Journal of Radiotherapy in Practice

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Utilising virtual bolus in superficial planning target volume dose optimisation (TomoTherapy): a phantom study

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Original Article

Cite this article: Ooi GC and Bin Mustafa IS. (2020) Utilising virtual bolus in superficial planning target volume dose optimisation (TomoTherapy): a phantom study. *Journal of Radiotherapy in Practice* **19**: 65–70.
doi: 10.1017/S1460396919000438

Received: 28 April 2019
Revised: 26 May 2019
Accepted: 27 May 2019
First published online: 20 June 2019

Keywords:
IMRT; Superficial Target; Superficial PTV; TomoTherapy; Virtual Bolus

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Abstract

Aim: This is a phantom study to evaluate the dosimetry effects of using virtual bolus (VB) in TomoTherapy Treatment Planning System (TPS) optimisation for superficial planning target volume (PTV) that extends to the body surface. Without VB, the inverse-planning TPS will continuously boost the photon fluence at the surface of the superficial PTV due to lack of build-up region. VB is used during TPS optimisation only and will not be present in actual treatment delivery.

Materials and methods: In this study, a dummy planning target was contoured on a cylindrical phantom which extends to the phantom surface, and VB of various combinations of thickness and density was used in treatment planning optimisation with TomoTherapy TPS. The plans were then delivered with the treatment modality TomoTherapy. Radiochromic films (Gafchromic EBT3) were calibrated and used for dose profiles measurements. TomoTherapy Planned-Adaptive software was used to analyse the delivered Dose-Volume Histograms (DVHs).

Results: The use of 2 mm VB was not providing adequate build-up area and was unable to reduce the hot spots during treatment planning and actual delivery. The use of 4 mm VB was able to negate the photon fluence boosting effect by the TPS, and the actual delivery showed relatively small deviations from the treatment plan. The use of 6 mm VB caused significant dose overestimation by the TPS in the superficial regions resulting in insufficient dose coverage delivered.

Findings: VB with the combination of 4 mm thickness and 1·0 g/cc density provides the most robust solution for the TomoTherapy TPS optimisation of superficial PTV.

Introduction

TomoTherapy (Accuray Inc, Sunnyvale, CA) is a unique Intensity-Modulated Radiation Therapy (IMRT) dedicated treatment modality in which 6 Mega-voltage (MV) photon treatment beam is delivered in a slice-by-slice manner, where the patient is simultaneously moved into the gantry bore at a predetermined constant speed while the gantry is rotating and delivering radiation dose modulated by binary Multi-Leaf Collimators (MLC) leaves at a fixed jaw size.[1]

Superficial target refers to the planning target volume (PTV) that is close to the body surface or extends up to the body surface. IMRT optimisation of superficial PTV becomes challenging due to the lack of build-up region for the 6 MV photon beam. Without any intervention during treatment planning, the inverse-planning TomoTherapy treatment planning system (TPS) will continuously boost the photon fluence at the surface of the superficial PTV in order to achieve the dose coverage. Virtual Bolus (VB) is a structure used only during treatment planning in TPS and it is not present in actual dose delivery. International Commission on Radiation Units and Measurements (ICRU) Report 62 suggested the use of artificial build-up material at the skin during optimisation but not in the actual treatment, known as the VB method.[2]

There are only a few studies related to the use of VB for IMRT treatment planning optimisation for superficial PTV. Tyran et al. studied on the safety and benefit of using VB in breast IMRT planning; the study showed improved dose coverage and lower organ at risk (OAR) doses compared to the plans optimised without VB.[3] The use of VB in optimising total body irradiation (TBI) treatment plan allows larger margin for setup error with compromised yet acceptable reduction in dose coverage and increase in global dose. The use of VB will negate the photon fluence boosting phenomenon produced by the TPS at the superficial target regions, hence giving a more homogenous treatment plan. However, this will create uncertainties in the actual delivery because there is no presence of bolus during actual treatment.[4] There was a study which compared an alternative to the use of VB by reducing the PTV contour at a fixed distance from the body surface; it was shown to be not feasible as reducing PTV contour will cause reduction in

actual dose coverage. The study showed VB is the superior solution.[5] There is, however, limited data for the direct dosimetric effects of VB utilisation.

