# Multi-year audit of adaptive radiotherapy in a small centre

**Background:**

We have observed a steady and significant increase in the number of patients requiring a replan. The aim of this work was to perform an audit of all replans over a multi year period to investigate the reasons behind this. The vast majority of replans are requested by the clinician in response to changes noted on CBCT imaging (reactive adaptive planning). Pro-active adaptive planning is not routinely practiced in our department. CBCT assessments are generally requested by the treating radiographers or during off-line review and are performed in the following way; registered (rigid registration) CBCT images imported into TPS -> OAR of concern contoured onto CBCT image and copied to planning CT and/or density differences e.g. separation change introduced via density overrides -> DVH assessed against planning constraints -> results generally accepted if planning constraints met and/or discussed with the clinician if appropriate.

**Method:**

Data for the period 2015-2021 was extracted from the R&V system (Aria) using the AURA reporting module. Individual queries were built to extract specific data sets: treatments which were replans, CBCT assessment tasks, number of CBCT images per treatment plan. CBCT assessment tasks, CBCT image numbers and replans were stratified into treatment site and year and the reasons for replan being requested identified by reviewing notes made in the R&V system. Only radical treatments where CBCT imaging is routinely performed were considered. Data was analysed using a combination of excel and in-house Python scripts.

**Results and discussion:**

Of 3883 patients treated, 133 have been replanned over the 7-year period (3.4%), however this rate has increased from 2.0% in 2015 to 7.7% in 2021.

The number of patients where a CBCT assessment is requested has risen from 11.2% in 2015 to 41.2% in 2021; the majority of these were urology treatment sites (prostate and bladder). Urology sites account for 584/903 (64.6%) of all CBCT assessments and 94/133 (70.7%) of all replans. The primary reason for CBCT assessments is to monitor bowel or rectum dose as a result of bladder filling differences and the primary cause of all replans is some combination of bladder, rectal or bowel filling accounting for 84/133 (63.2%) of all replans. Our data shows that despite a relatively high lung workload, CBCT assessments and replans for lung treatments are uncommon.

The rate at which CBCT assessments yield a request for a replan has remained reasonably consistent and has fluctuated between approximately 3-5% in all of the 7 years audited suggesting that increased CBCT usage is the primary driver of increasing replan numbers rather than any other factors. The total number of CBCTs taken has increased from 1182 in 2015 to 6036 in 2021 and the use of daily CBCT matching has expanded throughout this time and is now routine for several sites.

Two published studies (1,2) have suggested that a replan rate of <5% should be expected, which our data shows has been exceeded in 2020 (5.4%) and 2021 (7.7%), although it is not clear if this is significant. A study from a large centre (1) showed that adaptive interventions for prostate treatments were rare and the most common sites were head/neck and lung. We have observed the inverse case to this with respect to prostate and lung treatments. It is not straightforward to benchmark this data as there is minimal published data for comparison, furthermore this would be dependent on a large number of factors.

**Conclusion:**

We have shown that increased use of daily CBCT image guidance has led to a substantial increase in the number of CBCT assessments with a subsequent uplift in the number of replans. This information will be used to inform and potentially further refine IGRT workflows.

**References:**


1. R Chuter et al **An audit of adaptive radiotherapy in a large centre** ESTRO 2018 EP-2063 *Radiotherapy and Oncology* April 2018
2. C Rowbottom **The practical 'costs' of adaptive radiotherapy** ESTRO 2016 SP-394 *Radiotherapy and Oncology* April 2016

**Right Dose, Right Place, Right Time**

Dr Hannah Chantler, Cambridge University Hospitals NHS Foundation Trust

With the introduction of more sophisticated imaging systems, both for pre-treatment imaging and on treatment verification, it has become easier to monitor the efficacy of a radiotherapy treatment. The robustness of a plan can be directly linked to motion management within the radiotherapy patient pathway - from pre-treatment imaging (DIBH, DEBH, 4DCT) to on-treatment verification (e.g 4DCBCT). What motion can, and should, be corrected for before treatment? How do we ensure that the plans we produce continue to be robust whilst increasing the complexity and accuracy of planning? Is it better to make robust plans up-front or to adapt during treatment?

