Determination and use of patient curvature correction factors in electron MU calculations (or when is it too curvy to calculate)

Aims / Background: In our department, monitor units (MU) for electron treatments are calculated in the RayStation treatment planning system (RaySearch Labs AB, Stockholm) and independently checked using RadCalc software (Lifeline Software Inc., Tyler, TX). An audit found that 22 of 50 independent checks failed the ±5% local tolerance level, leading to further investigations. The mean difference between calculations was -5.3 ± 3.3% (μ ± σ), with Raystation MU larger than Radcalc. RayStation calculations use a Monte Carlo type algorithm to calculate dose on a patient CT scan, whereas RadCalc is based on interpolation of measured output factors. As such, Radcalc assumes that the electron beam is perpendicular to a flat patient surface. This work investigates the differences in MU calculations between RayStation and Radcalc in the presence of surface curvature, comparing them against measured data, and proposes a method to correct for this effect.

Methods: Bowl-shaped moulds were 3D-printed and used to create six wax "domes" and "bowls" with radii of curvature ranging from +0.33 cm^{-1} to -0.13 cm^{-1} (see Figure 1). The number of MU to deliver 1Gy at d_{max} to a calibrated NACP type chamber (PTW, Freiburg) were determined by measurement under each wax mould. The fields were delivered using 6 to 18MeV electrons from a Varian TrueBeam linac (Varian Palo Alto, CA). The change in delivered dose with respect to the radius of curvature of the wax mould was recorded. These data were used to determine a set of electron energy dependent correction factors to be applied to the independent MU calculations.

Results: The measured data shows that the number of MU per Gy at d_{max} varies linearly, for a given electron energy, with the radius of curvature of the wax mould irradiated (see Figure 2) due to the change in scatter conditions. RayStation results show similar behaviour, whereas RadCalc MU were invariant, as it does not incorporate any contour information and assumes a flat irradiation geometry.

The change in measured dose with surface curvature, shown in Figure 2, was used to create a set of correction factors to be applied to the 50 patient RadCalc independent MU checks. For each patient, the radius of curvature of the patient surface within the applied electron field was retrospectively determined from their CT scan images. When the appropriate correction factor was applied to the Radcalc MU, the mean difference to RayStation changed from -5.3 ± 3.3% to -1.9 ± 2.6% and only 3 of the 50 calculations were beyond the local tolerance level.

Discussion / Conclusion: The RayStation electron Monte Carlo dose calculation algorithm can calculate the number of MU required for patient treatment while accounting for surface curvature. Radcalc, having no information relating to patient shape, assumes beam incidence on a flat surface. This difference results in a significant number of independent MU check calculations that exceed our tolerance limits. By measuring correction factors for surface curvature and incorporating them into the check MU calculations, the agreement with the primary MU calculation improves, with a significant reduction in out of tolerance results, from 22 of 50 to just 3 of 50.

Key Words: Electrons, Independent MU calculations

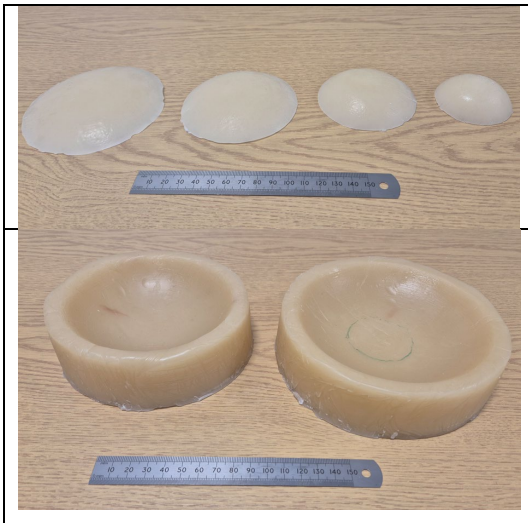

Figure 1: Wax domes and bowls used for electron MU Gy^{-1} measurements.

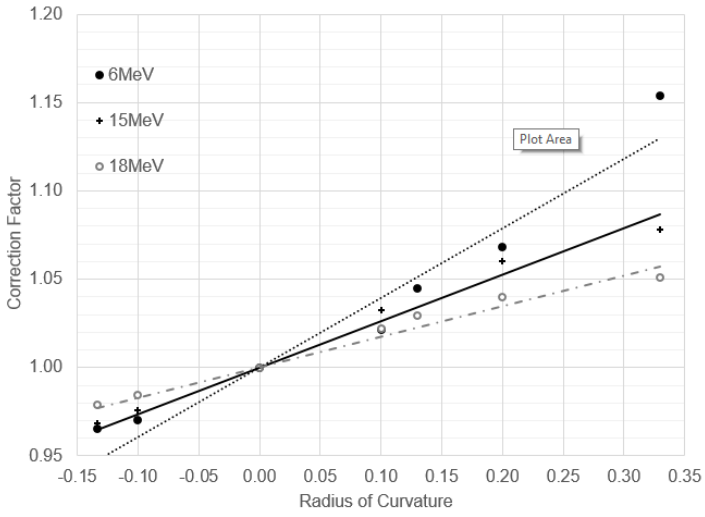

Figure 2: Derived correction factors for electron MU calculations vs surface radius of curvature.

Log file comparison for Elekta linear accelerators

Paul Booker, Amber Dixon

Background. Linear accelerators (linacs) log real-time or 'dynamic' data which can be exploited to optimise performance [Childress et al (2015)]. In the case of Elekta linacs (Stockholm, Sweden), these log files have been incompletely documented in the literature [Azzi et al. 2023), Nishiyama and Takemura (2023) and Pasler, Hernandez et al. (2018)], potentially contributing to under-utilisation of these data [Pasler, Kaas et al. (2015).]. This study sought to identify, characterise, analyse and compare all dynamic log files that can be obtained from an Elekta linac.

Methods. A simple beam sequence consisting only of the transition between two square fields was used for comparative purposes. Robustness Index was used as a means of quantifying the relationship between planned MLC motion and the differing measured MLCmotion identified. Six different log file types were identified: IMRT.dat, service graph .xml, iCom .randv, third party iCom files, .trf (treatment record files) and Mosaiq's own log files. Since log file availability varies by linac mode (service vs clinical), a four-way comparison was made for the simple beam sequence, with planned total MLC movement of 1440mm

Results. A table of the differing log files along with key characteristics is follows:

Log file type	Temporal sampling	MLC positional data	Linac mode
Service graph, .xml	4Hz	Expected and actual	Service only
IMRT.dat	Control point	Deviation only	Both
iComVx .randv	Variable, ≈4Hz	Actual	Both
iComVx (3rd party)	Variable, ≈4Hz	Actual	Clinical only
.trf	25Hz	Actual	Both
Mosaiq logs	Control point	Expected and actual	Clinical only

Results for actual MLC movement ranged from 1440.6 for the IMRT.dat to 4262.3 mm for the .trf file. Excluding MLCs behind the jaws reduced the same variation to between 1440 and 1498.6mm

Discussion. Each log file type has varying properties and levels of suitability for comparison with planned fields, with service graphing the preferred choice, particularly if considering linac adjustments. Where robustness index is used to compare planned and actual deliveries, care should be taken to restrict the calculated motion to exclude out of field movement

Conclusion. Six dynamic log file types were identified for Elekta linacs, one of which has not been previously documented. These represent a freely-available supplementary source of data for clinics to measure, verify and optimise their delivery of radiotherapy treatments.

Key references.

Azzi, A. et al. (2023). 'Impact of log file source and data frequency on accuracy of log file based patient specific quality assurance'. In: Zeitschrift fur medizinische Physik. issn: 1876-4436

Childress, N., Q. Chen and Y. Rong (2015). 'Parallel/Opposed: IMRT QA using treatment log files is superior to conventional measurement-based method'. In: Journal of Applied Clinical Medical Physics 16.1, p. 4. issn: 15269914

Nishiyama, S. and A. Takemura (2023). 'A method for patient-specific DVH verifica tion using a high-sampling-rate log file in an Elekta linac'. In: Journal of applied clinical medical physics 24.3. issn: 1526-9914

Pasler, M., V. Hernandez et al. (2018). 'Novel methodologies for dosimetry audits: Ad apting to advanced radiotherapy techniques'. In: Physics and Imaging in Radiation On cology 5, pp. 76–84. issn: 2405-6316.

Pasler, M., J. Kaas et al. (2015). 'Linking log files with dosimetric accuracy– A multi institutional study on quality assurance of volumetric modulated arc therapy'. In: Ra diotherapy and Oncology 117.3, pp. 407–411. issn: 0167-8140.

Facilitating Safe Childcare for Low Dose Rate Prostate Brachytherapy Patients.

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Background. IPEM Report 106 (1) recommends precautions around small children and pregnant women for two months following low dose rate (LDR) brachytherapy treatment.
For patients for whom close contact childcare is not optional following brachytherapy, Cambridge University Hospitals (CUH) have provided a solution through the loan of a lead skirt.
Practicalities of return however, dictate that patients return the lead apron to CUH at the six week post implant CT/ review appointment, rather than the two months indicated by IPEM 106 as length of time for precautions to be observed.
The aim of this project was to calculate and measure dose rates to justify the use of a lead skirt and evidence whether potential doses at six weeks post implant are sufficiently low to relax precautions and return the skirt to CUH at this juncture, rather than at two months as recommended by IPEM 106. This justifies continued safe childcare for LDR patients who might otherwise not have the treatment option of brachytherapy.

Methods. Assuming the lead HVL for I-125 = 0.025 mm and lead skirt is 0.35 mm lead equivalent, the worst case scenario of prolonged close contact dose commitment with lead skirt was estimated.
Dose rates were calculated using existing literature and risk assessment data and then compared to dose rate measurements taken in theatre immediately after the implant. ICRP98 (ICRP 2005) (2) recommends that dose measurements are taken at 30 cm from the patient surface. Dose rates posterior and anterior to patient were taken in theatre at the patient surface, 30 cm, 50 cm and 1 m. This required anaesthetist engagement and input in theatre to safely roll the patient onto their side to allow posterior dose rate measurements immediately after the brachytherapy procedure.
Dose rates were then decayed to the six week value and measured in clinic at the six week appointment to verify calculations. These were compared to IRMER17(3); *dose limits for member of public exposed as a result of someone else's medical exposure, but who is too young to consent to the dose/risk.*

Results. Dose rates at the patient surface depend on direction, patient size, the total air kerma strength implanted and the extent of internal shielding. Table 2.1 of IPEM report 106 (1) gives the highest surface dose in the posterior direction, alongside a measured mean dose rate at the posterior patient surface immediately following implantation of 40.3 μSv/hr (range 0.8 to 169.7)
This would give a dose commitment (total dose to child over subsequent months) without additional shielding of: 28 mSv, assuming 8hr contact/day (range 0.07 to 116.1)
Estimated dose commitment with lead skirt is 0.002 mSv, assuming 8hr contact/day: (range 0.00003 to 0.007). IRR17(4) allows for a dose of 5 mSv in 5 years to someone in this situation.

Dose rates measured in theatre were in agreement with Report 106 (1), indicating maximum dose rates at the patient surface in the range 10 to 87 μSv/hr. Using maximum posterior dose rates recommended in IPEM 106(1), at six weeks this would be 24 μSv/hr, compared to 20 μSv/hr at two months. Dose rates measured in clinic at six weeks were in agreement.

Conclusion. The provision of a lead skirt for LDR patients with childcare commitments is a pragmatic solution that maintains the option of brachytherapy treatment for patients that otherwise may not be available. Dose rates are sufficiently low that the "peace of mind" two months indicated in IPEM 106 (1) can be safely relaxed to six weeks to allow practical implementation that fits with clinic appointment requirements.

Key references.

(1) IPEM Report 106, UK guidance on radiation protection issues following permanent iodine-125 seed prostate Brachytherapy
(2) ICRP98 (ICRP 2005)
(3) The Ionising Radiation (Medical Exposure) Regulations 2017, UK Statutory Instruments, 2017 No. 1322
(4) The Ionising Radiations Regulations 2017, UK Statutory Instruments, 2017 No. 1075

Diffusing alpha-emitters Radiation Therapy – the role of the Radiotherapy Physicist

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Background. Diffusing alpha-emitters radiation therapy (Alpha DaRT) is an emerging treatment which combines the destructive power of alpha particles with the physical advantages of interstitial brachytherapy. The Alpha DaRT device, manufactured by Alpha Tau Medical Ltd., comprises radioactive sources (hollow tubes coated with a layer of Ra-224) which are inserted into tumours using dedicated applicators.

The decay of Ra-224 within tumour tissue releases short-lived alpha-emitting atoms which disperse by diffusion, resulting in a diffusion zone around each source of ~5mm in diameter. In normal tissue, the different vasculature characteristics limits the diffusion zone around implanted sources to <2mm resulting in a complete absence of ≥G3 acute or late toxicities in patients treated so far [1].