The primary aim of this research is to determine the optimal thickness and density of the VB used for the TomoTherapy optimisation of superficial PTV. This study characterises the VB in terms of its assigned thickness and density by comparing the optimisation results with the actual delivery measurements. The dose profiles of the actual delivery plans were measured using radiochromic films in a cylindrical phantom. The parameters of planning dose-volume histogram (DVH) were compared with the delivered DVH that were recalculated based on the acquired mega-voltage computed tomography (MVCT) scans. The MVCT was acquired prior to the treatment delivery for image guidance and dose recalculation.

Materials and Methods

A cylindrical phantom was simulated using Somatom Sensation Open (Siemens Medical Solutions, Erlangen, Germany) Computed Tomography (CT) scanner with departmental protocol of 120 kVp and 250 mAs. The CT images were imported in Oncentra MasterPlan® v4.5.3 (Nucletron BV, Veenendaal, Netherlands) software for contouring of the PTV and VB. The PTV was simply a dummy rectangular cuboid structure that extends up to the phantom surface. Two PTVs with exactly the same volume (70 cc) were delineated, with PTV A situated more superiorly than PTV B. Two VBs were contoured at the surface of PTV A and PTV B, respectively. The VBs were created in three thicknesses of 2, 4 and 6 mm. The VB for PTV A was assigned with 0·5 g/cc density, while the VB for PTV B was assigned with 1·0 g/cc density.

The contours delineated were exported to the TomoTherapy TPS v2.1.2 (Accuray Inc, Sunnyvale, CA) software. Four TomoTherapy plans were created, one being the control set and three other plans were optimised with the three respective VB thickness. All the experimental sets were prescribed to 15 Gy in ten fractions to the median of PTV A, and optimised using the same parameters of 2·5 cm jaw size, 0·43 pitch and 2·4 modulation factor.

Gafchromic EBT3 films (Ashland Specialty Ingredients, Bridgewater, NJ) were used in this study. The EBT3 were handled appropriately as described by Borca et al.[6] One piece of EBT3 film was cut into 12 equal size films to construct a film calibration curve of 0–2·5 Gy. The films were irradiated with known radiation doses, and then scanned after 2 hours of post-irradiation using Vidar® Dosimetry Pro Advantage™ (VIDAR Systems Corporation, Herndon, VA, USA) red channel film scanner. The corresponding film pixel values and irradiated doses were computed into TomoTherapy Film Analyzer software to construct the film calibration file.

The phantom setup position was corrected to the best possible registration match using image guidance through TomoTherapy's MVCT scan, known as the best setup in this study. The MVCT scan range included the whole phantom, so that it can be used for dose recalculation by the TomoTherapy Planned Adaptive v2.1.2 (Accuray Inc, Sunnyvale, CA) software. Langen et al. studied on the MVCT recalculations using TomoTherapy Planned Adaptive software and concluded that the dosimetric endpoints varied by less than 2% in general.[6] A quarter of EBT3 film was used as depicted in Figures 1 and 2 to measure the dose profile for each experimental set.

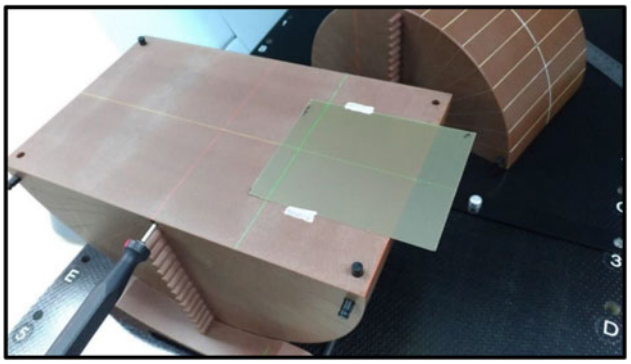

Figure 1. Position of the EBT3 Film.

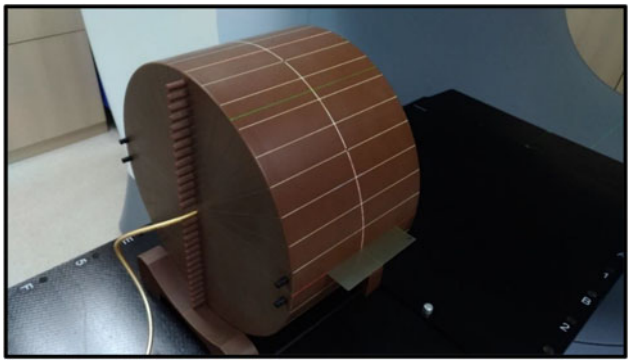

Figure 2. The actual setup of the experiment. Ready to perform pre-treatment MVCT verification and then irradiation.