I will give examples of processes we have put in place in the pre-treatment pathway to ensure correct delivery. These processes have reduced re-plan requirements for certain treatment sites where a patient's motion can be controlled or accounted for, from simple breast tangent plans, to the use of 'planning bolus', to abdominal compression immobilisation. In situations where a patient's motion cannot be controlled or accounted for (e.g lung SABR), we must also strive for robust delivery without increasing PTV margins. Accordingly, we have recently introduced mid-ventilation-based PTV margins for stereotactic lung radiotherapy treatment plans (1). This enables us to minimise the PTV size whilst maintaining adequate tumour coverage. I will demonstrate how we ensure that we are still delivering a suitable treatment to the right place, at the right time.

1. Simon J. Thomas, Barry J. Evans , Lakshmi Harihar , Hannah J. Chantler , Alexander G.R. Martin , Susan V. Harden: An evaluation of the mid-ventilation method for the planning of stereotactic lung plans, Radiotherapy and Oncology 137 (2019) 110–116

# EARLY EXPERIENCE WITH RADICAL BLADDER TREATMENTS ON THE ELEKTA UNITY MR-LINAC

**Frank Brewster[1], Linnéa Freear[1], Simon Meara[1], Katherine Jones[1], Emily Johnstone[1], Claire Nelder[1], Abigael Clough[1], Rebecca Benson[1], Eleanor Pitt[1], Robin Portner[1], Robert Chuter[1,2], Geoff Budgell[1], Phil Whitehurst[1], Joe Beresford[1], Ananya Choudry[1,2]**

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**Background** – The Elekta Unity MR-Linac (MRL) allows for daily treatment plan adaptation based on diagnostic quality MR images. In bladder treatments, the target is highly deformable and can display large degrees of variability in shape and size, making the MRL an ideal treatment tool. The first bladder patient has been treated at the Christie, our experience in commissioning and treating is presented.

**Methods** – Test plans were made for five patient volunteers recruited under an ethically approved study and were independently reviewed by physicists and an oncologist. For two patients, test adaptations were made and also reviewed. The class solution was made based on the departmental bladder VMAT solution using 55Gy in 20#, and the technique already used on the MRL for other pelvic sites using 15 equi-spaced IMRT beams. The primary dataset used was MR with bulk density overrides applied to body and bone only. Adaptation was done using the Adapt to Shape (ATS) workflow with the CTV +/- rectum deformed based on daily anatomy and other structures rigidly translated from the base plan. An initial PTV margin of 1.5 cm was used with a view to reduce this with increased experience.

**Results** – All test plans and adaptations were judged as good quality and clinically acceptable. During the treatment it was noted that:

- The deformation of the CTV was generally of good quality unless bladder size was significantly different to the planned volume.
- The rectum contour rarely required a deformation but was deformed well when this option was chosen and edits were not required.
- The patient was treated after a 2-hours nil by mouth. However, bladder volume still varied significantly. The ATS workflow was able to compensate for this, producing clinically acceptable plans on every fraction. Variability was due to general hydration, patient co-morbidities, compliance and weekly GEM-X infusion.
- During the treatment, radiographers were trained by the attending oncologist in approving or editing the deformed CTV contour. Treatments were then moved to a “clinician-lite” model where the radiographers were responsible for the CTV and rectum contour, with the oncologist no longer attending and instead only being available on site. The clinician was still to be contacted for any dosimetric criteria out of tolerance.
- The PTV margin comfortably accounted for changes during plan adaptation and checking and future work could explore the possibility of reducing this.

**Discussion** – Despite significant inter-fraction changes in the CTV contour, acceptable treatment plans could be achieved by using the ATS workflow and without needing a clinician present. There may be potential to reduce normal tissue dose by reducing the PTV margin.

**Conclusion** – Radical bladder patients can be successfully treated on the MRL with daily adaptation, without requiring daily clinician input.

# An Evaluation of Robustness of Robust Optimised Dual Partial Arc VMAT Plans for IMC Radiotherapy.

Authors:Andrew Bird and Gareth Webster

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Purpose / Objectives: In the UK IMC irradiation is becoming standard of care for breast radiotherapy patients considered at intermediate risk of recurrence. The development of techniques that deliver high plan quality and robustness to motion are challenging. It is important to establish achievable plan quality and robustness to inform best practice before restricting access or treatment options.