At Cambridge University Hospitals, the DaRT-V trial was set up to assess Alpha DaRT for the treatment of squamous cell carcinoma of vulva. We report the radiotherapy physicist experience of commissioning a novel treatment with a unique mechanism of action which intersects sealed source and unsealed source dosimetry. We also discuss the practical implementation and role of the radiotherapy physicist in the routine clinical process.

Methods. The Treatment Planning System (TPS) provided by Alpha Tau for Alpha DaRT pre- and post-implant dosimetry was MIM Symphony Alpha DaRT v7.2.

Commissioning was based on IPEM Report 81 [2] which outlines a set of commissioning tests to be performed for a conventional brachytherapy TPS while making adjustments for the unique characteristics of Alpha DaRT sources. Dose distributions in MIM were compared to those produced using a MATLAB program provided by Alpha Tau, which generates dose data using an adapted TG43 model [3], and data produced by Heger et al. [4] using COMSOL Multiphysics simulations.

The routine process was developed to include MR outlining and fusion on Raystation, with an in house pre-plan ordering tool developed. Post implant dosimetry was carried out using MIM.

Results. Dose distribution commissioning was challenging, in part due to steep dose gradients and limited published data. Dose profiles generated using MIM demonstrated good agreement with published data in the clinically relevant dose range of 1-10 Gy.

The role of the radiotherapy physicist in the clinical process developed during the study to include preplanning, source ordering, assistance and staff dose monitoring in theatre and post implant planning.

Conclusion. MIM passed all the tests adapted from Report 81 it was assessed against. The role of the radiotherapy physicist in Alpha DaRT therapy is varied and requires close work with a multidisciplinary team.

This has given us a strong foundation as a team as Alpha DaRT therapy extends to other clinical indications and hospital sites in the UK.

Key references.

[1] Popovtzer A, *et al.* Extended Follow-Up Outcomes from Pooled Prospective Studies Evaluating Efficacy of Interstitial Alpha Radionuclide Treatment for Skin and Head and Neck Cancers. Cancers (Basel). 2024;16(13).
[2] IPEM Report 81. Physics Aspects of Quality Control in Radiotherapy.
[3] Heger G, Arazi L. Technical Note: adapting the TG-43 formalism for use in Diffusing alpha-emitters Radiation Therapy.
[4] Heger G, et al. Alpha dose modeling in diffusing alpha-emitters radiation therapy-Part I: single-seed calculations in one and two dimensions. Med Phys. 2023 Mar;50(3):1793-1811.

Commissioning Thermoplastic Bolus for use in Head and Neck Radiotherapy Treatments

Tervinder Matharu, Douglas Northover, Thomas Roberts, Adam Frankland

Aims and Background: The depth of maximum dose for a megavoltage x-ray beam is some distance below the surface of a medium, due to the build-up effect. When a clinical target volume (CTV) is close to or at the skin surface, bolus material is often applied to increase the surface dose.

Wax is one of the more commonly used bolus materials and was previously used for this purpose in the department. Issues such as department workload, staffing levels and lack of expertise in the use of wax, necessitated a search for other suitable bolus materials. In 2023, the department acquired some MacroMedics Thermoplastic bolus, which is easily mouldable when heated in a water bath and would keep its shape with consistent thickness.

There was very little information available about the properties of this bolus material and its use clinically. It was therefore necessary to determine the density of this material and to assess its impact on the depth dose profiles of clinical radiotherapy beams. In this poster we describe our journey from testing to clinical use based on our scientific approach.

Methods: The density of the bolus was determined by three different methods and the results were compared. The density of the bolus was first determined through physical measurements of its mass and its volume. CT scans of the thermoplastic bolus were performed and the density of the bolus that was indicated in the Pinnacle treatment planning system was compared to the measured value. Percentage depth dose curves were measured for thermoplastic bolus and for wax. These depth dose curves were compared to water tank depth dose profiles and profiles that were simulated on Pinnacle for different values of medium density.

Results: The density of the bolus was determined to be $1.1 gcm^{-3}$. The percentage depth dose curves measured using the bolus were found to be in line with those that were simulated on the treatment planning system for this density.

Discussion: Following the determination of the density of the material, the thermoplastic bolus was approved for clinical use and has now been used routinely for head and neck patients for over a year. Skin reactions are comparable to wax bolus and time savings during bolus manufacture can be up to 70%, which are complimented by the ease of use during treatment.

Conclusions: This bolus has proven to be a worthwhile purchase, due to the assurance of uniform thickness and, although it is more expensive than wax, the time savings that have been made have outweighed the additional cost.

Key Words: Head and Neck, Radiotherapy, Thermoplastic Bolus, Treatment Planning, Surface Dose

The Development of an MRI Imaging Protocol for Pancreatic Radiotherapy Planning

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Background: Pancreatic cancer is the 10th most common cancer in the UK, and the 5th most common cause of cancer deaths. 5-year survival rates are currently around 7% and it has the lowest survival rates of all the most common cancers [1]. Until recently the role of RT has been limited due to the pancreas' anatomical position, adjacent to radiosensitive structures such as the stomach, liver and spinal cord. However recent advancements in the field of RT have now made it possible to safely and reliably deliver high doses of radiation to the pancreas whilst avoiding surrounding structures [2] This makes the precise planning of RT imperative. There is growing evidence of the benefits of employing MRI imaging in addition to CT since MRI can distinguish the pancreatic tumour from the normal pancreas as well as the surrounding healthy anatomical structures [3]. In early 2022 the team in the MRI RT planning scanner at the BWoSCC were approached by the upper GI clinical team to start the process of optimising and producing an MRI planning protocol for pancreatic cancer. This abstract will describe that process and the results.

Methods. We undertook a multi-disciplinary, collaborative approach. After detailed discussions with the oncologists and specialists to ascertain exactly what their requirements were, the team engaged with a radiologist and diagnostic colleagues to seek advice on the best sequences to utilise. A diagnostic research radiographer also provided advice and support. The next stage was to scan a healthy volunteer with the Siemens applications specialist in attendance. The MRI radiographers also had to balance patient comfort and compliance with scan time and necessary sequences. The radiographers and physicists in the team worked with the apps specialist to optimise the required sequences and some members of the upper GI team also attended the training to give feedback. At this juncture we engaged with mould room technicians who were able to slightly adapt the current immobilisation used for pancreatic treatment to ensure the same method of immobilisation would work within the limitations of the MRI scanner.

Results. The first patient with pancreatic cancer was scanned in December 2022. Patients are scanned on a 1.5T Siemens Magnetom Sola in a feet first supine position with arms above their head. They are supported with a wing board and vacbag. The patient is lying on a 48-channel embedded spine coil and a 24-channel contour coil in placed over the abdomen. A localizer scan is run, followed by 3 x 2D T2 TRUFI sequences (in all 3 planes), these 3 sequences are performed in breath hold to reduce motion artefact. Finally, a 4 B-Value DWI ADC scan is performed in free breathing. To date 66 scans have been successfully carried out. We have had excellent feedback from both oncology clinicians and radiologists about the quality and efficacy of the scans produced.

References.

1. UK PC. Pancreatic Cancer Statistics 2025 [cited 2025 April 12th]. Available from: https://www.pancreaticcancer.org.uk/what-we-do/media-centre/pancreatic-cancer-statistics/.
2. Yu JI. Redefining the role of radiation therapy in pancreatic cancer management: innovations and future directions. Precision and Future Medicine. 2024;8(3):74-91.
3. William A Hall CS, Eric Paulson, Eugene J Koay, Christopher Vrane, Martijn Intven, Lois A Daamen, Gert J Meijer, Hanne D Heerkens, Michael Bassetti, Stephen A Rosenberg, Katharine Aitken, Sten Myrehaug, Laura A Dawson, Percy Lee, Cihan Gani, Michael David Chong, Parag J Parikh and Beth A Erickson. Magnetic Resonance Guided Radiation Therapy for Pancreatic Adenocarcinoma, Advantages, Challenges, Current Approaches, and Future Directions. Frontiers in Oncology. 2021; 11:1.

You've been framed: conclusions of an investigation into the effect of CBCT frame rate on image quality

William van den Berg[1], George Thickett[1], Angharad Ganguli[1], Isabel Palmer[1], Esmé Votta[1], Rubeena Polli[2], Bradley Robinson[2], Ondrée Severn[1]

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[2]Radiotherapy, Barts Health NHS Trust

Background: We have previously reported [1] on an imaging incident that resulted in 116 patients receiving a fractional concomitant imaging dose 36% higher than intended for a total of 309 fractions. This was the result of the frame rate parameter for customised modes reverting to the higher default frame rate value without the users' knowledge. Due to the unique opportunity this presented, part of the investigation focussed on comparing the image quality between clinical images taken with the two frame rates [2]. Further work involved a phantom study to establish CBCT exposure parameters which could produce equivalent dose at a fixed default frame rate [3]. This was supported by a recent image quality audit which showed that modes were well optimised.

The final element in the investigation was to implement and audit the new CBCT modes. The new modes were implemented on each treatment machine separated by a few weeks to allow patients to be treated on machines with the new imaging parameters as well as on machines which were yet to be updated. We were therefore able to audit and directly compare clinical image quality using both sets of CBCT parameters.

Methods: Qualitative image quality data was acquired from the treatment radiographers using a simple scoring system that rated the ease of the image match from 1 to 5, with 1 meaning inadequate image quality, and 5 meaning excellent image quality. This was done for all 5 TrueBeam machines, and for 4 CBCT modes which had been adjusted. Basic comparative analysis was carried out for all images with old and new parameters, as well as by machine and by mode.

Results: A total of 156 clinical CBCT images were scored by treatment radiographers. The mean score with the old parameters was 3.2 and was 3.4 with the new parameters. A histogram of the results is given in Figure 1.

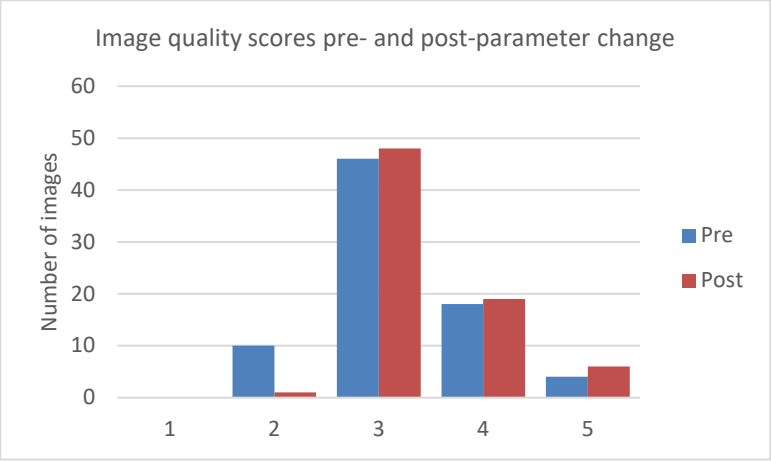

Figure 1

Analysis by machine showed that image quality was maintained or slightly improved. Analysis by mode also showed that image quality was marginally improved with the new parameters.

Conclusion: Based on these results, we conclude that the image quality with the new parameters is sufficient and is potentially slightly improved compared with previous parameters. We therefore recommended that no further changes are required to the new parameters.

Key references:

[1] Thickett G, Ganguli A, Palmer I, Votta E, Polli R, Severn O. (2024). Investigating the effect of increased CBCT frame rate on image quality, does it justify the increase in patient dose? Varian User Meeting, Torbay.

[2] Ordóñez-Sanz C, Cowen M, Shiravand N, MacDougall N. D. (2021). CBCT imaging: a simple approach for optimising and evaluating concomitant imaging doses, based on patient-specific attenuation, during radiotherapy pelvis treatment. *The British Journal of Radiology*, 94(1124). https://doi.org/10.1259/bjr.20210068.

[3] Khan M, Sandhu N, Naeem M, Ealden R, Pearson M, Ali A, Honey I, Webster A, Eaton D, Ntentas G. (2021). Implementation of a comprehensive set of optimised CBCT protocols and validation through imaging quality and dose audit. *The British Journal of Radiology*, 95(1139). https://doi.org/10.1259/bjr.20220070.

Key words: imaging, optimisation, image quality, audit

Auto-generated Radiotherapy Plan Quality: A Comparison of Ethos v2.0 and v1.1 for Head and Neck Cancer Treatment

Polly Darby, Andrew Bromiley, Rafael Moleron, Anne E Kiltie, John McLellan

Background. The Varian Ethos treatment planning system (TPS) uses an intelligent optimisation engine (IOE) designed to automate a significant portion of the planning process and minimise the impact of inter-operator variations on plan quality (1). Ethos TPS v1.1 has been proven to generate clinically acceptable plans, comparable to those produced manually, over several treatment sites (1-6). Recently, Varian released Ethos TPS v2.0, which includes notable enhancements to the optimisation engine. This study aims to provide quantitative evidence comparing the plan quality achieved with the Ethos TPS v2.0 to that of v1.1. This information is crucial for centres transitioning from v1.1 to v2.0 and those considering the purchase of an Ethos machine that comes with v2.0 pre-installed.