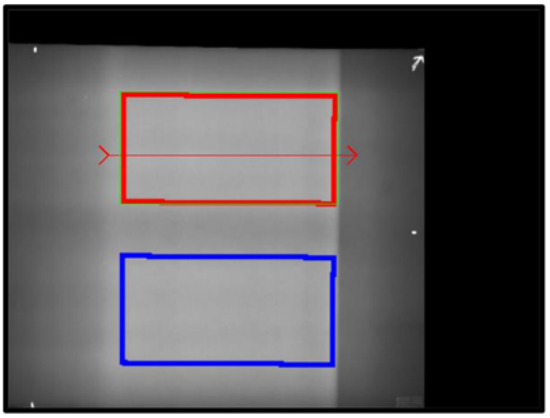

Figure 3. EBT3 film scanned after 2 hours of post-irradiation, the red contour is PTV A while blue contour is PTV B.

Figure 3 shows one of the irradiated EBT3 films which covered both PTV A and PTV B, it was scanned after 2 hours of post-irradiation. The post-irradiation development of the EBT3 film was observed to be stable after 2 hours.[7] The scanned film is applied with the film calibration file to convert all the pixel values to absorbed doses. Five measurements of the central dose profiles were taken for PTV A and PTV B, respectively, for each plan. The standard error was calculated, and uncertainty of 1·96 times the standard error was used in this study indicating 95% confidence limit for the values reported in this study.[8]

https://doi.org/10.1017/S1460396919000438 Published online by Cambridge University Press

Table 1. Planning DVH data from Tomotherapy TPS

		Planning DVH results (%)				
		D_{max}	$D_{2\%}$	D_{min}	$D_{98\%}$	$V_{95\%}$
Control set	Ctrl-A	108·89	105·95	94·14	97·37	99·99
	Ctrl-B	109·00	105·75	94·15	97·28	99·97
Set 1 (2 mm VB)	1-A	109·56	106·91	94·78	97·32	99·99
	1-B	108·83	105·75	94·98	97·09	99·99
Set 2 (4 mm VB)	2-A	104·34	103·00	95·03	97·32	100·00
	2-B	103·57	102·57	95·55	97·06	100·00
Set 3 (6 mm VB)	3-A	103·27	102·49	94·96	97·46	99·99
	3-B	103·50	102·49	95·67	97·41	100·00

After evaluating the results from the delivery at best setup, the plan optimised with 4 mm VB (Set 2) was observed to provide the best solution. Set 2 was then experimented again, by deliberately shifting laterally towards the high radiation fluence region with 1, 2 and 3 mm shifts. The shifts were accomplished through TomoTherapy's MVCT image guidance by deliberately adding the specific shift distance to the image registration of the best setup.

Results

TPS plan optimisation

The dose coverage $V_{95\%}$ and near minimum dose $D_{98\%}$ were relatively similar for all the plans optimised with or without VB. However, without the use of VB (Control Set), the surface of the PTVs was covered with hot spots above 105%. The plan optimised with 2 mm VB was ineffective in reducing the hot spots. When 4 mm VB is used, the near maximum dose $D_{2\%}$ was reduced to 103·00 and 102·57% for PTV A and PTV B, respectively. The density of the VB assigned to PTV A was 0·5 g/cc and PTV B was 1·0 g/cc. The plan optimised with 6 mm VB showed reduced hot spots too; the $D_{2\%}$ was 102·49% for both PTV A and PTV B. The planning DVH data for all the plans are tabulated in Table 1.

Planned versus delivered dosimetry

The central dose profiles measured for all the experiment sets are plotted as shown in Figure 4. Figures 4a and 4b show that the planned and delivered dose profiles were relatively similar, which is expected since there was no VB used during optimisation for both the control sets. Figure 4c shows relative similar profiles too, where there was over-fluence photon peak observed. Figure 4d for Set 1-B shows a lower peak for the delivered dose profile compared to the planned dose profile. The maximum dose D_{max} measured by EBT3 for Set 1-B was 104·24 ± 0·81% but the optimised D_{max} was 108·83%. Figure 4e for Set 2-A shows a relatively homogenous profile with minimal increase in the peak at the phantom edge, and the measured profile fits relatively well with the computed planned profile. The D_{max} measured by EBT3 for Set 2-A was 103·27 ± 0·56%, the TPS optimised D_{max} was 104·34%. In Figures 4f–h for Set 2-B, although the over-fluence peak was not present, the measured profiles showed significant reduction in dose coverage at the phantom edge.