Methods / Materials: 7 left and 11 right-sided breast patients were planned on RS v7 or v9 with dual partial arc VMAT for IMC Radiotherapy using a local Class Solution employing RayStation's Robust Optimisation. Breast CTV robustness to lateral and anterior motion of 7.5mm, 10mm and 12.5mm, corresponding to vector lengths of 10.6mm, 14.1mm and 17.7mm were evaluated using RayStation's perturbed dose features. All plans followed standard workflow and met target coverage and OAR criteria, were checked by MPEs, approved by Consultant Oncologists and were delivered in full. Where achievable a voluntary DIBH setup was used.

Results: Robustness evaluation was quantified as breast CTV covered by 95% isodose following a shift. 95% CTV was covered by 95% dose in 18/18 cases for 10.6mm vector shift (range 95.1% to 100%), 15/18 for14.1mm shift (range 85.7% to 100%) and 5/18 for 17.7mm shift (range 62.8% to 99%). All plans achieved 90% dose coverage to 95% of CTV criteria following all shifts (ranges for 10.6mm, 14.1mm and 17.7mm were 99.1-100%, 99.0-100% and 96.4-100% respectively). 105% hotspots of >5% were seen in the same 4/18 cases for all shifts, maximum hotspot volume of 10.2% seen in 1 case for 17.7mm shift. OAR were optimised in all cases and considered clinically suitable.

Conclusion: High quality plans, robust to delivery uncertainties and likely inter and intra-fraction patient shape changes, can be created using partial arc VMAT for both left and right sided breast cohorts. Consideration of patient shifts during optimisation using RayStation's Robust Optimisation planning tools does create plans that evaluate as robust to patient shifts in the clinical context.

**Evaluation of Stereotactic Radiosurgery Plan Robustness to Residual Setup Errors and Geometrical Variations in Linac Performance**

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**Background:** The adoption of zero margin approach for linac-based single-isocenter multitarget stereotactic radiosurgery (SIMR SRS) technique can make plans prone to geometrical uncertainties, especially with increasing distance of metastases from isocenter where any rotational deviations can potentially be amplified. The aim of this study was therefore to evaluate SRS brain plan robustness to residual setup errors and geometrical variations in linac performance when planned using the BrainLAB Elements Multiple Brain Mets treatment planning system.

**Methods:** Residual setup errors for 13 previously treated patients (8 1-fraction patients with a total of 78 metastases and 5 3-fraction patients with a total of 32 metastases) had been extracted from the BrainLAB ExacTrac image-guided radiotherapy (IGRT) system used for setting up these patients. Linac mechanical errors were evaluated by performing 20 consecutive weekly multi-metastases Winston-Lutz (MMWL) measurements. This data was then combined, and the patient CT scans were translated and rotated based on both the median and 90th percentile of the quantified values using 3D Slicer image computing platform. Doses to patients were then recalculated and the impact on target dose coverage was assessed. Of the 110 metastases, 12 had a volume of <0.02cc and required a 0.5mm margin to meet minimum volume requirements of the planning software. These targets were assessed by considering the PTV as a target with no margin (and including this data in the target results below) and also the GTV as the target itself with margins being applied, such that the impact of margins could be evaluated retrospectively.

**Results:** The mean (±stdev) percentage coverage of all targets in the original clinical plans were 99.4% (±0.9%) and 98.9% (±1.0%) for 1 and 3-fraction patients respectively. These were reduced to 99.1% (±1.4%) and 98.1% (±1.8%) in the presence of median geometrical errors (no statistically significant difference from original). The coverage reduced further to 91.4% (±10.4%) and 93.0% (±9.6%) under 90th percentile geometrical errors. The effect of a 0.5mm margin was also evaluated and showed target dose coverage well above 95% even at 90th percentile scenario.

**Discussion:** Applying median geometrical shifts to the patient data did not lead to any notable changes in target dose coverage. The robustness of the plan could in part be due to the fact that dose was delivered from multiple planes. Target dose coverage was substantially worse under the 90th percentile scenario but this was an overestimation of the impact of geometrical uncertainties by applying shifts experienced by worst 10% of the targets to the whole population. Target dose coverage was seen to decline slightly with increased target-isocenter distances and also with smaller metastasis volumes, but the correlation was not strong in either case.

