Initial evaluation of modulated electron radiotherapy using customised 3D printed bolus

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INTRODUCTION

Electron radiotherapy (ERT) is particularly useful in treating superficial tumours where the maximum sparing of deep underlying normal tissue is required. ERT treatment planning is usually limited to varying the treatment beam angle, energy and field shape. An additional mechanism to modify the treatment plan involves the placement of uniform thickness bolus on the patient surface which increases the dose to the superficial part of the tumour volume and helps reduce the dose to the underlying normal tissues. However, the degree to which the dose conforms to the deeper section of the target is often poor. The consequence is that electron therapy often delivers an unnecessarily high dose to immediately underlying structures. Improving plan quality by overcoming these ERT limitations can be achieved by implementing Modulated Electron Radiation Therapy (MERT). Implementing MERT would typically involve modifying the linac head which is expensive and disruptive to undertake. An emerging alternative offering a cost-effective means to implement MERT is to produce modulated thickness bolus created using dedicated software (3DBolus^{TM}) and printed using a 3D printer with specialised materials specifically designed for radiotherapy treatments.

3D PRINTER

The AirWolf Axiom 20 3D printer was used to print each bolus using Wolfbend filament. Each bolus was printed using a 0.5mm nozzle with 100% fill selected. Wolfbend used a layer height of 0.3mm, print temperature of 250°C and a bed temperature of 60°C. Due to the flexible nature of each filament, the print speed was reduced to 40mm/s with retraction tuned to ensure pressure build-up at the printer nozzle did not result in the filament jamming. Print settings were saved in a print material "profile" to enable users to quickly set the most appropriate settings for the filament and bolus required.

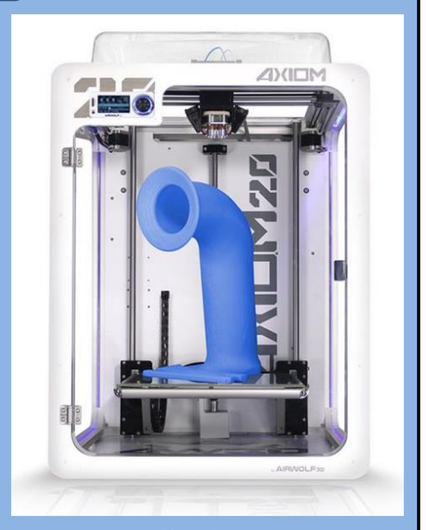


Figure 1. AirWolf Axiom 20 3D Printer

METHODS

Several MERT test cases and two clinical cases were evaluated. MERT bolus was generated and compared with plans created by our institution's standard planning protocol where each PTV was covered by at least the 90% isodose. Plans were compared by evaluating dose conformity of the prescription isodose, target homogeneity, volume of 90% isodose outside the PTV and the dose to any underlying OAR structures. Three of the test cases are shown below (A, B and C), demonstrating the different clinical scenarios that may benefit from MERT. The two clinical cases represent two scenarios where the underlying OAR (D) or shape of the PTV (E) justified the use of a modulated approach.

The workflow used to obtain a Modulated Electron Bolus (MEB) can be seen in Figure 2. Electron plans were initially created in Varian Eclipse^{TM} (Varian Medical Systems, Palo Alto, CA) and calculated using Eclipse's Electron Monte Carlo algorithm such that the prescription isodose covered the entire PTV. The plan, structure set and CT images were then exported along with the 90% isodose to a software package called 3DBolus for optimisation. 3Dbolus considers the bolus thickness, the shape of the PTV, any inhomogeneity within the calculation volume and the prescription isodose when optimising the thickness of the bolus structure. A second or third iteration was used when required to minimise hotspots or further optimise the resultant dose distribution.

