A novel hotspot correction algorithm in Modulated Electron Radiation Therapy (MERT) utilizing 3D printed boli

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PURPOSE

Treating superficial tumors with megavoltage electron beams often requires usage of water equivalent bolus material for shifting the dose build-up region to the surface of the patient. Utilizing 3D printed boli not only improves physical fitting to the patient, but improved conformity of the prescribed dose to PTV can be achieved by further modulating the bolus shape. In Modulated Electron Radiation Therapy (MERT) the shape of the bolus is being optimized resulting in a 3D printed non-uniform thickness device which ultimately modulates the electron beam conforming the prescribed dose to the distal part of the PTV (Figure 1).

However, employing modulated electron bolus (MEB) may introduce a certain trade-off between the resulting dose conformity and homogeneity to the PTV due to the scattered component of the electron radiation originating from the modulated surface of the bolus.

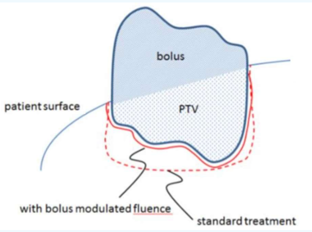


Figure 1 - Modulated Electron Radiation Therapy (MERT)

Since beam energy, field aperture, optimization of the plan and bolus material are all pre-set for a particular electron treatment plan, the shape of the modulated surface of the bolus represents a feature preferred to be further optimized resulting in less scattered radiation and the overall reduction of hot-spots while maintaining the level of dose conformity of the original MEB treatment plan.

MATERIALS & METHODS

The hot-spot correction algorithm employed in MERT treatment planning (Figure 2) essentially works as follows :

(a) Hotspots are identified within the TPS and converted into contours upon which the algorithm determines a search area, i.e. a margin around designated hotspots near which the correction of the surface of the MEB will occur.
(b) A "topographic map" of the MEB contours is created patient-surface outward, identifying peaks and its bases. Intersections between projections of hot-spot search areas and bases of the peaks are then found. If a base of the peak and a hot-spot search area intersect, that particular peak is of interest to undergo the scaling process.
(c) A user-selected peak-to-valley ratio (scaling function) is applied for the reduction of designated peaks.

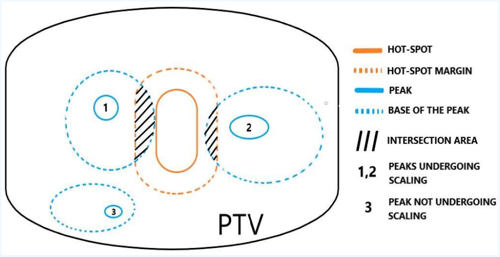


Figure 2: Determining the MEB peaks undergoing scaling within the hot-spot correction algorithm

Overall, 6 data sets (5 phantom and 1 patient) were studied using simple bolus (5mm), MEB and hot-spot corrected MEB with different peak-to-valley ratios which were generated in 3D Bolus software (Adaptiiv Medical Technologies, Inc.) according to the workflow presented in Figure 3. All plans were calculated using electron Monte Carlo algorithm (Eclipse, Varian Medical Systems, Palo Alto, CA). A 12 MeV electron beam, a volume-based optimization (D90% to V99.9%) and SSD=105cm were used in all RT treatment plans. Influence of different peak-to-valley ratios of the hot-spot corrected MEBs was evaluated concerning clinical plan parameters such as maximum, minimum and mean dose to the PTV, conformity and homogeneity indexes.