**Conclusion:** Plans have been shown to be robust to typical geometrical uncertainties despite targets having no margins. The margin was also proven to substantially improve the target dose coverage for extremes of uncertainties experienced during treatments.

**Key References:**

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**Radiotherapy plan robustness in clinical practice**

**Abstract:** "A dosimetric evaluation of Velocity deformable image registration of planning CT to cone-beam CT for adaptive photon and proton head and neck treatment planning"

**Author:** Virginia Marin Anaya, University College London Hospitals NHS Foundation Trust

**Aims and Background:** There can be significant changes in patient anatomy during the course of radiotherapy treatment. The aim of this study was to assess whether the adaptive CT generated by Varian Velocity version 4.0 could be used as a decision tool to trigger replanning for photon and proton head and neck treatments.

**Methods:** 10 head and neck patients treated with RapidArc (65Gy and 54Gy in 30 fractions) were selected retrospectively. In Eclipse treatment planning system, the initial plan calculated on the planning CT (pCT) was recalculated on the adaptive CT (dCT) and replanning CT (reCT) using the same settings. Various dose volume histogram (DVH) points were used for the analysis. For protons, the nominal case was used for the comparison. Statistical analysis was performed using IBM SPSS Statistics version 27. A Wilcoxon Signed Rank test between the dCT and the reCT was carried out to determine whether the differences in DVH points for the different volumes and structures between the dCT and the reCT relative to the pCT were statistically-significant. The statistical significance was set at 0.05.

**Results and Discussion:** For both photons and protons, in general, larger median percentage differences between the dCT and the pCT were observed for the structures than for the clinical target volumes (CTVs).

| | | Photons | | | Protons | | |
|---|---|---|---|---|---|---|---|
| Volume or structure | DVH points | dCT | reCT | p-value | dCT | reCT | p-value |
| **CTV1** | **Dmean** | 0.7 (-9.2, 1.3) | 0.9 (-2.2, 2.2) | >0.05 | 0.2 (-1.1, 0.6) | -0.1 (-1.0, 1.3) | 0.695 |
| | **D99%** | 0.1 (-3.8, 1.0) | -0.9 (-6.0, 1.9) | >0.05 | -0.6 (-21.2, 12.8) | -2.2 (-19.0, 6.3) | 0.203 |
| | **D95%** | -0.2 (-1.1, 0.5) | -0.3 (-2.5, 0.6) | >0.05 | -0.4 (-8.3, 0.2) | -1.1 (-8.3, -0.2) | 0.012 |
| | **D2%** | 1.2 (0.0, 3.3) | 1.5 (-0.6, 1.9) | >0.05 | 1.6 (0.0, 2.4) | 2.5 (1.2, 5.4) | 0.008 |
| **CTV2** | **Dmean** | 0.9 (-7.1, 2.7) | -1.2 (-4.3, 2.4) | >0.05 | 0.3 (-0.2, 1.4) | 0.7 (-6.5, 1.8) | 0.625 |
| | **D99%** | -0.2 (-7.1, 1.2) | -3.3 (-6.5, -0.4) | >0.05 | -2.0 (-17.1, 0.0) | -2.7 (-29.3, -0.6) | 0.129 |
| | **D95%** | 0.0 (-1.5, 1.3) | -1.9 (-4.7, 1.1) | >0.05 | -0.5 (-3.8, -0.2) | -1.1 (-6.5, -0.6) | 0.027 |
| | **D2%** | 2.2 (0.0, 6.1) | 0.4 (-0.8, 3.7) | >0.05 | 1.9 (-0.6, 6.4) | 3.3 (-1.4, 9.5) | 0.492 |
| **Brainstem** | **Dmax** | 1.6 (-1.0, 4.1) | 2.2 (0.0, 13.4) | >0.05 | 0.1 (-11.9, 11.9) | 2.8 (-16.4, 15.2) | 0.131 |
| | **D0.1cc** | 1.0 (0.3, 2.5) | 2.3 (0.3, 9.7) | >0.05 | 0.2 (-14.1, 11.4) | 4.0 (-17.9, 14.4) | 0.105 |
| **Spinal cord** | **Dmax** | 2.1 (0.1, 38.1) | 5.6 (0.5, 16.1) | >0.05 | 3.5 (-12.9, 22.7) | 1.1 (-13.7, 21.6) | 0.875 |
| | **D0.1cc** | 2.6 (0.1, 39.4) | 3.5 (0.6, 11.1) | >0.05 | 1.8 (-14.4, 17.9) | 0.7 (-14.3, 18.7) | 0.063 |
| **Left Parotid** | **Dmean** | 0.8 (-3.9, 17.0) | 1.0 (-4.1, 32.0) | >0.05 | 4.1 (-6.5, 38.7) | 6.7 (-6.5, 19.5) | 0.734 |
| **Right Parotid** | **Dmean** | 6.3 (-10.3, 16.4) | 0.8 (-13.9, 22.2) | >0.05 | 14.3 (4.8, 25.4) | 12.0 (-0.2, 21.6) | 0.938 |

