
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<th>Status</th>
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<td>2:34:23</td>
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<td>36.48</td>
<td>593.3</td>
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<td>0.0662</td>
<td>36.43</td>
<td>594.2</td>
<td>COMPLETED</td>
</tr>
</tbody>
</table>

Engineers log files at the time of pulse 12

What happened to the 12th pulse? Was it delivered? Still remains inconclusive. Was it due to system failure, radiation detector, machine fault or programming fault?

Flexitron PDR treatment unit is housed in a separate room on the cancer ward frequently visited by relatives.

Aim: How could we monitor the pulse record actively in the future avoiding physically being present at the expected pulse time?

Resolution: A Berthold Micro Gamma detector was installed, tested and implemented into routine use which allowed us to monitor radiation pulses remotely via hospital network.

We will present in detail installation of such a system for similar applications and will discuss advantages, disadvantages and recommendations.

Conclusion: With the implementation of an independent radiation detector actively monitoring radiation treatment pulses has given us the confidence to carry on using Flexitron PDR treatment unit.
Big brother comes to personal dosimetry compliance for the eye.
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University Hospitals of Leicester NHS Trust, Leicester, Leicestershire, UK (1)

An investigation was funded by the IPEM Research and Innovation fund to determine whether a device currently used in ophthalmology to monitor eye patch wear could be used to determine the wear periods of eye dosimeters in radiation areas. The determination of wear periods was automated using k-cluster analysis with 2 clusters in SPSS.

During controlled testing, 10 subjects wore the device for one hour, recording data every 1 minute and preceded and followed by 30 minutes of non-wear periods. The difference between the temperatures determined was then analysed using a two-tailed paired-test. The mean temperature during wear (M=33.0°C, SD=1.48°C) was found to be significantly different to the temperature when not worn (M=22.5°C, SD=0.43°C) with a mean temperature difference of 10.5°C (95% confidence interval 9.6-11.5°C) and a p-value<0.005. The median value of the percentage of correctly identified data points was 99.17% (corresponding to 1 incorrectly identified point in 120).

During a real life example whether the badge was worn was correctly identified in 99.98% of data points. During tests where the badge was not worn or was worn around the neck rather than on the head the temperature differential between the two clusters was less than 5°C, this could be used to exclude data from an unworn or incorrectly worn badges.

Initially this investigation was limited to eye dosimeters due to the impeding legislation changes. It should also be possible to monitor the wear of lead glasses and other PPE wear in this way. By doing so not only can compliance be checked but accurate dose reduction factors could be applied.

Observer Experiments for the Clinical Optimisation of Regularised Iterative PET Reconstruction Algorithm
Mark Pether (1,2)
NHS Grampian, Aberdeen, UK (1) University of Aberdeen, Aberdeen, UK (2)

Conventional iterative reconstruction algorithms like OSEM are commonplace for the reconstruction of PET images. One issue with OSEM is that noise increases with increasing number of iterations, this is often accounted for by setting a limit on the number of iterations and by post reconstruction filtering. The problem with filtering and avoiding convergence is that desirable quantitative information is lost, resulting in smaller hotter objects appearing less intense than they actually are. Q.Clear is a Bayesian penalised likelihood reconstruction algorithm containing an additional regularisation term which acts to reduce background noise and preserve the edges of objects. There is the potential to improve the detection and quantification of disease by sharpening or smoothing the images. The strength of the smoothing and sharpening is determined by the parameter β, a non-zero integer selected prior to reconstruction. Current reconstructions use default values recommended by the manufacturer, however it is likely that different types of study will benefit from different β values. This work is therefore concerned with determining the optimum regularisation parameter for different patients groups within the Nuclear Medicine department at Aberdeen Royal Infirmary. Initial work involved imaging a Hoffman brain phantom with artificial lesions and an ROC analysis of lesion detectability scores provided by an experienced radiologist. The results of this study were used to narrow the range of potential β values for brain studies. Experiments were then conducted using images of patients with confirmed Alzheimer’s disease, initial results indicate optimum observer performance at β=50.
Radio-frequency resonant cavity measurements for rapid, accurate assessment of body composition and human exposure to electromagnetic fields
Martin Robinson (1) Xiaotian Zhang (1) Ian Flintoft (1)
University of York, York, UK (1)

Body composition measurements play an important role in nutritional studies, renal medicine and sports science, while human exposure to electromagnetic fields (EMF) is an area of growing concern owing to the implementation of Directive 2013/35/EU on EMF. Resonant cavity techniques offer an attractive alternative to traditional methods in these fields, as they allow rapid, non-invasive measurements without using ionising radiation.

At frequencies of a few tens of MHz, a large screened room can act as a cavity resonator. A human subject inside the room perturbs its low-order resonances, and the resulting shift in frequency depends on the tissue dielectric properties, which correlate strongly with water content. This approach has been well tested and shows good agreement with current methods of measuring total body water [1].

The number of resonant modes increases rapidly with frequency, so if we instead use microwaves at 1GHz and above, many modes can be excited simultaneously. Adding a rotating paddle to the room creates a ‘stirred mode’ environment, where the body is effectively illuminated by microwave radiation from all directions. For EMF exposure studies this a more realistic scenario than considering only a single direction and polarisation. The average absorption cross section (ACS), which is closely related to specific absorption rate (SAR), can be rapidly obtained over a very broad band (1GHz to 15GHz and beyond), whereas the alternative is detailed computer simulations that take many hours for just a single frequency [2].