Figures 5–7 show the DVH parameters for the optimised and delivered plans. The delivered DVHs were reconstructed from the MVCT acquired prior to treatment delivery; the recalculations were performed by TomoTherapy Planned Adaptive software. Error bars of 1% are displayed for all the plotted data in Figures 5–7. The $D_{2\%}$ for the planned and delivered plans was well within 1% except for Set 1-B. The $D_{98\%}$ and $V_{95\%}$ showed good agreement for the plans from Control Set up to Set 2-A. There was significant reduction for the $D_{98\%}$ and $V_{95\%}$ of Set 2-B and Set 3 when 4 mm VB with 1·0 g/cc density and 6 mm VB was used for the respective plan.

Optimisation of superficial PTV with the use of VB of 4 mm with 0·5 g/cc assigned density (Set 2-A) showed the best results when measured for the best setup. The plan for Set 2 was further experimented with lateral shifts to the higher photon fluence regions. Figures 8 and 9 show the measured central dose profiles for Set 2-A and Set 2-B, respectively, at 1, 2 and 3 mm shifts. The D_{max} measured with EBT3 for the plan of Set 2-A at best setup was 103·27 ± 0·56%, and for 1, 2 and 3 mm shifted setup were 106·69 ± 0·58, 109·96 ± 0·97 and 109·92 ± 0·82%, respectively. The D_{max} measured with EBT3 for the plan of Set 2-B at best setup was 103·31 ± 0·70%, and for 1, 2 and 3 mm shifted setup were 102·49 ± 0·80, 102·85 ± 0·49 and 103·41 ± 0·61%, respectively.

Figures 10 and 11 illustrate the change in $D_{2\%}$, $D_{98\%}$ and $V_{95\%}$ for Set 2-A and Set 2-B, respectively, at 1, 2 and 3 mm shifted setups. Based on the reconstructed DVHs, the $D_{2\%}$ of the delivered plans for Set 2-A increased from 102·91 to 106·54, 108·69 and 110·33% for 1, 2 and 3 mm shifted setups, respectively. The $V_{95\%}$ and $D_{98\%}$ for Set 2-A were relatively unchanged for the shifted setups compared to the best setup. For Set 2-B, the $D_{2\%}$ remains relatively unchanged for the shifted setups compared to the best setup but the $V_{95\%}$ increased from 96·33 to 99·85, 99·96 and 99·94% for 1, 2 and 3 mm shifted setups, respectively. The $D_{98\%}$ also increased from 92·52 to 96·57, 96·69 and 96·56% for 1, 2 and 3 mm shifted setups, respectively.

Discussion

For superficial PTV, the challenge in TomoTherapy TPS dose optimisation arises due to the lack of build-up regions for the photon beam. With the inverse planning algorithm, the TPS will continuously boost the photon fluence around the superficial target volumes in order to achieve the specified dose coverage.[9] The plan optimisation stage of this study showed the use of 2 mm VB is insufficient to provide an adequate build-up region. The use of 4 and 6 mm VB was able to produce optimised plans with D_{max} and $D_{2\%}$ below 105%. This shows that virtual build-up depth of 4 mm and above is sufficient. The density assigned to the VB had minimal impact during plan optimisation as the planning DVH results for PTV A and PTV B showed no significant differences.