**Table1. Dosimetric analysis showing differences in DVH points relative to pCT expressed as a percentage and presented as median value and range between brackets. CTV1 is the high dose clinical target volume and CTV2 is the low dose clinical target volume.**

For photons, our dosimetric analysis suggests that there are no statistically-significant differences in the DVH points for CTVs and structures between the dCT and the reCT relative to the pCT.
For protons, our study suggests that Velocity has a tendency to increase CTV1 and CTV2 D95%, overestimating target coverage. For structures, our study indicates that there are no statistically-significant differences in DVH points between the dCT and the reCT relative to the pCT

**Conclusion:** For both photons and protons, there was no statistically-significant difference in the DVH points of structures between the dCT and the reCT relative to pCT.
Velocity is a promising tool for adaptive photon and proton treatment planning of head and neck cancer.

**VMAT plan complexity reduction by using the Aperture Shape Controller and MU Penalty in Eclipse TPS**

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**Background**. excessive plan complexity may reduce the dose calculation and delivery accuracy [1]. The Aperture Shape Controller (ASC) optimisation tool was first introduced in Eclipse TPS version 15 [2]. This study aims to investigate these optimisation tools in order to reduce VMAT plan complexity and improve robustness.

**Methods.** 8 lung, 6 H&N, 4 brain, 5 prostate and 5 prostate and pelvic nodes (PPN) plans were replanned with different ASC settings and/or MU penalty in the Eclipse optimiser. The coverage to PTVs and dose to OARs were compared between the generated plans with different ASC/MU penalty settings. Several plan complexity metrics were assessed such as the number of MU, modulation complexity score (MCS) and small aperture score (SAS10mm). Patient-specific QC (PSQC) for the Lung plans were carried out on the PTW 1500 ion chamber array for clinical plans and plans with ASC set to low and MU penalty on (ASC-low-MU). PSQC plans were evaluated using 2%/2mm and 1%/1mm local gamma evaluation.

**Results**. On Average, no significant reduction in PTV coverage or increase in OARs doses was observed for different ASC settings for lung, prostate and brain plans. However, there was a slight reduction in PTV coverage and/or an increase in OAR dose for H&N and PPN plans when increasing the ASC strength and activating the MU penalty during plan optimisation. For plan complexity matrices, there was a slight reduction in the number of MU as ASC strength increased. It is more noticeable when MU penalty was switched on. SAS10mm score and MCS results showed a decrease in plan complexity as ASC strength increased. For example, in H&N plans, the average SAS10mm over 6 plans were decreased from about 0.21±0.02 to 0.14±0.03 when ASC was set to moderate and MU penalty was switched on. In lung plans, the average MCS increased from 0.40±0.05 to 0.50±0.06 when ASC was set to high and MU penalty was switched on. The average 1%/1mm and 2%/2mm gamma pass rates were 81.6±6.3% and 97.8±1.9% for clinical plans and 84.7±6.9% and 98.7±1.5% for ASC-low-MU, respectively.

**Discussion.** Plan quality was not affected when ASC and MU penalty optimisation tools were used for lung, brain and prostate plans. For H&N and PPN, plan quality decreased slightly as the ASC strength increased due to the complexity of these plans. In most cases, MUs and plans complexity decreased as the strength of ASC increased. However, the magnitude depends on the treatment site and the complexity of the plan. On average, the PSQC gamma results showed slight improvement for ASC-low-MU compared to clinical plan.