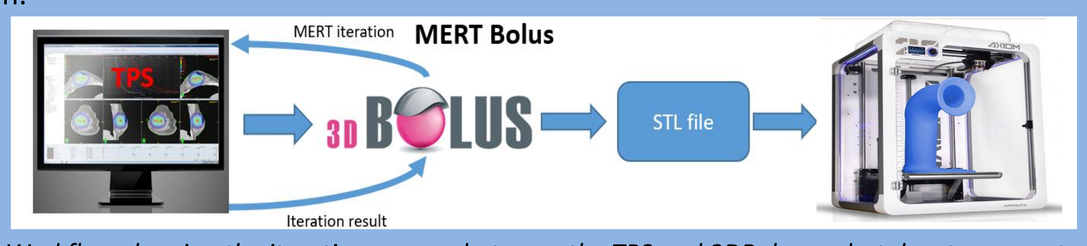


Figure 2. Workflow showing the iterative process between the TPS and 3DBolus undertaken to generate an STL file suitable for printing.

The optimiser works on an algorithm previously described by Su et al. Ray lines are traced from the virtual source to each point on the grid, and extended to both the distal side of PTV (T1) and 90% isodose surfaces (T2). The effective shift of bolus thickness (SBT) of a certain point p along a ray trace from the electron virtual source is given by the formula in Figure 3. For ray lines intersecting the PTV, the distance $z = T_1\text{-}T_2$ is calculated. The coefficient of equivalent thickness (CET) is used to scale z to obtain an effective distance. This ensures the thickness of bolus surface to distal edge of the target remains consistent. Several subsequent operators described by Su et al further modify the optimised bolus to improve coverage and reduce hotspots.