Methods. Fifty H&N patients, representing a variety of treatment sites and dose prescriptions, were re-planned in Ethos TPS v2.0. This was done using the same RT intent as in their original clinical plans with the Ethos TPS v1.1 system. All RT intents for these H&N patients were based on a standard, proven approach (4). Plans auto-generated using v1.1 – specifically the 7-field, 9-field, and 12-field IMRT plans – were compared to the 7-field, 9-field and 12-field IMRT plans, as well as the 2-arc and 3-arc VMAT plans created using v2.0. All plans from both versions were normalised such that the median dose (D50%) of the high-dose PTV (PTV_HD) equated to 100% of the prescribed dose. Target and key organ-at-risk (OAR) dose-volume metrics were assessed to evaluate the plans. A one-way ANOVA was performed using IBM SPSS Statistics to compare the effect of field arrangements and version on the resulting dose-volume metrics.

Results. A one-way ANOVA revealed that there was a statistically significant difference in the 95% dose coverage (D95%) of the PTV_HD between at least two groups (p = <0.001). A statistically significant difference was also seen between at least two groups for the medium-dose PTV (PTV_MD) D5% (p = <0.001), D2% (p = <0.001), PTV_LD D95% (p = <0.001), the Brainstem D0.1cm^3(p = <0.001), and the Spinal Cord D0.1cm^3(p = <0.001). There was no statistically significant difference between versions and field arrangements for the mean dose to the left Parotid (p = 0.549) or right Parotid (p = 0.191).

Tukey's HSD Test for multiple comparisons found that the mean value of D95% for the PTV_HD volume was significantly different between the 12-field IMRT using v1.1, used for the majority of clinical plans, and the 7-field IMRT using v2.0 (p = 0.002), the 2arc VMAT using v2.0 (p = <0.001), and the 3arc VMAT using v2.0 (p = <0.001). The mean D95% for the PTV_HD was lower for all v2.0 field arrangements, but still within clinical tolerance; this is also the case for PTV_LD D95%.

v2.0 gave a lower D0.1cm^3 for the Brainstem, for all field arrangements, with a statistically significant difference compared to the v1.1 12-field IMRT for the 7-field (p = <0.001), 9-field (p = <0.001), and 12-field v2.0 IMRT (p = <0.001).

Discussion. The plans created using Ethos TPS v2.0 are clinically acceptable; however, the PTV coverage is inferior to those created using v1.1. The changes to the IOE, particularly in the way it handles variance values, indicate that improvements are needed to achieve the quality of plans created using v1.1 for H&N patients. Therefore, the introduction of v2.0 necessitates the development of a new RT intent for H&N patients, with careful attention to the values assigned to the variance within each dose objective.

Conclusion. Transitioning from Ethos TPS v1.1 to v2.0 will require time to assess and potentially modify the clinical RT intent templates. This could delay the delivery of online adaptive radiotherapy treatments immediately after a version upgrade. The reason for this delay is the resource-intensive process required to develop clinically acceptable RT intents. While this may not apply to other treatment sites, it is an important factor to consider.

Key Words. Autoplanning, Ethos, Head and Neck, Treatment Planning

Key references.

1.Prunaretty J, Lopez L, Cabaille M, Bourgier C, Morel A, Azria D, et al. Evaluation of Ethos intelligent optimization engine for left locally advanced breast cancer. Frontiers in Oncology 2024;14:1399978.

2.Pokharel S, Pacheco A, Tanner S. Assessment of efficacy in automated plan generation for Varian Ethos intelligent optimization engine. Journal of Applied Clinical Medical Physics 2022;23(4):e13539.

3.Visak J, Inam E, Meng B, Wang S, Parsons D, Nyugen D, et al. Evaluating machine learning enhanced intelligent-optimization-engine (IOE) performance for ethos head-and-neck (HN) plan generation. Journal of applied clinical medical physics 2023;24(7):e13950.

4.El-Qmache A, McLellan J. Investigating the feasibility of using Ethos generated treatment plans for head and neck cancer patients. Technical Innovations & Patient Support in Radiation Oncology 2023;27:100216.

5.Nasser N, Yang GQ, Koo J, Bowers M, Greco K, Feygelman V, et al. A head and neck treatment planning strategy for a CBCT-guided ring-gantry online adaptive radiotherapy system. Journal of Applied Clinical Medical Physics 2023;24(12):e14134.

6.Byrne M, Archibald-Heeren B, Hu Y, Greer P, Luo S, Aland T. Assessment of semi-automated stereotactic treatment planning for online adaptive radiotherapy in ethos. Medical Dosimetry 2022;47(4):342–347.

IPEM topical report: guidance for the use of linac manufacturer integrated quality control.

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Aims and/or Background*:*

Manufacturer-integrated-quality-control (MIQC) systems have been developed by the radiotherapy linear accelerator (linac) vendors. They usually utilise the Electronic Portal Imaging Device (EPID), but may acquire data from other sources, and automatically perform and analyse tests of various treatment machine QC parameters. Examples are: Varian Machine Performance Check (MPC), Accuray Tomotherapy quality assurance (TQA) for TomoTherapy and RadIxact systems; automatic quality assurance (AQA) and end-to-end (E2E) on the CyberKnife Robotic Radiosurgery system, and Elekta Machine QA (also known as AQUA). These systems have the potential to improve both the quality and efficiency of linac QC but are currently being developed and utilised in the absence of specific best-practice guidance. The Institute of Physics and Engineering in Medicine set up a Radiotherapy Special Interest Group working party with a view to develop guidance for the commissioning, implementation and safe use of MIQC.

Methods*:*

Working party members were appointed based on expertise in the linacs from each manufacturer and includes early adopters of MIQC systems. Guidance was developed utilising a survey of UK radiotherapy departments performed by the working party. The survey was distributed to all heads of radiotherapy physics in the UK and investigated availability and uptake, community beliefs and opinions, utilisation, user experience and associated procedures. The recommendations within the guidance report were derived from the survey results, experience of the working party members, existing guidance and literature.

Results*:*

Topics covered in the guidance include developing an understanding of the QC system, independence review of MIQC, commissioning, implementation, ongoing QC and calibration, software upgrades and periodic review. The commissioning section covers detector commissioning, repeatability and reproducibility, baseline and tolerance setting, concordance with existing QC, sensitivity testing, cost-benefits analysis, and risk assessment methods. In order to offer practical guidance, case studies covering each aspect of commissioning are included. They are real-world examples or experiences from early adopters, each applied to a different example MIQC system. The examples will be directly applicable to users of that specific MIQC system, but also provide practical guidance on clinical implementation to users of the other systems.

Conclusion:

The report presents guidance for the commissioning and implementation of MIQC, and was published in April 2025.

Key Words:

commissioning, QC, MIQC, Manufacturer Integrated Quality Control, radiotherapy, linac

References:

1: Pearson et al, IPEM topical report: results of a 2022 UK survey on the use of linac manufacturer integrated quality control (MIQC), Phys. Med. Biol. 68 (2023) 245018
2: Pearson et al, IPEM topical report: guidance for the use of linac manufacturer integrated quality control. Phys. Med. Biol. 70 (2025) 085016

Local validation and retrospective impact assessment of AI auto-contouring in radiotherapy

Lawrence Gilfrin, Royal Berkshire NHS Foundation Trust

Background – Artificial Intelligence (AI) auto-contouring is a new and emerging technology in radiotherapy but the principles build on existing technologies and methods such as atlas based segmentation [1]. Contouring represent some of the most time intensive tasks for a clinician and one of the areas of greatest variability [2, 3]. There are numerous methods that can be used to compare contours with volumetric and surface Dice similarity coefficients (vDSC, sDSC), 95% Hausdorff distance (HD95) and percentage volume difference being used. MVision AI auto-contouring was introduced into the radiotherapy pathway in 2024 for head and neck, breast, lung, brain, and pelvis patients. The purpose of this study was to assess the impact that AI auto-contouring had on the radiotherapy pathway and associated doses and structures.

Methods – Contours were compared using the Verify tool which is part of MVision using the vDSC, sDSC, HD95 and percentage volume difference metrics [4]. Manually delineated contours and edited AI auto-contours were compared to AI auto-contours, no direct comparison between manual contours and edited AI auto-contours was carried out. This two stage comparison allowed for a large number of contours to be compared, a total of 36 manually delineated contours and 33 edited AI auto-contours for the breast site and 40 manually delineated and 40 edited AI auto-contours for the head and neck site. A comparison of doses received by 12 oropharynx patients before AI auto-contouring was introduced and 15 oropharynx patients after AI auto-contouring was introduced was carried out to assess any changes in reported dose. Timing data was gathered for all diagnosis groups where AI auto-contouring was introduced. Quality checklist (QCL) sign-off dates were used to determine the time between when tasks were completed to assess if AI auto-contouring had an impact on pathway timing.

Results – There was an increase in conformity to AI auto-contours when they are edited rather than when contours are manually delineated. Further, all OARs saw a large increase in the sDSC and vDSC and a reduction in HD95. Structures that were used to form the nodal CTV for breast patients saw a smaller and more varied increase in sDSC and vDSC.

Only the oral cavity saw a statistically and clinically significant change in dose with all other OARs and targets receiving similar doses when planned on edited AI auto-contours vs manual contours. Timing data showed that generally AI auto-contouring had little impact on the average time taken to contour in the pathway with only one of the 5 diagnosis groups analysed having a statistically significant reduction in time taken to contour.

Discussion – The results from this study show a much greater conformity to AI auto-contours directly after the implementation of AI auto-contouring which leads to a discussion on the risk of automation bias and its impact on clinical practice. The reported doses, excluding the oral cavity, have not changed but analysis suggests that the volume of most OARs has increased which may lead to other clinical implications. AI auto-contouring generally made little to no change in pathway timing, excluding the urology group, and this may be due to the way the pathway is set up, tasks are completed with the patients start date in mind and hence, there is no incentive to complete tasks sooner as the patient start date will not be moved forward.

Conclusion – The introduction of AI auto-contouring had little or no effect on dose or timing except in a few clear circumstances. The sharp increase in conformity to AI auto-contours highlights the clear impact that it can have in conformity and consistency but leads to a discussion on the risk of automation bias.

Key Words – *AI auto-contouring, pathway timing, contour consistency*

Key References

[1] B. Schipaanboord, et al., "An Evaluation of Atlas Selection Methods for Atlas-Based Automatic Segmentation in Radiotherapy Treatment Planning," IEEE Transactions on Medical Imaging, vol. 38, no. 11, pp. 2654-2664, 2019.

[2] L. J. Peters, et al., "Critical impact of radiotherapy protocol compliance and quality in the treatment of advanced head and neck cancer: results from TROG 02.02," Journal of Clinical Oncology, vol. 28, no. 18, pp. 2996-3001, 2010.

[3] N. Ohri, et al., "Radiotherapy Protocol Deviations and Clinical Outcomes: A Meta-analysis of Cooperative Group Clinical Trials," Journal of the national cnacer institute, vol. 105, no. 6, pp. 387-393, 2013.

[4] MVision AI Oy, "MVision Verify 1.1.0 Version: d01266e01aab," [Online]. Available: https://gbs.mvision.ai/verify. [Accessed 2025].

Title of Study: Commissioning and Implementation of TBI on Eclipse

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Background. Total body Irradiation (TBI) is used in the treatment of certain leukaemia, lymphomas and some immunological diseases and disorders (1)
At UCLH patients are treated with parallel opposed 10 MV fields at extended SSD. A hybrid technique is used whereby the patient's shoulders to upper legs are planned and the rest of the body (head and legs) is treated as a box using a head base and filling between the patient's leg with bolus bags. MLC defined segment and boost fields are used to achieve the required dose homogeneity and to keep organ at risk doses within tolerance. A Perspex screen is placed in front of the patient to provide full dose at the skin. In vivo dosimetry is performed at each fraction using diodes. How this was planned on Oncentra Master Plan (OMP) is described in (2). This work was carried out to move TBI planning from OMP to Eclipse.

Methods.
The TBI beam is modelled by using the standard 10MV beam at extended SSD in combination with a screen support structure, The following dosimetric properties (PDD, profile, TPR, open output and OPF) in normal tissue and lung (central and off axis) were compared with measured data.
In order to determine the implications for TBI planning 6 patients were double planned in Eclipse. The original plan on OMP was recreated on Eclipse (same field shapes and MU) and a new re-optimised plan created (with field shapes and MUs to achieve the TBI aims). For the recreated plans the measured diode results were compared with the original OMP and Eclipse plans. End to end testing of the TBI process was carried out by planning and delivering TBI treatment on the Anderson Radiation Therapy (ART) phantom (RANDO) and a CIRS ATOM whole body phantom (from NPL) respectively. Once Eclipse was implemented into clinical use an audit of the diode results was carried out.