The utilisation of VB introduces discrepancies in actual dose delivery because there is no physical bolus used in actual delivery. The build-up region that the TPS took into account for calculation and optimisation is absent during the actual delivery. The $D_{2\%}$ calculated from the TPS plans was relatively consistent for the delivered plans except for Set 1-B where 2 mm VB with 1·0 g/cc was used. The TPS overestimated the $D_{2\%}$ for Set 1-B by 3·27%. The $D_{98\%}$ and $V_{95\%}$ were also overestimated by the TPS for Set 2-B and Set 3 when VB of 4 mm with 1·0 g/cc density and 6 mm VB were used. When VB with adequate thickness is utilised during dose optimisation, the TPS assumes there is sufficient matter in the

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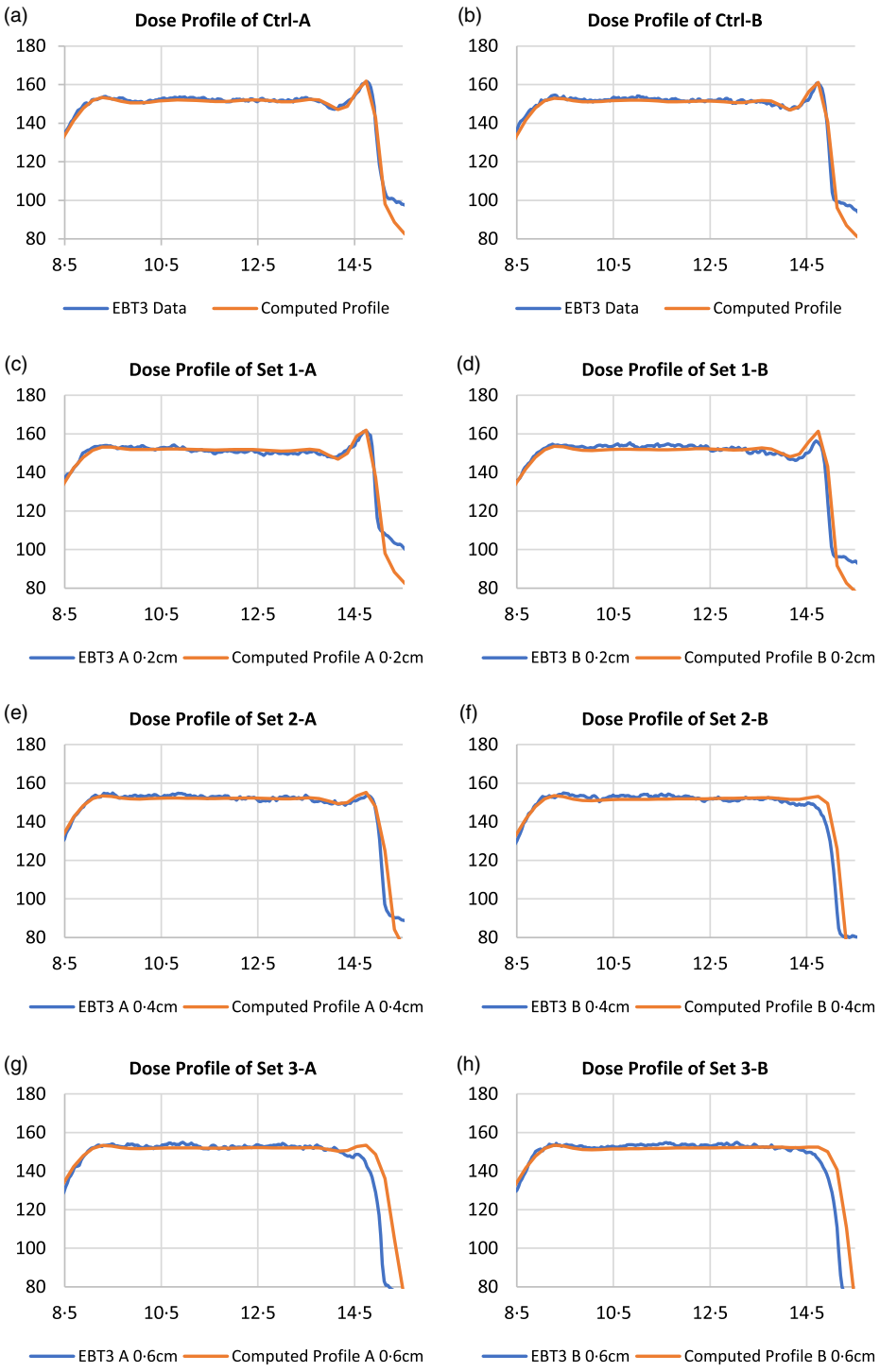

Figure 4. Central dose profiles for all the plans at best setup.
[Note: Y-axis Absolute Dose (cGy), X-Axis Lateral Distance (cm)].

photon paths for energy deposition and hence the photon fluence was significantly reduced to achieve the similar dose coverage. However, the use of 6 mm VB showed significant reduction in the delivered dose measurement for the PTV at the phantom edge. Overcompensation of virtual build-up depth resulted in insufficient photon fluence assigned by the TPS to achieve the desired dose coverage in actual delivery. VB of 2 mm was insufficient while VB of 6 mm was overcompensating for the lack of build-up region.