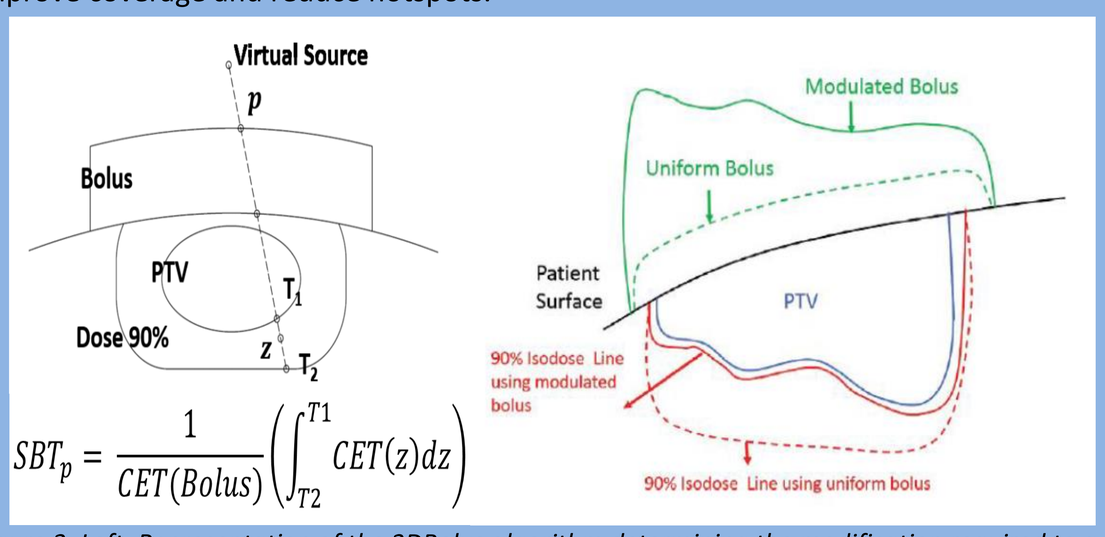


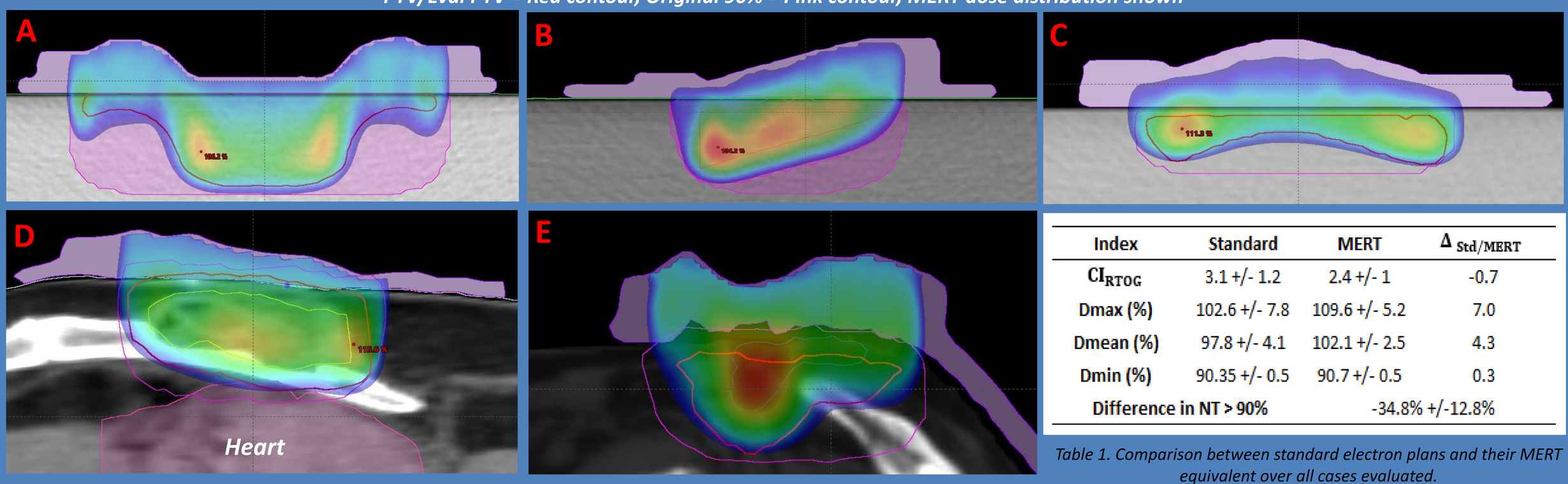
Figure 3. Left: Representation of the 3DBolus algorithm determining the modification required to a bolus structure along ray line shown, reproduced from Su et al (2014). Right: Final result of an optimisation compared to original electron plan, reproduced from 3dbolus.com.

RESULTS

Each plan was covered by the 90% isodose before and after optimisation. Dose conformity improvements were found in all MERT cases with an average CI_{RTOG} of 2.4 +/- 1 for MERT cases vs. 3.1 +/- 1.2 for the standard electron cases evaluated. An overall reduction in normal tissue receiving at least 90% of the prescription dose (NT > 90%) was also found for each case. The reduction in NT > 90% ranged from 18-50% for the "ideal" test cases (A-E). However, similar reductions in NT >90% of 24% (D) and 45% (E) were found for the clinical cases evaluated. For all cases evaluated, the target d_{max} was found to increase as a trade-off for improved conformity and underlying OAR sparing. We found that the greater the modulation required, the higher the d_{max} of the final MERT plan. The largest hotspot (114.8% within the GTV) was found in clinical case "E" as the plan required significant modulation due to the depth (3.7cm) and complex shape of the PTV. This case required three iterations where the other cases (A-D) required a maximum of two iterations.

Implementation Test Cases

PTV/Eval PTV = Red contour, Original 90% = Pink contour, MERT dose distribution shown



Index	Standard	MERT	$\Delta_{Std/MERT}$
CI_{RTOG}	3.1 +/- 1.2	2.4 +/- 1	-0.7
Dmax (%)	102.6 +/- 7.8	109.6 +/- 5.2	7.0
Dmean (%)	97.8 +/- 4.1	102.1 +/- 2.5	4.3
Dmin (%)	90.35 +/- 0.5	90.7 +/- 0.5	0.3
Difference in NT > 90%		-34.8% +/-12.8%	

Table 1. Comparison between standard electron plans and their MERT equivalent over all cases evaluated.

DISCUSSION AND CONCLUSION

We found that modulated bolus improved our electron planning capabilities and provided preferable plans compared to our standard electron planning approach. The result is a customized dose distribution within the patient that both conforms to all parts of the target volume and further minimizes dose to any distal organs at risk compared to standard electron planning approaches. However, this comes at a trade-off of a higher plan d_{max} compared to the standard electron approach. Compared to other bolus fabrication techniques, the patient was not required to attend for the bolus fabrication offering practical advantages in the clinic. The additional time required to export the plan, optimise and import the new bolus structure was minimal compared to the benefits observed.

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