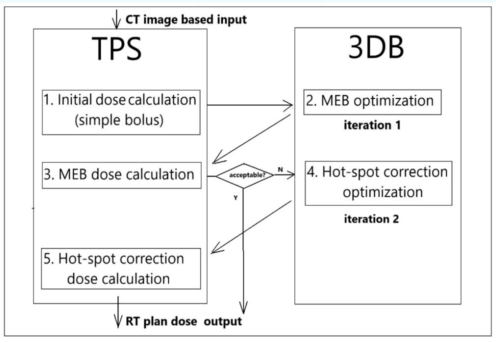


Figure 3: Clinical workflow for MERT treatment planning using a standard TPS and 3D Bolus software with the new hot-spot correction algorithm

RESULTS

In all 6 data sets, plans with a simple bolus (5mm) resulted in the conformity index ranging between 2.07 and 4.05 [Graph 1] while the homogeneity index was generally maintained close to 0.1 [Graph 2].

When MEBs were employed, conformity index was significantly improved in all plans ranging from 1.53 to 2.81 [Graph 1]. However, homogeneity index regressed in all MEB plans compared to simple bolus cases, ranging from 0.25 to 0.46 [Graph 2], yielding hot-spots to PTV ranging from 112.8% to 131.3 [Graph 3].

In all 6 data sets, plans with hot-spot corrected MEB were calculated using peak-to-valley ratios of 0% (maximally reduced peaks), 20%, 40%, 60% and 80% (minimally reduced peaks) and its influence on clinical plan parameters is summarized in Table 1 for the "Phantom case 1". In Graphs 1-3 and Figure 4, one plan with hot-spot corrected MEB was presented per data set, yielding a conformity index comparable to the original MEB plan while resulting in homogeneity index comparable to the corresponding simple bolus plan. Clinically acceptable and favourable levels of both dose conformity and homogeneity were achieved in presented MERT cases using the new hot-spot correction algorithm.

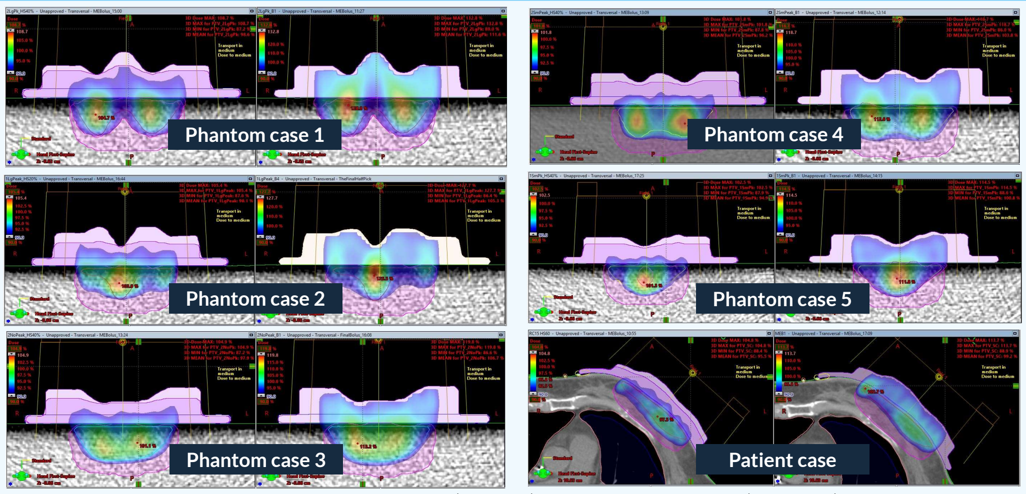
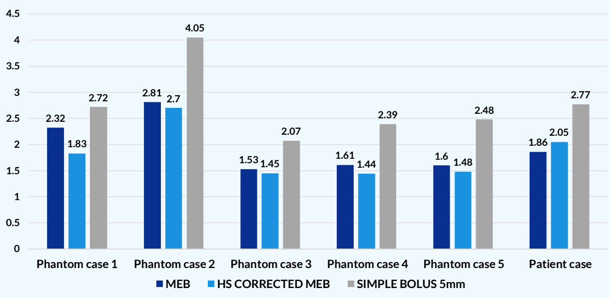