**Conclusion.** In general, plan complexity was reduced by utilising ASC and MU penalty optimisation tools in Eclipse without significantly degrading the target coverage, OAR dose or delivery accuracy. It is recommended to start optimisation using ASC at low setting then increase and/or add MU penalty depending on plan complexity.

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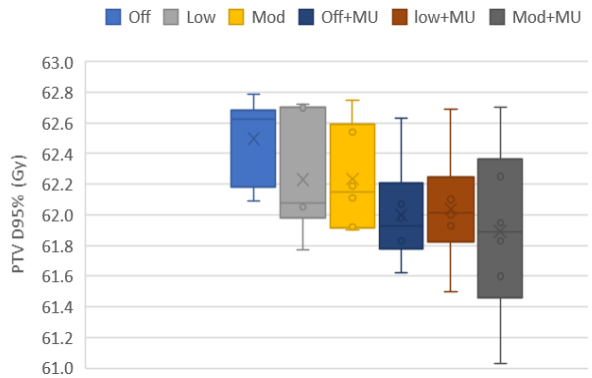
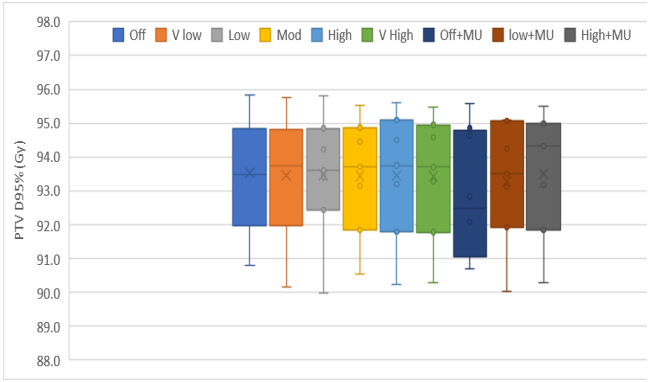
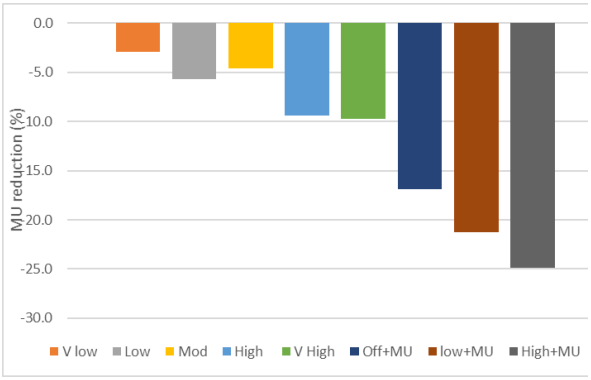


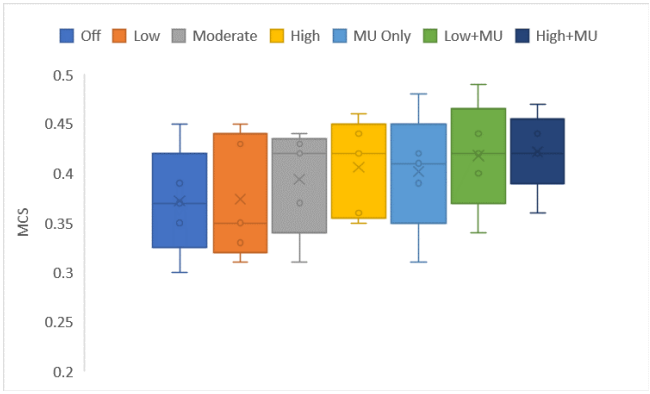

PTV D95% coverage for different ASC and MU penalty settings for H&N plans




PTV D95% coverage for different ASC and MU penalty settings for Lung plans




The percentage MU reduction for different ASC and MU penalty settings for lung plans in comparison to clinical plan.




Modulation Complexity Score for different ASC and MU penalty settings for Prostate plans

**Radiotherapy Plan Robustness in Clinical Practice: Evaluation of Planning Methods Used to Compensate for Increased Fluence at the Surface for Inverse Planned Head and Neck Cancer Treatment**

Julie Kirk, The Clatterbridge Cancer Centre NHS FT

**Abstract**

**Purpose:** In radiotherapy of the head and neck it is common for the clinical target volume (CTV) to extend to the patient's skin. Adding a margin for set-up uncertainty and delivery creates a planning target volume (PTV) that extends beyond the patient surface. For inverse planning this results in excessive fluence being delivered to the build-up region and therefore the skin. There are a number of solutions to compensate for this problem but no consensus in what planning method gives the best solution for optimising in the build-up region for head and neck plans. This study evaluates four different planning methods used to compensate for excessive fluence in the buildup region when planning head and neck cancer treatments using volumetric modulated arc therapy (VMAT). The aim of the study is to determine which planning method gives superior plan quality when considering CTV coverage, skin dose and plan robustness.