Results
PDD and profile comparison (within 70 cm from the central axis) gave good agreement with measured data. OPF gave agreement within 4% except for small field sizes. Comparison of the double planning indicated no major difference in dosimetry between Eclipse and OMP. Eclipse achieved planning goals in all cases. End to end results on ATOM phantoms indicated that Eclipse modelled the lung dose more accurately than OMP which overestimated the dose by about 5%. Diode results from RANDO indicated Eclipse predicted dose on average 6.2% lower at the shoulders than was measured.

Discussion.
The profile comparisons indicated Eclipse was accurate enough for the volume being planned (head and legs are not planned).The OPF comparison indicated that boost fields less than 3x3 cm should not be used. Double planning gave reassurance that the dosimetry is similar so moving TBI planning to Eclipse will not change the dose delivered to TBI patients

Conclusion. Undertaking this work indicated TBI planning could be moved to Eclipse using the same planning criteria as with OMP with the advantage that the lung doses were more accurately modelled. It also highlighted that there was some uncertainty in the dose delivered to the sternum and shoulders.

Key references..

1 Van Dyk *et al* The Physical Aspects of Toatal and Half Body Photon Irradiation AAPM Report 17
2 Patel *et al In vivo* dosimetry for total body irradiation: five-year results and technique comparison Journal of Applied Clinical Medical Physics Volume 15 number 4 2014

A RapidPlanPT Model for Craniopharyngioma Proton Beam Therapy Treatment Planning

Rachel Gordon, Anamaria Bernett, Angus Main, Poppy Nikou, Emma Patel, Christian Brunet, Sarah Gulliford

Background. Proton Beam Therapy (PBT) treatment planning is an iterative, field-based process, where optimal plans are generated by altering dose-volume objectives and field arrangements. Achievable dose-volume histograms (DVHs) are significantly impacted by the geometry of internal anatomy relative to the fields. Due to inter-patient variability, plan quality is highly dependent on the planner's experience [1]. RapidPlanPT (RP-PT) is an automated planning tool, which can reduce inter-planner variability, minimise planning times, and improve the standardisation of PBT plan generation [2,3]. This abstract details the development and verification of a Craniopharyngioma RP-PT model at UCLH.

Methods. Data from 22 previously treated patients was used to build the RP-PT model. Initial testing was performed on patients used to build the model, with existing clinically used field arrangements. The model was then used to generate plans on 9 unseen patients, using 3 standard field arrangements (Figure 1). Model success was defined as the generation of plans that adhered to local protocols and achieved a comparable dose distribution to the clinical plan.

Field Arrangement	G1	T1	G2	T2	G3	T3
RP-PT 1	60	300	300	60	-	-
RP-PT 2	60	340	45	270	280	20
RP-PT 3	180	0	40	270	-	-

Figure 1: Standard field arrangements used, where G`X' and T`X' represents the gantry and table angle for field number X.

Results. Testing on the patients used to build the model showed RP-PT could generate plans with adequate CTV coverage and OAR doses, that adhered to local protocols, using the patient's clinical field arrangement. Figure 2 shows target dose coverage for unseen patient plans generated in RP-PT was comparable to manually generated clinical plans, but regions of high dose in the optic chiasm exceeded the optimal clinical constraint in some cases.

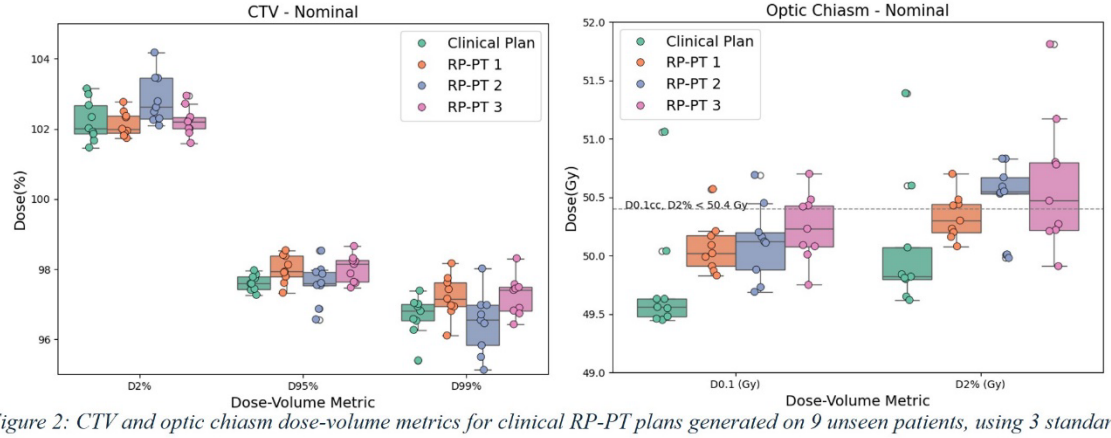

Figure 2: CTV and optic chiasm dose-volume metrics for clinical RP-PT plans generated on 9 unseen patients, using 3 standard field arrangements (100% dose represents 50.4Gy). The dotted line shows the constraint that optic chiasm D0.1cm³ and D2%<50.4Gy.

Discussion. RP-PT plans had suitable target coverage in the nominal case, but were poorer under uncertainty compared to clinical plans. RP-PT plans were acceptable according to local protocol, with further optimisation needed in some cases to remove high dose regions from optic structures. RP-PT success was highly dependent on the field arrangement. This correlated closely with the arrangements seen in the model, with the RP-PT 2 plans performing the best.

Conclusion. The Craniopharyngioma RP-PT model generated plans comparable to clinical plans for patients in the model and external test patients, which were or were close to clinically acceptable. As a result, the plan has been released for clinical use.

Key references. [1] L. Yuan, Y. et al., *Medical Physics*, 39(11), 2012. [2] K. Kubo, et al., *Physica Medica*, 44, 2017. [3] K. van Gysen, et al. *Med Radiat Sci.*, 67, 2020.

Key Words. *RapidPlanPT, Protons, Craniopharyngioma, automated treatment planning*

Developing In-House Software to Audit Treatment Verification Imaging in Radiotherapy

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Background

Recent changes to IR(ME)R require the establishment of dose reference levels for treatment verification imaging in radiotherapy. Additionally, changes to SAUE guidelines introduced a requirement to report three or more verification images acquired as a result of software or hardware failure. Both of these changes emphasise the importance of monitoring and auditing verification images on linear accelerators. At our centre (BHRUT), there is currently no available software that can help efficiently monitor dose reference levels. In this project, a Python program was created to analyse verification imaging data from DICOM Radiation Dose Structured Reports (RDSRs) and display data for instances where a patient has received three or more imaging exposures in a single fraction, which may be reportable to the CQC under IR(ME)R.

Processes

We first determined which variables in the RDSRs would be most relevant for audit purposes, which included acquisition protocols, software versions, exposure times, and dose length products. Pydicom and Tkinter were used to create a simple GUI that displays all data, which can be filtered by date, patient ID, and several other parameters. We then developed a function to plot interactive histograms of numerical data and a chart that can display the total exposures and number of exposures per day for a given patient. By grouping exposures that occurred during the same fraction, we also obtained a summary of all instances where there have been three or more exposures. Throughout its development, the program has undergone testing with phantom data that has been acquired across the last five years, spanning different acquisition protocols, treatment units, and software versions.

Lessons Learned

One of the significant challenges in developing in-house software is doing so with the support of Trust IT, particularly as this software will ultimately need to connect to a database that is continuously updated with RDSRs. We currently do not have a formalised in-house software development policy, and if this had been established, we may have met our goal of applying this program to patient data earlier. If starting this project again now, we could have worked more closely with IT to establish timeframes for when different aspects of the project could be tested and implemented.

Best Practice

This project's biggest achievement is that it has potential to be used as an audit tool to establish and monitor dose reference levels, and to identify potentially reportable instances of multiple exposures. This is particularly advantageous in a centre with several types of treatment unit and treatment planning systems. Data can be interrogated further and audited to monitor changes, e.g. following the implementation of a new protocol or a software upgrade. It was useful to discuss requirements of the program with users so that essential features could be implemented early in the project.

Conclusion

Overall, this project has shown that in-house software development is a viable option to develop an audit tool for verification imaging. Further work must be conducted in collaboration with Trust IT to integrate a DICOM listener with this program, and to install an instance that can be used with patient data. This will enable the program to be used continuously to analyse and investigate exposures.

End to End dosimetric verification for multi isocentre limb VMAT delivery on a Truebeam Linac

K Hughes-D'Aeth, T. Skopidou, M. Pearson, R. Begum, C. Sisodia, S. Naz, M. Patel, S. Morris, V. Sim

Purpose

A new long limb multi-isocentre VMAT treatment technique (primarily for cutaneous lymphoma and extensive Kaposi sarcoma patients) has been commissioned for delivery on VarianTrueBeam Linacs v2.7 for PTVs up to 70cm length. These treatments were previously delivered in an Accuray Hi.Art TomoTherapy unit that has been recently decommissioned. The phantom and patient were scanned in appropriate immobilisation equipment on a GE lightspeed scanner and planned using the Varian Eclipse v.15.6 utilising the auto-feathering feature in the overlapping field junctions. In-vivo verification was used for an end to end study and in the first clinical case and the results are reported below. This was particularly challenging to implement as there is a lack of current literature and guidance on this topic for treating these types of patients with this technique.

Materials and Methods

The delivery of the clinical plan was verified using ScandiDos Delta4 reconstructed 3D dose distribution measurements, and point dose measurements and EBT4 film dosimetry in the field junction. Following that, an end to end test was carried out on an anthropomorphic phantom and TLDs (LiF:MgTi 3.2 x 3.2 x 0.89 mm (TLD-100™, Thermo Scientific RMP, Franklin MA, USA)) were used to verify the delivery. This provided confidence that the technique was suitably robust and that the machine was delivering a distribution similar to that shown within the planning system. It also allowed all staff groups that were involved in the process to rehearse protocols and work instructions, so that the first patient's experience could run as smoothly as possible. The first clinical limb patient plan due to be treated was selected for the end to end testing, an arm with a PTV approximately 50cm long. A further benefit of the end to end test was that the day 0 appointment was not required for the patient as the treatment team could use the phantom to check for any collisions or possible imaging problems without the patient being present.

TLDs were used to measure doses in the phantom for comparison against the estimated dose taken from the planning system. We selected a range of positions on the arm to place TLDs, so that the skin dose of the patient along the entire length could be measured, including locations within the feathered junction. TLDs were also measured for the first clinical patient in similar locations.

Results

Table 1. Summary of in vivo verification results showing difference between predicted dose and measured dose

	End to End Testing	First Clinical Case
Measurement Points	20	20
Within 10% Agreement	18/20 (90%)	16/20 (80%)
Within 5% Agreement	13/20 (65%)	7/20 (35%)
Maximum Dose Difference	9.5%	13.4%
Minimum Dose Difference	-12.3%	-10.6%
Average Dose Difference	-2.8	4.3
Standard Deviation	4.9	6.9

Discussion

Due to the novel nature of the technique end to end testing was essential. Following this we decided to implement in vivo verification measurements for the first five clinical patients. Table 1 also shows the TLD results of the only clinical case, treated in September 2024. The patient in vivo measurements yielded similar results to the end to end test. The largest difference between measurement and planning system point doses was 13.4% also being in the shoulder region. We infer that this variation is due to patient setup around the joint. In this case, 75% of results showed lower planned doses. All measured doses that were higher than planned were within 4%, therefore within protocol

Conclusion

TrueBeam multi-isocentre limb VMAT for targets of up to 70cm length can be safely delivered in our centre following thorough end to end testing. TLD in vivo verification results of the first clinical case confirmed that skin doses were within the protocol dose tolerance.

Title of Study: Developing a Career Pathway for Dosimetrists

Nicky Whilde, Head of Radiotherapy Physics, MSE

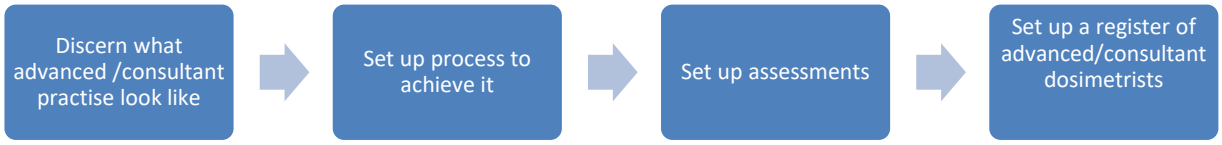
Background. Up to now, dosimetrists have not had the opportunity for career advancement based on their specialist expertise. This work demonstrates that despite the difficulties, it is possible to give Dosimetrists the chance to advance their skillset, and to improve recruitment and retention in the field.