Figure 4: Comparison of hot-spot corrected MEB (left side) and original MEB plans (right side); Dose colourwash was set to 90% in all plans. Magenta RT structure represents a 90% isodose in all simple bolus plans

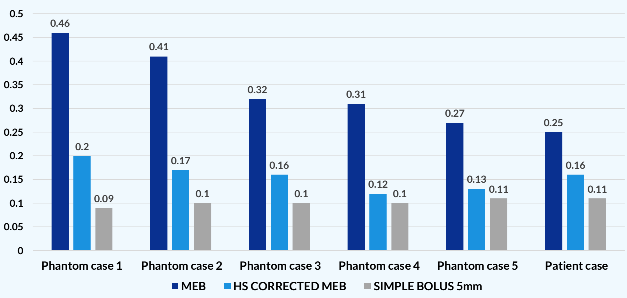
GRAPHS AND TABLES

Conformity index (V_{D90}/V_{PTV})



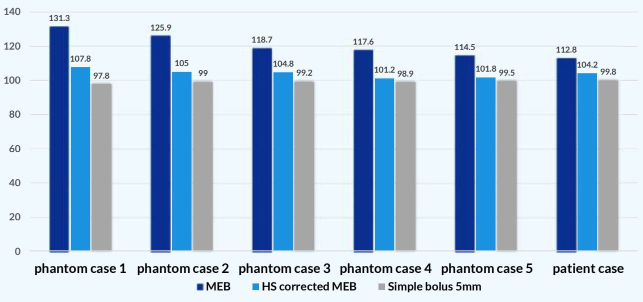
Graph 1: Conformity index in MERT and simple bolus electron treatment plans

Homogeneity index (Dmax-D90)/D90



Graph 2: Homogeneity index in MERT and simple bolus electron treatment plans

Maximum dose to PTV



Graph 3: Maximum dose to PTV in MERT and simple bolus electron treatment plans

Table 1: Influence of different peak-to-valley ratios of the hot spot corrected MEB on clinical plan parameters such as: maximum, minimum and mean dose to PTV, conformity and homogeneity indexes. Data presented for Phantom case 1.

Peak-to-valley ratio [%]	Maximum dose to PTV [%]	Minimum dose to PTV [%]	Mean dose to PTV [%]	Conformity Index V_{D90}/V_{PTV}	Homogeneity Index (Dmax-D90)/D90
100 (uncorrected MEB)	131.3	89.0	111.6	2.32	0.46
80	119.6	89.2	104.9	2.05	0.33
60	112.0	86.5	100.7	1.87	0.24
40	107.8	87.2	98.6	1.83	0.20
20	102.4	86.3	96.4	1.79	0.14
0 (max. corrected MEB)	100.8	87.0	96.6	2.01	0.12
Simple bolus 5mm	97.8	89.5	93.7	2.72	0.09

CONCLUSIONS

Comparing to present designs where modulation of the bolus in electron radiation therapy ensures the conformity of the prescribed dose to PTV, but does not address dose homogeneity, the new hotspot correction algorithm:

- Achieves a specific dosimetric goal within MERT treatment plans where dose homogeneity can be improved while at the same time maintaining dose conformity to PTV comparable to an original MEB plan.
- Allows medical physicists and radiation oncologists choose the optimal balance between dose homogeneity and dose conformity to PTV in MERT treatment plans.
- May lead to improved quality of electron RT treatment plans which would otherwise be unfeasible or clinically unacceptable, ensuring patients receive the optimal cancer treatment modality.
- Reduces the time of manual designing of the hot-spot-corrected MEB from several hours to 5 minutes.

REFERENCES

1) Shiqin Su, Kathryn Moran, James L. Robar - "Design and production of 3D printed bolus for electron radiation therapy" – JACM vol.15, No.4, 2014

2) Sarah Burleson, Jamie Baker, An Ting Hsia, Zhigang Xu – "Use of 3D printers to create a patient-specific 3D bolus for external beam therapy" – JACM, vol.16, No.3, 2015

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