Following the results analysed for the plans at best setup, in which Set 2-A that uses the VB of 4 mm with 0·5 g/cc combination showed the best solution, it was decided that Set 2 to be experimented again with lateral shifts towards the higher fluence region. The space next to the superficial PTV at the phantom edge was assumed to be the higher fluence region. The $D_{2\%}$ increased by approximately 2% with every 1 mm shift towards the higher fluence region for Set 2-A while it remained relatively consistent for Set 2-B up to 3 mm shifts. The $D_{98\%}$ and $V_{95\%}$ for Set 2-A remained consistent for best setup and up to 3 mm shifts. The $D_{98\%}$ and $V_{95\%}$ for Set 2-B increased by approximately 4 and 2·5%, respectively, for 1 mm, and remained consistent thereafter at 2 and 3 mm shifts.

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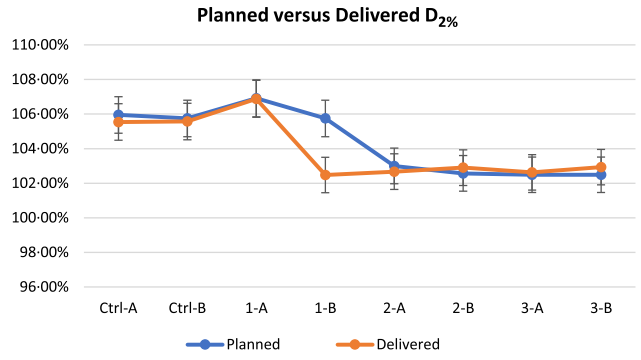

Figure 5. Near maximum dose $D_{2\%}$ of planned and delivered for all the plans. (Note: 1% error bar).

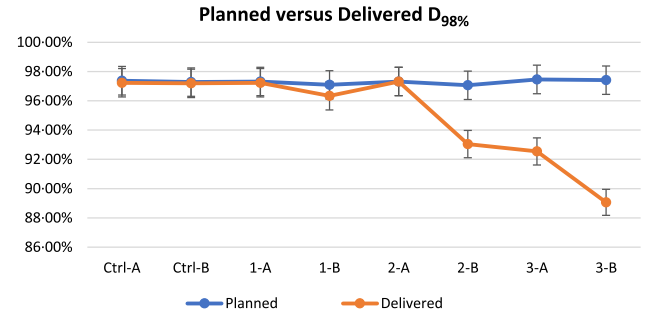

Figure 6. Near minimum dose $D_{98\%}$ of planned and delivered for all the plans. (Note: 1% error bar).

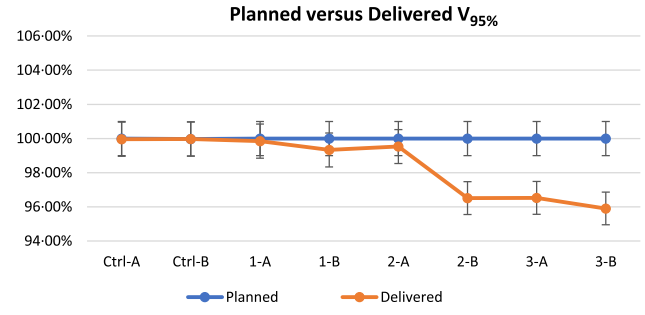

Figure 7. Dose coverage $V_{95\%}$ of planned and delivered for all the plans. (Note: 1% error bar).