Methods.

The Radiotherapy Professional Standards Panel (RTPSP) are an IPEM group of senior Radiotherapy Physics staff, whose remit includes issues relating to workforce, professional practice standards, funding of services, role extension and multi-disciplinary team working.

One of the strategic objectives of the RTPSP is to support the possibilities for formal career progression for Dosimetrists. In March 2023, a Task and Finish Group was formed to scope out the problem, work out the previous barriers to progression, establish a working group, and an expected endpoint. Attendees are volunteers from Clinical Scientist, Dosimetrist and Consultant Clinal Oncologist professions and include 2 workforce strategists from IPEM.

To get to a position that Advanced or Consultant Dosimetrist roles are clearly defined and recognised, the strategy of the T&F group is:



Results. It has proved complex get Dosimetrists on the Advance Clinical Practise Framework[1], for reasons which will be presented. This even though in 2025, a framework was published for the non-surgical workforce in Oncology.[2]

The Task and Finish group are therefore working towards establishing new national job profiles for 8A and 8B higher specialist and consultant healthcare science practitioners respectively, with IPEM and SoR backing. A standardised and quality assured training route and framework is also required, as discussed in the IPEM document Roadmap for Advancing Clinical Technology Careers[3].

Conclusion. The advanced clinical practise route has controversially not been available to dosimetrists; but it is planned to be able to demonstrate that their involvement in oART is a possible way to support entry onto this route.

New roles for higher specialist practise and consultant level Healthcare Science Practitioners are being submitted by IPEM to support a career framework for Dosimetrists.

Key references. In alphabetical order, numbered.

1. Multi-professional framework for advanced clinical practice in England (NHSE)
2. Non-Surgical Oncology Advanced Practise Curriculum Framework (NHSE)
3. Roadmap for Advancing Clinical Technology Careers (IPEM)

Title of Study IPEM Task & Finish group on Breast & IMC Plan robustness

Andrew Bird (On behalf of the IPEM Task and Finish Group)

Background: The 2016 Royal College of Radiologists (RCR) consensus statements for postoperative breast Radiotherapy strongly recommended considering internal mammary chain (IMC) radiotherapy for patients at high risk of locoregional recurrence. Techniques that minimise dose to organs-at-risk are recommended; volumetric techniques are generally preferred over tangential techniques. These complex techniques present additional robustness-related considerations when compared to tangential approaches which are inherently more robust.

In June 2022 IPEM's "Radiotherapy Plan Robustness in Clinical Practice" meeting took place in London. One of the outcomes was a request from the community for more guidance on Robust planning. It was decided that an IPEM Task & Finish group under RT SIG would be formed, to provide guidance on the creation and evaluation of robust treatment plans for Breast + IMC irradiation. Although the guidance concentrates specifically on providing advice for planning this site, it is intended to include general principles that are applicable across other Radiotherapy planning sites.

Methods: The Task and Finish group was proposed and approved by IPEM, and the working party formed by selection from expressions of interest to an advert on the jisc mailing list. The working party has met regularly since April 2024 including an in-person Working Day in London in December 2024. Discussions have included the definition and quantification of robustness and considerations of differences between planning software and delivery techniques.

Results: There were over 50 expressions of interest to join the group. A balance of experience and geographical spread were considered to form the multidisciplinary team of 9 members. The group have drafted a guidance document which will be circulated for consultation from the wider community this summer. The report introduces a structured three-phase approach: (i) identifying areas where consideration of robustness is necessary, (ii) determining and describing strategies to address these robustness needs, and (iii) evaluating plans produced using those strategies.

The group agreed that robustness tools should be applied to plans during commissioning of new planning techniques and throughout the time the technique is used to produce plans. Suggested metrics have been agreed to provide a starting platform to investigate plan robustness. Imaging techniques and notes are included along with patient motion and contour change ranges that might be expected for the average treatment centre.

Discussion: The aim of the guidance document is to provide practical support for centres that want to develop and implement robust planning techniques for Breast + IMC radiotherapy. It is hoped that the impact of the group's work will be to reduce the resources needed to develop and continually improve robust planning methods for complex sites through encouraging the use of general approaches and shared learning and experience.

Conclusion: Through this endeavour, the collective experience of the members of the Task and Finish group has been brought together to draft a guidance document which will be circulated for consultation from the wider community this summer.

Key references.

The Royal College of Radiologists. Postoperative radiotherapy for breast cancer: UK consensus statements. London: The Royal College of Radiologists, 2016.

Impact of photon beam profile optimisation between matched Linacs, demonstrated via Patient Specific Quality Assurance (PSQA) using 3D gamma analysis.

P. Birmpakos, A. Chown, K N. Chuang, J. Cruise, L. Gilfrin, O. Awunor, I. Di Biase

Background. It is vital that all Linacs that share a beam model within the Treatment Planning Software are correctly beam matched [1]. Small inconsistencies in beam profiles between Linacs may not be detected by routine QA but can have an impact on PSQA results. Following a period of inconsistent PSQA results, it was identified at the Royal Berkshire Hospital (RBH) that while the beam quality and percentage depth doses (PDDs) were matched between Linacs, there was a discrepancy in the profiles. This study reports the investigation and resolution process undertaken to optimise beam matching and improve PSQA consistency across matched Linacs.

Methods. PDDs and beam profiles measured at 10 cm deep using the watertank, acquired at commissioning, and before and after major services over the past five years, were reviewed to assess the agreement between two nominally matched Linacs (LA5A and VHD1) at RBH. Additionally, beam uniformity for 6MV, acquired monthly over the past year using IC Profiler™, was audited. Using the watertank, adjustments were made to optimise the profile matching. 3D dose distributions for a selection of VMAT plans were acquired with the PTW Octavius 4D inserted with the 1500 2D Array. Pre- and post-adjustment PSQA results, calculated using 3D gamma analysis (3%, 3 mm) [2], were compared to assess the impact of beam matching.

Results. An initial difference in the order of 2% between the pre- and post-adjustment profile horns was reduced by optimising the beam profile, until all the profiles horns are within 0.5% of each other across the two Linacs, as shown in Figure 1.a and 1.b. This change in beam configuration had a direct impact on the PSQA results, one example of which is shown in Figure 1.c and 1.d; here, the blue areas indicate the failure points and their reduction once the beam profiles are optimised.

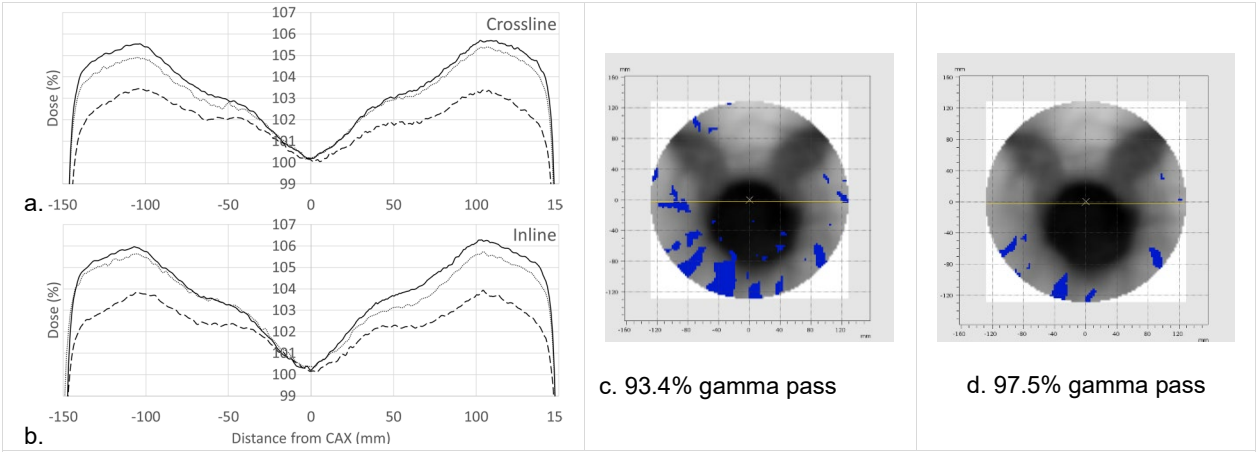


Figure 1. Crossline (a) and inline (b) 6MV profiles at dmax for VHD1 (-) and LA5A pre (- - -) and post (...) adjustment, and a transverse slice of the PSQA gamma analysis (3mm DTA/3% DD) of the same plan pre-adjustment (c), and post-adjustment (d)

Discussion. This investigation highlighted the sensitivity of clinical plan delivery to inconsistencies in beam uniformity across matched Linacs. This was evidenced by variations in PSQA results across Linacs, and the relative insensitivity of current routine beam uniformity QA. This will inform a review and update of routine QA practices, including tolerances, reference data, and verification that matched Linacs continue to operate within an optimised tolerance in all aspects of beam characteristics.

Conclusion. It is essential that beam matching across Linacs is achieved using both PDDs and beam profiles (inline and crossline) to ensure consistency in treatment delivery across all matched Linacs.

Key words. Beam matching, Beam profiles, Elekta, Gamma analysis, Optimisation, PDD, PSQA

Key references.

[1] Sjöström, David et al. “A beam-matching concept for medical linear accelerators.” Acta oncologica (Stockholm, Sweden) vol. 48,2 (2009): 192-200. doi:10.1080/02841860802258794

[2] Low, D A et al. “A technique for the quantitative evaluation of dose distributions.” Medical physics vol. 25,5 (1998): 656-61. doi:10.1118/1.598248

QUANTIFYING THE GEOMETRICAL UNCERTAINTIES INVOLVED IN END-TO-END TESTING

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Background.
Over the past decade, several proposals have advocated for the integration of end-to-end (E2E) testing in radiotherapy. As the complexity of radiotherapy treatment techniques continues to escalate, developing an E2E focused QA protocol has the potential to enhance our comprehension of overall treatment uncertainty. The Royal Marsden Hospital at Chelsea has been proactively working to increase the number of dosimetric and geometric E2E tests conducted. At each stage of the patient pathway, potential errors may occur, collectively contributing to the treatment uncertainty. Consequently, the department must assess individual geometric uncertainties to understand the overall uncertainty from E2E testing itself.

Methods.
The project mapped out the CT based treatment pathway for geometric E2E testing that is based on the meningioma patient pathway. Ten repeat measurements were performed at each step of the pathway, using an anthropomorphic phantom together with film to quantify the geometric uncertainty of each stage. Uncertainties were evaluated following JCGM guidelines [1]. The standard uncertainty was defined as the standard deviation divided by the square root of the sample size. These were combined in quadrature and multiplied by a coverage factor, k, of 2 to give the expanded uncertainty at 95% level of confidence.

Results.
The expanded uncertainty was ±0.28, ±0.26 and ±0.25mm in the left-right, anterior-posterior and superior-inferior axes respectively. Manual contouring and inter-planner variability were highlighted as the primary systematic sources of geometric uncertainty, while treatment delivery and film analysis were highlighted as the main random sources of uncertainty.

Discussion.
The geometric uncertainties were determined, giving reference values against which other geometric E2E test results can be compared. There are several key differences between the geometry E2E testing and patient treatments, therefore the geometric uncertainties of patient treatments are expected to be greater than the E2E values. By identifying the dominate uncertainties, action can be taken to reduce the uncertainties in E2E testing and in patient treatments.

Conclusion.
Geometric uncertainties in modern radiotherapy are important, they can and should be quantified. This enables improving both quality assurance and patient treatments. Further action is needed to quantify uncertainties in a range of treatment pathways.

Key Words.
Radiotherapy. End to end testing. Geometric uncertainties.

Key references.

[1] JCGM. "100:2008, Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement JCGM 100:2008 (GUM 1995 with Minor Corrections)." *BIPM Joint Committee for Guides in Metrology* Paris (2008).