**Method:** Ten head and neck cancer patients with a CTV contoured to the skin surface were planned using four different planning methods. The planning methods compared were cropping the optimisation planning target volume (PTV) back from the skin surface by 5.0 mm, 3.0 mm and 0.0 mm and a virtual bolus method. For each planning the method the increased fluence at the skin surface was analysed. The CTV coverage and skin dose were compared. Plan robustness was evaluated by applying an isocentre shift of ±3.0 mm in the principal axes. The effect this shift has on CTV coverage and skin dose was evaluated for each planning method.

**Results:** The planning method of cropping the PTV 0.0 mm from the skin surface results in an increased fluence in the buildup region. Cropping the optimisation PTV reduced CTV coverage. The average volume of CTV receiving 98% of the prescription dose (D98%) was 89.6% when cropping 5.0 mm, 91.6% when cropped by 3.0 mm, 93.5% when cropping 0.0 mm and 93.4% for the virtual bolus plan. Introducing a plan uncertainty effects CTV coverage the most when using the planning method of cropping 5.0 mm. The maximum reduction in D98% averaged over the 10 patients was 4.2% when cropping 5.0 mm, 2.3% when cropped by 3.0 mm, 0.9% when cropping 0.0 mm and 0.7% for the virtual bolus plan. Cropping the optimisation PTV from the skin surface reduces the skin dose. When plan uncertainties are considered the planning methods of cropping 5.0 mm, 3.0 mm and the virtual bolus method all have the same average skin dose within ±0.3%.

**Conclusion:** This study shows that a virtual bolus planning method achieves no increased fluence at the patient's surface, improves CTV coverage and is the most robust to changes in setup and patient anatomy. The study also shows that reducing the amount the optimisation PTV is cropped back from the skin surface improves the plan robustness and improves CTV coverage.

**Title: Investigating the efficacy of robust optimisation and evaluation in clinical Lung SABR planning**

**Authors:** Meagan de la Bastide, Joshua Mason, Ruth McLauchlan (Imperial College Healthcare NHS Trust)

**Background and Objectives:** To evaluate the clinical impact on plan dosimetry of incorporating motion and setup uncertainties into lung SABR plan optimisation and evaluation, in comparison to conventional PTV-based planning.

**Materials/Methods:** A total of 10 patients were selected retrospectively for lung SABR planning, covering a range of tumour locations and dose prescriptions in accordance with the UK SABR Consortium guidelines[1]. For each patient, 3 plans were generated in RayStation V9B using: (i) conventional PTV volume-based optimisation with 5mm ITV-PTV margin, (ii) ITV-based robust optimisation with a 5mm setup uncertainty and (iii) GTV-based robust optimisation including setup uncertainty and internal motion uncertainty using 4DCT image phases. Plan quality was compared using conventional SABR dosimetric parameters. Plan robustness was assessed by (i) re-calculating the dose distribution on each CT phase of the 4DCT dataset and (ii) using robust evaluation to determine the plan pass rate and worst-case-scenario (WCS) dose distribution under specified setup uncertainty. The dosimetric effect of 4D motion on the different plan types was also investigated using the CIRS respiratory phantom.

**Results & Discussion:** Plan quality was assessed on the nominal plan CT, and was found to be comparable across all three planning techniques. All plans resulted in full D99 coverage of the prescription dose (PD) to the GTV in the nominal planning scenario, with the PTV, ITV-robust and GTV-robust plans giving a mean D99 GTV coverage of 114(±2)%, 112(±2)% and 110(±3)% respectively. OAR doses showed no significant correlation to target coverage or optimisation technique used. The most significant influence on OAR dose was relative position to target. No improvement in plan robustness was observed when using robust optimization techniques, with PTV-based and ITV-based plans achieving GTV D99 coverage in the worst-case-scenario in 8/10 patients, and GTV-based plans in 6/10 patients. On average, the WCS GTV D99 was 9(±3)% less than the value in the nominal planning CT, with no dependence on planning technique observed.