At these microwave frequencies, the field penetration into tissues is a few cm, so the ACS gives useful information about the composition of tissues near the body surface. Normalising the ACS to body surface area gives us an ‘absorption efficiency’ that is independent of body size. Results will be presented of the relationship between this parameter and the thickness of subcutaneous body fat.

Both techniques are comfortable for the subject, use safe levels (around 1mW) of non-ionising radiation, and allow measurements to be made in less than 10min.


Influence of the geometrical arrangement of the gold nanoparticles for the calculation of the local dose enhancement in gold nanoparticle enhanced Proton Therapy
Marios Sotiropoulos (1), Michael J. Merchant (1,2) Ranald Mackay (3) Karen J. Kirkby (1,2)
University of Manchester, Institute of Cancer Sciences, Manchester Academic Health Science Centre, Manchester, UK (1) The Christie NHS Foundation Trust, Manchester, UK (2) The Christie, Manchester Cancer Research Centre, Manchester, UK (3)

Introduction: It has been shown that gold nanoparticles (GNPs) have enhanced the effect of radiation therapy. The increased sensitivity of cells is due to the enhanced local dose of radiation when GNPs are present in the cell. This local dose enhancement can be calculated in microscopic scale by the utilization of Monte Carlo simulations. However, the GNPs are not uniformly distributed inside the cell, but vesicles containing the GNPs are formed. The effect of the spatial distribution of the GNPs in the local enhancement was investigated.

Method: The case of a single GNP was compared with the case of clustered GNPs accumulating within vesicles inside the cell. The vesicle diameter was set to 200 nm, GNP diameter was 50 nm, and 25 MeV protons where used for the irradiation. The Geant4 simulation toolkit was implemented to calculate the radial dose distributions and the dose enhancement ratio, which is the ratio with and without the GNP, in spherical shells with increasing radius from the GNP. Also a comparison between the different interaction models implemented in the low energy physics lists PENELPO and Livermore available in the Geant4 toolkit was made.
**Results/Conclusion:** While the simulations support a local dose enhancement, the dose enhancement ratio per incident particle interacting with a GNP was reduced from about 10 in the case of a single nanoparticle to about 3 in the case of the gold nanoparticle filled vesicle. Differences of up to 20% were observed when different Geant4 physics models were used to calculate the dose enhancement.

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**Paediatric CT Imaging - a multi site investigation of practices**
Chelsey Turner (1), David Gentle (1)
NHS Greater Glasgow and Clyde, Glasgow, UK (1)

Paediatric CT imaging is difficult to optimise via conventional audits as with adult imaging due to the relatively low numbers undergoing these procedures. A national project using three ATOM CIRS paediatric phantoms aged 1, 5 and 10 years was devised and established by the Scottish Radiation Protection Advisers (SRPA) group. The aim of this drive was to unify practices not only locally but across Scotland. It is important to note that the vast majority of paediatric CT imaging will be completed at the dedicated children hospitals. However, particularly in the case of an emergency; paediatrics may be imaged at other centres. It is therefore these centres where it is most important to assess the protocols used due to the lack of opportunity for optimisation.

The project is to be accomplished by sending these three phantoms around all NHS centres in Scotland with CT capabilities. The phantoms were to be scanned by radiographers using the protocols that would be used clinically. The dose metrics (CTD1vol and DLP) are recorded along with all scanning parameters. The mean CT number and the standard deviation are then retrospectively measured using PACs workstations to provide a measure of image quality. This work will be carried out by each of the five Radiation Protection departments in Scotland and data shared. In the West of Scotland, NHS Greater Glasgow and Clyde provide support to 33 diagnostic CT scanners.

To date 8 CT scanners have been assessed in the West of Scotland. These results have been compared to early results from the Scotland-wide study, where 21 scanners have currently been assessed.

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**Raising concerns in the NHS**
Hugh Wilkins (1)
Unaffiliated, Exeter, UK (1)

Clinical scientists are obliged by the HCPC to take appropriate action and report any concerns about patient safety\(^1\). Other registered healthcare professionals are under similar obligations. They may however be unaware of the risk of reprisals against them by hospital managers more concerned with reputation than the concerns raised. This alarming state of affairs has been well documented in publications such as the report of the *Freedom to Speak Up Review*\(^2\) and *Learning not blaming*\(^3\).

A growing number of scandals have come to light where the standard of care in hospitals fell far below acceptable levels, resulting in the avoidable deaths of many patients\(^4,5,6,7\). In some cases healthcare staff who have raised concerns have, to their astonishment, found themselves perceived as troublemakers and been subject to disciplinary procedures including dismissal, loss of career and worse\(^8,9\). Such retaliation has been described as “a stain on the reputation of the NHS”\(^10\).

Many NHS whistleblowers are ambivalent about the term – they are after all simply doing their job, and are unprepared for the hostility with which their concerns are all too often received by misguided employers. This is now a hot topic, with growing unease at high level within the Department of Health, Care Quality Commission and NHS England. There is recognition of the need for substantial culture change to remedy the current highly unsatisfactory situation. A number of initiatives are underway, including creation of *Freedom to Speak Up Guardians*.

This talk will outline responses of the government and arms-length bodies responsible for the NHS in England. It will also attempt an overview of the legal position, note the questionable use of public sector
resources and describe such support as exists for whistleblowers who unexpectedly find themselves targeted after raising concerns in the NHS.

1. Health and Care Professions Council (2016). Standards of conduct, performance and ethics
5. Dr Foster / Dept of Health (2001). Hospital death rates after heart bypass surgery or treatment for stroke or broken hips.
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