TrueBeam version 4.1 & HyperSight CBCT Imaging Analysis

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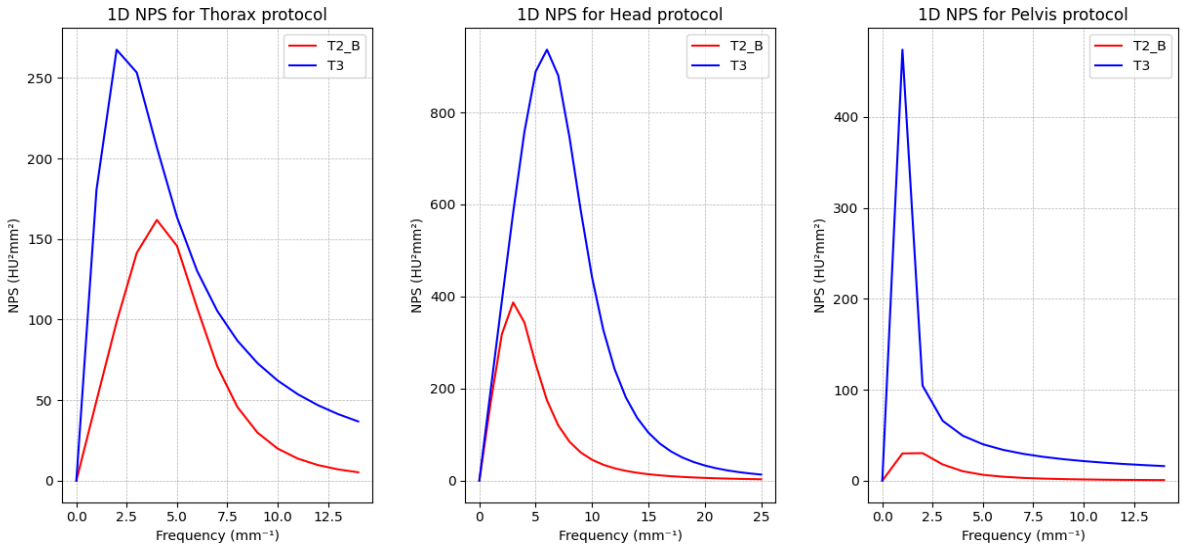
Background

The radiotherapy department at Aberdeen Royal Infirmary (ARI) recently obtained a new TrueBeam 4.1 Linac with the HyperSight CBCT imaging system. The physics department undertook testing of the CBCT system. Given the importance of image noise in soft-tissue image matching, the noise-power spectrum (NPS) was measured for the new optimised CBCT protocols on the TrueBeam 4.1 with HyperSight and then compared with the department's older TrueBeam CBCT protocols. A further comparison of the department's TrueBeam 4.1 with HyperSight and Ninewells Hospital's TrueBeam 4.1 without HyperSight was made. CBCT parameters were controlled so that a true comparison of the NPS difference with HyperSight could be made.

Method

A CatPhan 504 was scanned on all TrueBeams and the PyLinac library was used to generate noise-power spectra using Python.

Results



T2_B – Newer TrueBeam 4.1 Linac with HyperSight
T3 – Older TrueBeam Linac

Conclusion

Comparing the curves for both Linac's, it is obvious that the T3 linac's CBCT images have significantly more noise variance, particularly at lower spatial frequencies compared to the T2_B linac's CBCT images. This indicates that the HyperSight imaging system has allowed the radiotherapy physics team at ARI to create protocols that produce significantly less noise compared to the older TrueBeam model, while manging to maintain relevantly low dose, keeping under the UK cone beam dose index ($CBDI_w$) dose reference levels (DRL's).

Key words

CBCT, Hypersight, PyLinac, Python, TrueBeam, Radiotherapy, Noise-Power Spectrum

VCC experience in treatment of breast patients on Varian Halcyon linacs.

Dominic Rafferty, Velindre Cancer Centre. Cardiff

Background:

VCC is in the process of commissioning a growing fleet of Varian Halcyon and Ethos linacs, alongside the Eclipse TPS and other Varian systems as part of an integrated radiotherapy solution (IRS). Breast treatments make up a large proportion of the patients referred for radiotherapy at VCC, and so were a high priority for implementation on the new systems. The Halcyon platform presents unique challenges for implementing breast treatment techniques due to physical and dosimetric limitations, but also opportunities through advanced image guidance technology.

Effective techniques have been commissioned and brought into routine clinical application for various cohorts of breast patients, and ongoing development aims to expand inclusion to other risk groups. Whilst the established methods and workflows have been deployed successfully, there remain challenges for the inclusion of larger patients due to the physical dimensions of the bore and the unavailability of beam energies higher than 6FFF, which have previously been routinely used in the treatment of these patients on c-arm systems.

Methods:

The possibility of generating clinically acceptable plans using our current Halcyon breast planning technique is dependent on specific patient anatomy, and an inclusion decision is generally made based on simple geometrical measurements of patient shape and size in relation to established limits on these quantities. These criteria have been determined through planning studies which correlate simple geometric measurements with plan achievability, and adaptations to workflow have allowed these to be gradually expanded.

Results:

We have been able to establish relatively generous inclusion criteria according to geometrical considerations. However, the established workflow to treat breast patients using a DIBH technique, which is essential to limit the dose to the heart in left-side treatments, involves a dual scanning protocol to provide a free-breathing surface for patient setup using the IDENTIFY surface guidance system. This has necessitated an upstream decision about whether patients should be planned and treated on a Halcyon pathway when an assessment of the treatment volume by breast planning radiographers of suitability according to geometric criteria is not possible, in order to prevent patients receiving unnecessary imaging doses. A BMI < 40 threshold has been established as a method of making an initial decision about most suitable patient pathway, minimising the risk of unplannable patients being assigned to the Halcyon pathway and allowing us the requisite confidence to implement an SGRT-enabled tattooless workflow for this platform.

Conclusion:

As we have gained experience and confidence in treating breast patients on the platform, and adapted our methods and workflows, we have been able to gradually expand our patient selection criteria such that there are now very small numbers (~5%) rejected solely on the basis of patient size.

Capacity issues and aspects of the future plan for the configuration of machines between our main and satellite sites demand that the inclusion criteria for treatment on Halcyon be as wide as possible. Work is ongoing to determine methods to allow inclusion of all patients on the planned fleet.

Key references

1. **Flores-Martinez E, et al.** 2019, Journal of Applied Clinical Medical Physics, pp. 20(7):58-67.
2. **Kennedy C, et al.** 2018, Cureus, p. 29;10(10).
3. **Tsai YC, et al.** 2022, Journal of Applied Clinical Medical Physics, p. 23(7):e13635.
4. **Richter A, et al.** 2021, Radiation Oncology, p. 16(1):213.

Ultra-hypofractionated radiotherapy to the stellate ganglia for ventricular arrhythmia using MR-guided radiotherapy – pre-trial commissioning

Ben George[1], Maxwell Robinson[2], Tom Whyntie[1], Prabakar Sukumar[2], Ebison Chinherende[1], Benjamin Bussmann[2,3], Fintan Sheerin[2], Veni Enzhil[1], Neil Herring[2,3], Ami Sabharwal[1,2].
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3. University of Oxford

Background. Ventricular arrhythmias (VA) are life-threatening events and are the most common cause of sudden cardiac death. Most VAs are triggered by the sympathetic nervous system via the stellate ganglia, a nervous structure sitting above the heart in the lower neck region between the spinal cord and brachial plexus (1). Surgical removal of a portion of the stellate ganglia and sympathetic chain is an option in some patients with proven benefit. However, this invasive procedure currently has very high rates of complication (2). Direct cardiac radiotherapy to treat refractory VA has also been shown to be both safe and effective (3,4), but whether radiotherapy can be targeted at the stellate ganglia is unknown.

Here we describe radiotherapy planning consideration for the use of MR-guided ultra-hypofractionted radiotherapy to target the lower half of the stellate ganglia and T1-T2 sympathetic chain bilaterally. The aim is to reduce neuronal function and VA. Treatment was performed as part of the RADIO STAR trial (ISRCTN 49861434), a BHF funded, first in man, phase 1 clinical trial of radiotherapy to achieve cardiac sympathetic denervation (REC:24/SC/0005). All patients had implantable cardioverter-defibrillators (ICDs) in situ and had received 2 or more appropriate therapies for VA in the previous 6 months.

Methods. Using anonymised volunteer scans, a pre-trial treatment planning exercise was performed on both MR-Linac (ViewRay Systems MRIdian, Oakwood, OH) and conventional CT-Linac (Varian Truebeam, Palo Alto, CA) systems for cross platform validation and backup planning. Treatment plan deliverability and calculation accuracy was verified using 3D fluence and point dose measurements using suitable patient-specific quality assurance hardware (Sun Nuclear ArcCheck, Melbourne, FL). 3D MR distortion measurements were performed on the 1.5T (Siemens MAGNETOM Avanto Fit, Forchheim, DE) and MR-Linac scanners to quantify image spatial integrity in the presence of cardiac device using a large field of view phantom (Large Field of View Distortion Phantom, CIRS, Norfolk, VA). Patient immobilisation in a thermoplastic mask was tested and setup reproducibility assessed with repeat volunteer scans. Image guidance workflows were developed to utilise imaging capabilities available with MR-guided treatment and safety protocols high-risk patients with ICD established. Treatment delivery accuracy, image spatial integrity, and setup reproducibility influenced the inclusion of planning risk volumes for critical organs at risk (brachial plexus, spinal cord, oesophagus). All treatment was in 3 fractions with total dose ranging from 24 – 33 Gy across 4 cohorts with a 6-week period before dose escalation. An independent safety committee monitors all adverse events.

Results. Test plans showed adequate coverage of target (43%-91% depending on prescription dose) limited by brachial plexus dose constraint, with increasing mean and maximum dose (D(2%) = 29 – 40 Gy) for each cohort. MR distortion was shown to be <2 mm in the region of the stellate ganglion and critical OARs. Patient specific QA results show high gamma pass rates (>98% at 3%/2mm) and excellent point dose agreement (<2% difference). In line with local institutional policies and national guidance, ICD doses were limited to D(0.05 cc) <5 Gy for all test plans.

Conclusion. Planning to study objectives is feasible across all dose escalation levels on a range of volunteer scans. MR distortion is sufficiently low to utilise for delineation. MR-guided stereotactic to the stellate ganglia radiotherapy is feasible with development of a robust radiotherapy protocol. At the time of writing three patients have completed radiotherapy as part of the trial.

Funding. British Heart Foundation (FS/CRTF/22/24437 and FS/SCRF/20/32005)

Keywords. Ventricular arrhythmias (VA), stellate ganglia, MR linac, radiotherapy planning.

Key references.

1. Herring, N., Kalla, M., & Paterson, D.J. The autonomic nervous system and cardiac arrhythmias: Current concepts and emerging therapies. Nature Reviews Cardiology 2019;16(12), 707–726.
2. Shah R, Assis F, Alugubelli N, Okada DR, Cardoso R, Shivkumar K, et al. Cardiac sympathetic denervation for refractory ventricular arrhythmias in patients with structural heart disease: A systematic review. Heart Rhythm. 2019;16(10):1499-505
3. Cuculich PS, Schill MR, Kashani R, Mutic S, Lang A, Cooper D, et al. Noninvasive Cardiac Radiation for Ablation of Ventricular Tachycardia. N Engl J Med. 2017;377(24):2325-36.
4. Robinson CG, Samson PP, Moore KMS, Hugo GD, Knutson N, Mutic S, et al. Phase I/II Trial of Electrophysiology-Guided Noninvasive Cardiac Radioablation for Ventricular Tachycardia. Circulation. 2019;139(3):313-21.
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Auto-segmentation of Head and Neck Cancer nodal GTVs using an institutional in-house segmentation pipeline

Victoria Butterworth[1,2], Michael Woodward[1], Dr Tom Young[1,2], Anil Mistry[1,2], Dr Christopher Thomas[1,2], Sarah Misson[1,2], Dr Delali Adjogatse[1,2], Dr Imran Petkar[1,2], Dr Miguel Reis Ferreira[1,2], Dr Anthony Kong[1,2], Dr Mary Lei[1,2], Dr Rohit Srinivasan[1], Dr Cristina Dudau[1], Dr Steve Connor[1], Dijana Vilic[1,2], Dr Phil Touska[1], Professor Andrew King[2], Dr Teresa Guerrero Urbano[1,2].
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Background

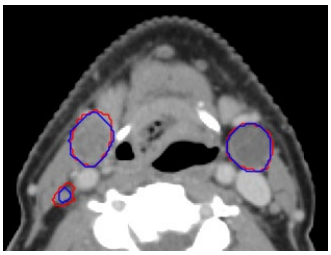
Artificial intelligence (AI) based auto-segmentation tools are beginning to become commonplace for delineating organs at risk (OARs) in radiotherapy (RT) however there remains a notable gap in commercial solutions for auto-segmenting gross tumour volumes (GTV) [1][2]. Given the ongoing workforce crisis in radiation oncology [3], coupled with the increasing demands of adaptive radiotherapy workflows, accurate and efficient auto-segmentation tools are vital to sustain high-quality patient care and maintain patient throughput. Additionally, auto-segmentation can significantly reduce inter-observer variability in volume delineation [4], minimising bias in downstream AI modelling applications. To address this unmet need, we utilised an in-house developed auto-segmentation pipeline to train a head and neck cancer (HNC) GTV nodal (GTVN) model using data from our federated HNC institutional data lake [5].