Independent to optimisation technique used, the robust evaluation module in RayStation identified several setup error scenarios in which the plan dosimetry failed to achieve either target coverage or OAR constraints. This not only provides a clear measure of plan robustness, but also allows clinicians/planners to evaluate the significance an likelihood of these failing scenarios, better equipping them to make clinical decisions around the patient's treatment.

Dosimetric measurements on the CIRS phantom were performed for 3 patient cases. All measurements were within ±3% of expected doses, with robust plans having smaller percentage dose differences than non-robust plans across the 3 patients. Measurements of more patient cases are required before conclusions can be drawn from the data.

**Conclusion:** No significant difference in plan quality or plan robustness was observed between non-robust and robust optimised plans for the 10 patients used in this study. Robust optimisation planning was found to be more time consuming than PTV-based planning with no apparent benefit to target coverage or OAR dose. The robust evaluation module was a useful tool in plan assessment and would be beneficial to quantify plan robustness for lung SABR.

*[1]Stereotactic ablative body radiation therapy (sabr): A resource. SABR UK Consortium 6.1 (2019). Faculty of Clinical Oncology of The Royal College of Radiologists.*

**Adaptive radiotherapy for prostate cancer: can Multiparametric MRI help?**

Angela Turnbull

Overview

An overview of Multiparametric MRI and the initial results of an investigation into whether it could help support adaptive radiotherapy for prostate cancer will be discussed.

Introduction

The overarching purpose of this research was to investigate whether multiparametric MRI (MP-MRI), involving diffusion-weighted (DW) and dynamic contrast-enhanced (DCE) MRI, can predict or assess response to radiotherapy (RT) and potentially support adaptive radiotherapy for high-risk prostate cancer. This was separated into three complementary studies: (1) investigation of the effect that neoadjuvant androgen deprivation therapy (ADT) has on the DW-MRI apparent diffusion coefficient (ADC) and the pharmacokinetic DCE-MRI parameters $K^{trans}$ ($min^{-1}$), $k_{ep}$ ($min^{-1}$), $v_e$ (%) and IAUGC60 (mmol.s); (2) exploration of whether MP-MRI acquired before or during RT can predict or assess treatment response; (3) assessment of how the radiotherapy plan could be adapted to escalate the dose delivered to a non-responding tumour.

Methods

Five patients, bringing six tumours, diagnosed with high-risk prostate cancer and referred for neoadjuvant ADT and RT were prospectively recruited to have MP-MRI examinations before ADT and before, during and after RT. Reproducibility of the MP-MRI parameters, calculated using Bland-Altman methodology, was used to indicate statistically significant changes. Comparison of MP-MRI parameters (1) between pre-ADT and pre-RT and (2) between pre-RT, during-RT and post-RT MRI scan measurements were analysed. (3) Clinical RT plans used for treatment were adapted by (i) incorporating a simultaneous integrated boost (SIB) for the whole treatment and (ii) by introducing a second treatment phase to escalate the tumour dose to 83Gy, (i) and (ii) were repeated for 90Gy tumour dose escalation.

Results

Study reproducibility compared favourably with similar published data. (1) Differences in pre-ADT baseline MP-MRI parameters were observed between benign and malignant tissues, these values agreed with the literature. Statistically significant changes were recorded at the pre-RT MRI, particularly in $v_e$. (2) Statistically significant changes in $K^{trans}$, $k_{ep}$ and $v_e$ were indicated for several during-RT and post-RT MRI measurements, the median $K^{trans}$, $k_{ep}$ and IAUCG60 values were lowest before radiotherapy and highest during radiotherapy. (3) It was generally possible to escalate the tumour dose to 83 Gy and 90 Gy using both adaptive approaches without significant increase in organ at risk (OAR) dose.

Conclusion

These early results suggest that it may be feasible to predict or measure poor high-risk prostate tumour response to neoadjuvant androgen deprivation therapy and radiotherapy using MP-MRI. Subsequent adaption of the radiotherapy plan to deliver an increased tumour dose with the aim of improving outcome also appears to be possible.