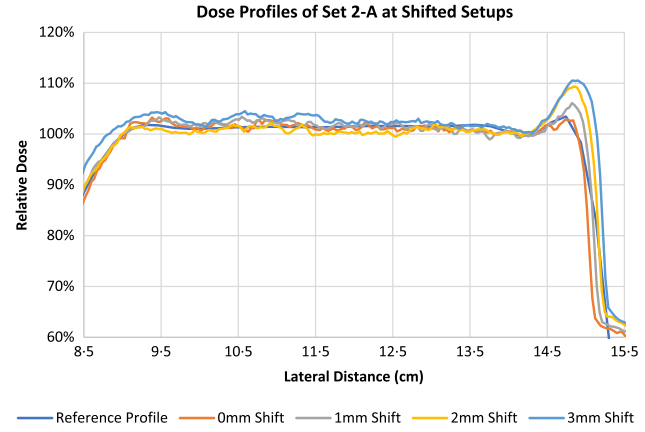

Figure 8. Central dose profiles for the delivered Set 2-A at lateral shifts.

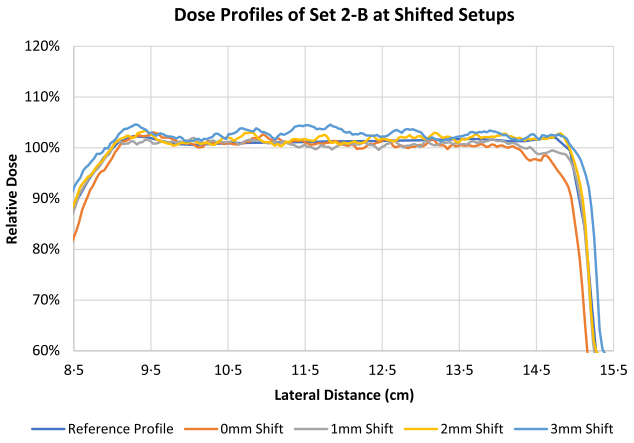

Figure 9. Central dose profiles for the delivered Set 2-B at lateral shifts.

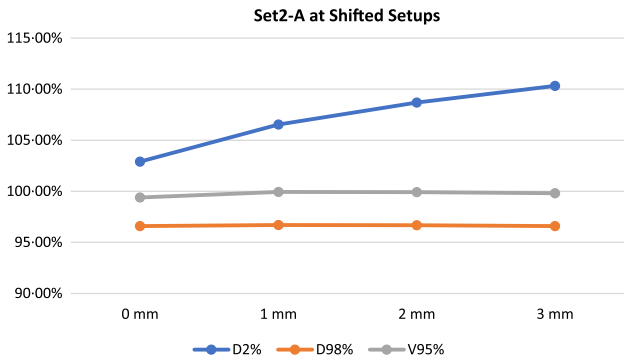

Figure 10. Delivered DVH parameters for the delivered Set 2-A at lateral shifts.

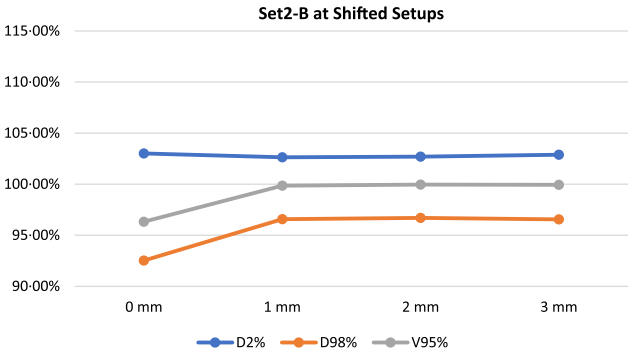

Figure 11. Delivered DVH parameters for the delivered Set 2-B at lateral shifts.

At best setup, the results for Set 2-A showed the least discrepancies between planning and actual delivery, and it seemed to be ideal. However, when lateral shifts were applied, it was shown that the photon fluence at the phantom edge was significantly higher than when 1·0 g/cc VB was used. This implied that the VB combination of 4 mm with 1·0 g/cc provided a more robust solution to the optimisation of superficial PTV.

The findings of this study can be used as a guide for the dosimetrists to consider in using VB of 4 mm with 1·0 g/cc assigned density for IMRT optimisation of superficial PTV or target volume that extends to the patient's body. Clinics should only use this as a guide and perform due diligence for verifications of this technique.

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Conclusion

The optimal thickness and density of the VB to be used for the optimisation of superficial PTV using TomoTherapy are 4 mm and 1·0 g/cc, respectively. The use of this VB combination was able to maintain the dose coverage $V_{95\%}$ above 95% and D_{max} below 105% in actual delivery. It was also shown to be robust enough to account for shifts into the higher fluence region up to 3 mm with no increase in hot spots.

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Acknowledgements. None.

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