Methods

780 patients with HNC (larynx, hypopharynx, oropharynx or nasopharynx) treated with definitive RT, chemo RT or cetuximab+RT were identified as suitable for inclusion. Of these patients, n=171 had documented radiologist peer reviewed contrast-enhanced GTVN segmentations on CT, which were used to train an nnU-net [6] model (3D-full resolution, 0.9 training/0.1 test split). Model evaluation utilised Volumetric Dice Similarity Coefficient (VDSC) between predicted segmentations and clinical ground truth (GT), alongside visual qualitative assessment.

Results

The median VDSC was 0.81 (IQR: 0.74-0.86, range: 0.43-0.90) in the test cohort (n=17). Informal qualitative assessment demonstrated consistently high-quality contours. Voxelwise median sensitivity per patient was 0.78 (range: 0.31-0.91) but was lower per node (0.75 (range: 0.25-1.00)), reflecting the model's propensity to overlook smaller nodes. A higher median precision on a voxel basis (0.88 (range: 0.70-0.93) vs 0.80 per node (range: 0.33-1.00)) highlights the model's ability to delineate the boundaries of detected nodes well but a slight susceptibility to segment additional nodes. No performance differences were observed between bilateral and unilateral cases.



GTVN GT contour (red), predicted segmentation (blue).

Discussion

This model demonstrates strong performance for GTVN segmentation from a single-modality input [7], attributed to stringent adherence to protocol and rigorous peer review. A major strength of our approach is the use of a federated institutional data lake which ensures known data provenance and enables future evaluation of model performance across key demographic and socioeconomic factors. This supports efforts to identify and mitigate bias, promoting equitable clinical implementation. The clinical ramifications of reliable GTV auto-segmentation are substantial and so careful validation and multidisciplinary oversight remain essential to mitigate automation bias and define acceptable clinical risk [1].

Conclusion

We successfully developed a robust GTVN auto-segmentation model demonstrating strong segmentation performance. Future work will involve refining the model using node-negative patient data to enhance sensitivity towards smaller nodal disease, alongside formal qualitative evaluation. Following these results, a prospective clinical pilot will assess model utility and clinical deliverability, extending an established in-house segmentation pipeline.

[1] Royal College of Radiologists, “Autocontouring in Radiotherapy: Guidance for Clinicians,” 2024. Accessed: Apr. 25, 2025. [Online]. Available: https://www.rcr.ac.uk/media/rqjlnlny/rcr-auto-contouring-in-radiotherapy-2024.pdf

[2] S. S. Gay *et al.*, “Fully-automated, CT-only GTV contouring for palliative head and neck radiotherapy,” *Sci Rep*, vol. 13, no. 1, p. 21797, Dec. 2023, doi: 10.1038/s41598-023-48944-2.

[3] A. Aggarwal *et al.*, “The future of cancer care in the UK—time for a radical and sustainable National Cancer Plan,” *Lancet Oncol*, vol. 25, no. 1, pp. e6–e17, Jan. 2024, doi: 10.1016/S1470-2045(23)00511-9.

[4] C. E. Cardenas *et al.*, “Comprehensive Quantitative Evaluation of Variability in Magnetic Resonance-Guided Delineation of Oropharyngeal Gross Tumor Volumes and High-Risk Clinical Target Volumes: An R-IDEAL Stage 0 Prospective Study,” *International Journal of Radiation Oncology*Biology*Physics*, vol. 113, no. 2, pp. 426–436, Jun. 2022, doi: 10.1016/j.ijrobp.2022.01.050.

[5] V. Butterworth *et al.*, “Data-centric Artificial Intelligence and Cancer Research: Construction of a Real-World Head and Neck Treatment Data Repository,” Feb. 16, 2025. doi: 10.1101/2025.02.12.25322092.

[6] F. Isensee, P. F. Jaeger, S. A. A. Kohl, J. Petersen, and K. H. Maier-Hein, “nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation,” *Nat Methods*, vol. 18, no. 2, pp. 203–211, Feb. 2021, doi: 10.1038/s41592-020-01008-z.

[7] C. Franzese *et al.*, “Enhancing Radiotherapy Workflow for Head and Neck Cancer with Artificial Intelligence: A Systematic Review,” *J Pers Med*, vol. 13, no. 6, p. 946, Jun. 2023, doi: 10.3390/jpm13060946.

Key words: Artificial Intelligence, Auto-segmentation

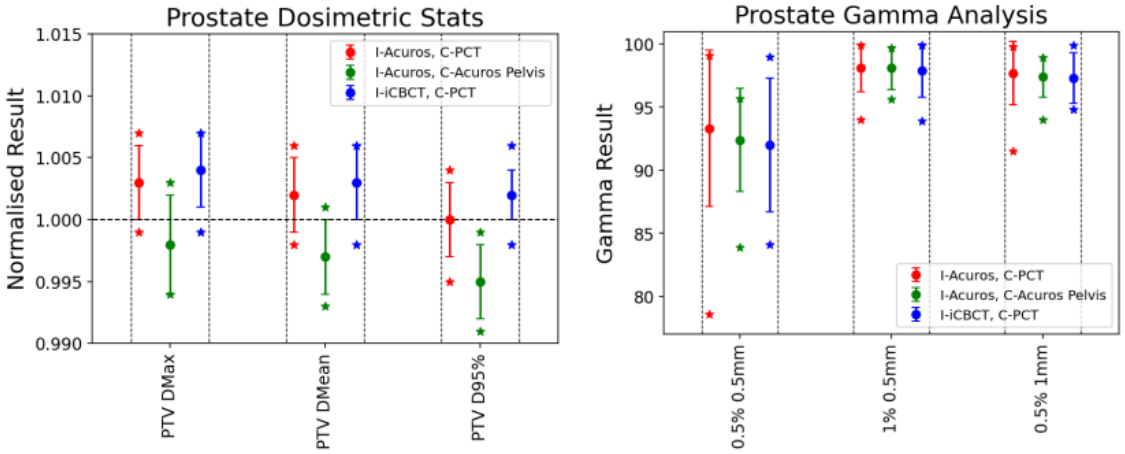
Suitability of Varian's Hypersight CBCT dose calculation for the application of prostate re-planning

Billy Chambers, Denis Mostafa, Daniel Sutcliffe, Dualta McQuaid, Melanie Cunningham, James Earley

Background. In 2024, a Halcyon linear accelerator Varian Medical Systems (Palo Alto, CA) was commissioned with Hypersight, enabling reconstructed Cone Beam CT (CBCT). These CBCTs are quoted to *deliver Hounsfield Unit (HU) accuracy rivalling that of a conventional CT scanner*. This study aimed to assess the suitability of treatment planning dose calculation directly on a Pelvis CBCT for re-planning applications.

Methods. Two CBCT reconstructions were used; the standard iCBCT and iCBCT Acuros. CBCT doses were calculated using two HU-electron density curves: Planning CT (C-PCT) and a Pelvis CBCT mode curve (C-Acuros Pelvis) created using a CIRS (Model 062MA) with 10cm solid water scattering material either side. Ten prostate patients were chosen with CBCT images from the initial treatment fractions to be comparative with the planning CT (PCT).

CBCTs had planning contours rigidly copied and to account for slight changes in body outline, the CBCT body contour had a Boolean subtraction from the PCT body to produce a missing tissue structure assigned with a constant HU value characteristic of the soft tissue missing from the CBCT. Dose calculations were run on Eclipse v16.1 (Varian, AAA 16.1.02 calculation algorithm) with PTV DMax, DMean and D95% stats generated. CBCT dose cubes were also assessed against PCT with global gamma analysis in Verisoft (PTW, v8.1).



(1) (2)

Figure (1). Mean and standard deviation comparing PTV dose statistics calculated with iCBCT and iAcuros using HU-ED curves normalised to the plan CT. Stars indicate minimum and maximum data points

Figure (2). Mean and standard deviation of the 3D global gamma results of CBCT against PCT plan dose.

+Stars indicate minimum and maximum data points

Results. The majority of mean dosimetry metrics in Figure 1 are within 0.5% of the PCT with comparable min – max ranges. iAcuros CBCT using the PCT curve gave the closest PTV metrics to the PCT. Whole dose cube analysis showed reduced pass rate deviation for iAcuros CBCT using the Acuros Pelvis curve, whilst the mean pass rate with iAcuros with PCT curve was slightly better in comparison.

Discussion.

The initial results indicate that both the Pelvis iCBCT and iAcuros reconstructions could be suitable for PTV dose calculation within a 0.5% error range. Clear differences can be seen in PTV metrics when applying HU-ED curves, but the PCT curve in this centre was found to be a suitable start point. There may be some marginal improved HU accuracy in iAcuros.

Conclusion. Hypersight Pelvis CBCT was found to be suitable for dose calculation with an accuracy of 0.5% compared to the planning CT.

Dosimetric Comparison of Hypo Fractionated VMAT Prostate Radiotherapy Plans Using 10MV Flattened Beam on TrueBeam vs. 6MV FFF Beam on Halcyon: A Retrospective Study

Nithya Kanakavelu[1], Charusheela Joshi[1] and Mark Porter[1]
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Background. Prior to the clinical implementation of the Varian Halcyon platform, prostate cancer patients receiving hypo fractionated volumetric modulated arc therapy (VMAT) were planned and treated using 10MV flattened beam on the Varian TrueBeam system. As technical differences exist between Halcyon and TrueBeam(1), we wanted to find out if there are significant dosimetric distinctions between them in context of prostate radiotherapy. This study aimed to evaluate the dosimetric impact of using 6MV flattening filter-free (FFF) beam on the Halcyon platform compared to 10MV flattened beam on TrueBeam. Additionally, the study assessed differences in conformity indices (CI) between the two systems, with particular attention to the influence of multi-leaf collimator (MLC) configurations.

Methods. A retrospective analysis was performed on treatment plans from ten prostate cancer patients. For each patient, VMAT plans were compared between 10MV flattened beam on TrueBeam and 6MV FFF beam on Halcyon. Dosimetric parameters were compared for the planning target volumes (PTVs) and normal tissues, including the rectum, bladder, and femoral heads. Additionally, 6MV FFF plans using TrueBeam were generated for each patient and CI were compared with 6MV FFF Halcyon plans to assess the impact of difference in MLC configurations. Statistical significance was evaluated using paired t-tests with a significance threshold of $p < 0.05$.

Table: Mean ± standard deviation, % difference and p-value of dose metrics between Halcyon and TrueBeam plans

Metric	6 MV FFF Halcyon	10 MV Flat TrueBeam	Difference	p value
PTVp CI	1.122±0.02	1.129±0.02 (6MV FFF TB 1.135±0.02)	-0.6%(-1.1%)	**0.0292 (0.0086)**
PTVpsv CI	1.130±0.01	1.141±0.01 (6MV FFF TB 1.137±0.01)	-1.0%(-0.6%)	**0.0225 (0.016)**
Bladder D50%	8.10±6 Gy	7.7±5 Gy	+4.9%	0.2897
Rectum D50%	26.88±4.15 Gy	26.61±4.15 Gy	+1.0%	0.2240
FemurHead L D50%	12.73±4.90 Gy	12.93±5.46 Gy	-1.6%	0.6812
FemurHead R D50%	13.72±3.71 Gy	13.80±4.45 Gy	-0.6%	0.8881
Body V50%	453.29±66 cc	449.35±67 cc	+0.9%	0.2868
Body V40%	718.16±107 cc	683.89±103 cc	+4.8%	**0.0021**
Integral Dose	54.24±14 Gy.L	48.76±12 Gy.L	+1.0%	**2.3×10^{-5}**
Monitor Units	989±76	837±44	+15.4%	**3×10^{-5}**

Results and Discussion. The Halcyon plans demonstrated comparable PTV and normal tissue doses, with statistically significant improvements observed in CI. However, these plans exhibited a statistically significant increase in integral dose, specifically in dose levels below 50%. The MUs were significantly higher in the Halcyon plans, attributable to the energy disparity, which aligns with findings from previous studies comparing 6 MV and 10 MV flattened beams (2,3). Additionally, comparison of the CI between TrueBeam 6MV FFF and Halcyon 6MV FFF plans revealed that the dual-layer 10 mm MLC of Halcyon closely approximated the performance of the 5 mm MLC in the TrueBeam, contributing positively to dose conformity to the PTVs. Further studies are required to assess the clinical significance of increase in low dose levels in Halcyon plans in relation to secondary malignancies.

Conclusion. VMAT prostate radiotherapy plans utilising 6MV FFF beam on the Halcyon platform provide dosimetrically comparable target coverage and organ sparing to those created with 10MV flattened beam on TrueBeam. These findings support the clinical viability of Halcyon-based treatment for prostate cancer.

Key references.

1. Huang, Y. and Liu, Z., 2023. Dosimetric performance evaluation of the Halcyon treatment platform for stereotactic radiotherapy: A pooled study. Medicine, 102(36), p.e34933.
2. Kleiner, H. and Podgorsak, M.B., 2016. The dosimetric significance of using 10 MV photons for volumetric modulated arc therapy for post-prostatectomy irradiation of the prostate bed. Radiology and oncology, 50(2), p.232.
3. Mazonakis, M., Kachris, S. and Damilakis, J., 2021. VMAT for prostate cancer with 6-MV and 10-MV photons: Impact of beam energy on treatment plan quality and model-based secondary cancer risk estimates. Molecular and Clinical Oncology, 14(5), p.89.

Title of Study: A UK audit of TPS calculation of dose to medium in radiotherapy

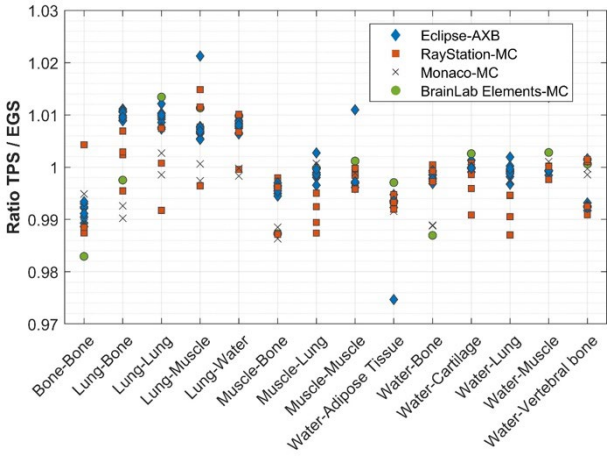
Joe Whitbourn, Nick Harding, Usman Lula, Chris South, Vanya Staykova, Alexandros Douralis, Catharine H Clark, Mohammad Hussein

Background: Modern developments of dose calculation in radiotherapy have supported the increasing clinical use of dose to medium (Dm) [1]. However, the UK radiotherapy dosimetry system does not currently incorporate any correction factors for this. IPEM have established a working party to investigate best practice in the use of Dm alongside the NPL. As part of these joint efforts a virtual audit approach to establishing the consistency of Dm calculation across the UK was conducted.

Methods: A virtual phantom dataset composed of a synthetic CT and associated structure set were electronically distributed across the UK using ProKnow and Sharepoint. This phantom is designed to reflect a reference dosimetry setup and consists of an outer rind surrounding a 5x5x5cm insert block with the isocentre 10cm deep within the phantom.

For the audit, centres were provided with TPS specific instructions on how to define material overrides (or to set densities) to create a variety of ICR-44 biological tissues. For a variety of permutations of material types for rind and insert structure, users calculated dose using a fixed MU 10x10cm field. Individual responses to the audit were normalised to the case of a water-only phantom to avoid differences introduced by different MU definitions. These results were compared to Monte-Carlo calculation results produced using EGSnrc (for 6MV only).

Results: Good agreement between user calculations and the Monte-Carlo reference data was found with most results agreeing within ±2%. The degree of variation found depended on the material configuration tested – this was lowest for water(rind)-muscle(insert) at ≈0.5% and highest for lung(rind)-muscle(insert) at ≈2.5%.



Discussion: Over 50 responses were received from UK centres demonstrating a high level of community engagement with the virtual audit approach as well as the underlying clinical need.

The variability observed is comparable to that due to daily linac output. This highlights the importance of this topic to the accuracy and precision of radiotherapy treatments.

Conclusion: This virtual audit establishes a methodology whereby centres can look to benchmark their Dm calculations in a standardised way with reference to other users results and Monte-Carlo simulations.

This work will be complemented by a follow-on physical audit based on the virtual audit that is being validated and tested at the NPL. Together, these virtual and physical audits are part of a broader project that will enable UK centres to have assurance in their Dm implementation through establishing how Dm algorithms should be commissioned, calibrated and audited.

References [1] Martin, C, Newton, V, Antoine, C, Caines, R, Venables, K and Clark, C (2023) 'Radiotherapy Dose-to-Medium Reporting: A Survey of UK Practice.' SCOPE - Spring 2023

Epistemic and aleatoric uncertainty in dose prediction models

Carver, A. and Heyes, G.

Proffered papers - please follow the style below:

Background. Neural network-based models that predict a full dose distribution offer a natural extension to existing knowledge-based planning models. A key challenge to using large neural network models in a numerically precise discipline is the incorporation of uncertainty in the model. Building a model that separately accounts for data variance (aleatoric uncertainty) and model parameter uncertainty (epistemic uncertainty) is challenging, more so in large neural network models with thousands or millions of parameters.

Previous studies in radiotherapy have used MC dropout [6] or deep evidential regression [8] to estimate uncertainties in dose grid prediction. MC dropout also requires additional consideration to extract aleatoric uncertainty [7]. In this study we use Bayesian neural networks to estimate both epistemic and aleatoric uncertainty individually.

Methods. A dose prediction model was trained using 340 head and neck cases from an AAPM grand challenge [1, 3]. Two hundred were used for training, 40 for on-line evaluation and the final 100 were held back for offline validation and analysis.

A cascading, three-dimensional UNet formed the basis for the dose prediction model [5]. To create a Bayesian network for estimating epistemic uncertainty [2] each weight in the network was replaced by a continuous, radial distribution [4] to ensure that the prior distribution had continuous support.
The UNet consisted of a single encoder and two decoders, one decoder to estimate the dose and a second to estimate the variance. The dose distribution exists on a bounded interval, $0 < D < D_{max}$. Consequently, the data were modelled with a Beta likelihood, which also has a bounded interval, in the loss function.

Each evaluation of the network produced an individual sample from the conditional dose and aleatoric uncertainty distributions. Epistemic uncertainty were the standard deviation of the conditional dose from multiple samples. The mean of the data variance samples were the aleatoric uncertainty.

Results. Figure 1 shows the effect of the epistemic and combined uncertainties for the Brainstem for the test patients. DVHs samples are shown, sampling from the epistemic uncertainty. Both sources of uncertainty contributed similarly to total uncertainty. Over all voxels in the dose grid, over all test patients the average uncertainties varied from approximately 2 Gy to 4 Gy from a 70Gy plan (approximately 2.8% – 5.7%).

Discussion and Conclusions. There are numerous clinical uses for models with both components of uncertainty. A key application is out-of-distribution detection, an abnormally high variance suggests that the case being evaluated was not adequately represented in the training sample.

The process of fitting models which estimate uncertainty aids in isolating the dominant sources of uncertainty. The models used here suggest that in the head and neck setting the epistemic uncertainty dominates. A key limitation to modelling variance is that the model has more parameters, which itself increases the uncertainty.

Key references

[1] Babier, A., Zhang, B., Mahmood, R., Moore, K. L., Purdie, T. G., McNiven, A. L., & Chan, T. C. (2021). OpenKBP: the open-access knowledge-based planning grand challenge and dataset. *Medical Physics*, *48*(9), 5549-5561.

[2] Blundell, C., Cornebise, J., Kavukcuoglu, K., & Wierstra, D. (2015, June). Weight uncertainty in neural network. In *International conference on machine learning* (pp. 1613-1622). PMLR.

[3] Chun, J., Hira, S., Zhang, H., Park, J. C., Kim, H., & Kim, J. S. The Open Knowledge-Based Planning (OpenKBP)–An 2020 AAPM Grand Challenge: Sharing Experience and Achievement. *Progress in Medical Physics*, *31*(S1), S13.

[4] Farquhar, S., Osborne, M. A., & Gal, Y. (2020, June). Radial bayesian neural networks: Beyond discrete support in large-scale bayesian deep learning. In *International Conference on Artificial Intelligence and Statistics* (pp. 1352-1362). PMLR.

[5] Liu, S., Zhang, J., Li, T., Yan, H., & Liu, J. (2021). A cascade 3D U-Net for dose prediction in radiotherapy. *Medical physics*, *48*(9), 5574-5582.

[6] Nguyen, D., Barkousaraie, A. S., Bohara, G., Balagopal, A., McBeth, R., Lin, M. H., & Jiang, S. (2021). A comparison of Monte Carlo dropout and bootstrap aggregation on the performance and uncertainty estimation in radiation therapy dose prediction with deep learning neural networks. *Physics in Medicine & Biology*, *66*(5), 054002.

[7] Skarf, F. (2023). Uncertainty Estimation in Radiation Dose Prediction U-Net.

[8] Tan, H. S., Wang, K., & McBeth, R. (2024). Deep evidential learning for radiotherapy dose prediction. *Computers in Biology and Medicine*, *182*, 109172.

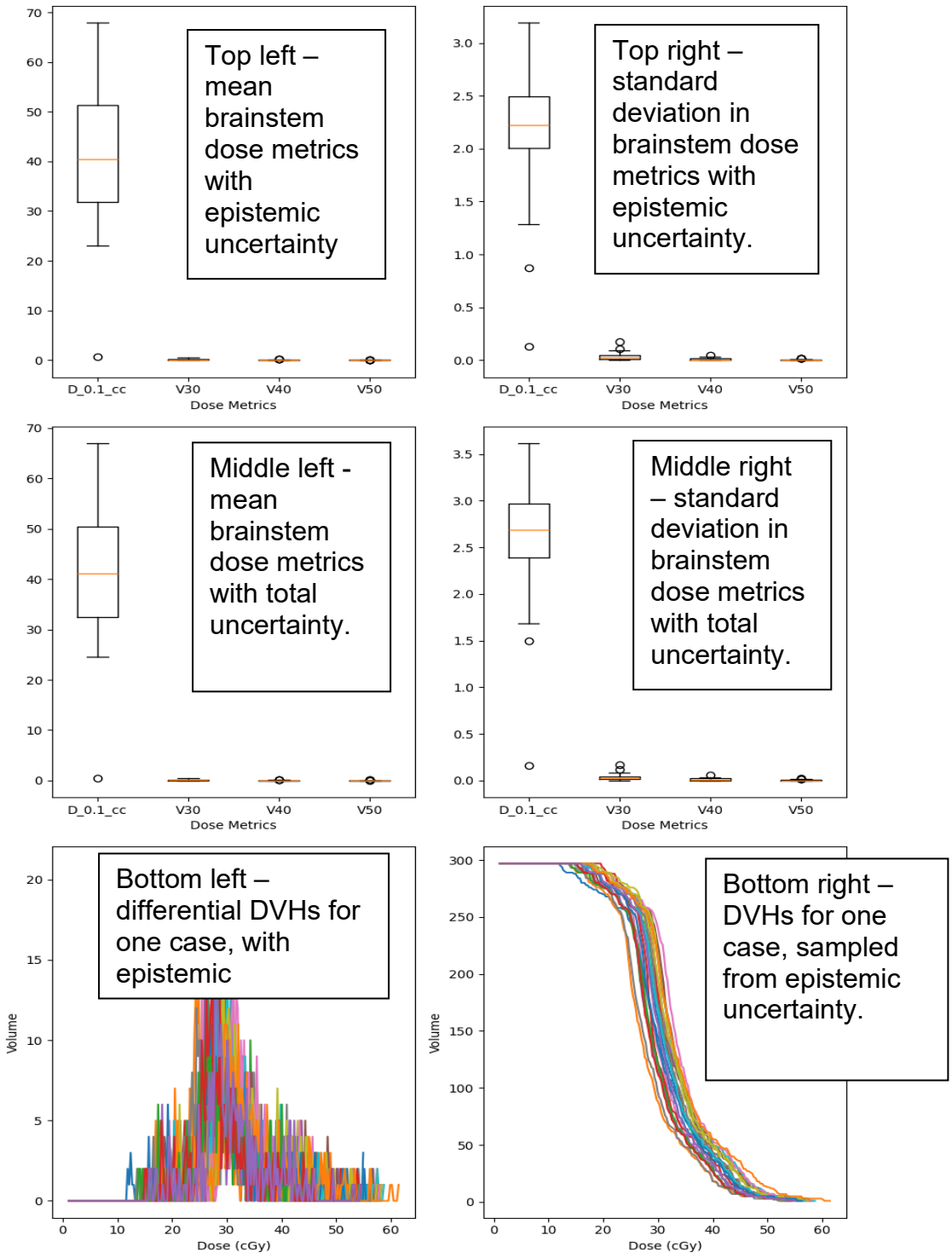

Top left – mean brainstem dose metrics with epistemic uncertainty
Top right – standard deviation in brainstem dose metrics with epistemic uncertainty.
Middle left - mean brainstem dose metrics with total uncertainty.
Middle right – standard deviation in brainstem dose metrics with total uncertainty.
Bottom left – differential DVHs for one case, with epistemic
Bottom right – DVHs for one case, sampled from epistemic uncertainty.
D_0.1_cc
V30
V40
V50
Dose Metrics
Volume
Dose (cGy)

Figure 1