The Accuracy of the CyberKnife Treatment Planning System in Correcting for the Effects of Tissue Heterogeneity

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Background and purpose

The CyberKnife Treatment Planning System (TPS) Multiplan (MP) has two dose calculation algorithms: Monte Carlo (MC) and Ray-Tracing (RT) [1]. RT is a 1D dose calculation algorithm and is currently being used clinically at Barts. Although it accounts for tissue heterogeneities using an effective depth calculation, it does not correct for changes in lateral electron transport that may occur in the presence of heterogeneities like bone and lung. These effects are more pronounced for the smaller radiation field sizes typically used in CyberKnife. Here we establish the accuracy of the RT algorithm in calculating the attenuation correction beyond regions of bone and lung equivalent materials using Barts custom-made phantom tissue equivalent material. .

Method

Lung and intracranial cases were first simulated using Barts custom-made bone, lung and solid water equivalent blocks (figure1). Control phantoms for both cases were also designed by replacing the heterogeneity with water-equivalent material. CT image sets of the phantoms for the test and control cases were acquired on a GE Lightspeed RT 16 CT scanner (using clinical protocols) and imported into MP v4.5. Simple treatment plans were generated using a single beam normal to the phantom surface with the central axis aligned to the centre of the detector volume, positioned at depths 1.6 and 5.6 cm from the heterogeneity (800mm SSD, 60mm and 30mm collimator sizes). The plans were treated on CyberKnife (Accuray Inc, Sunnyvale, CA, v.9.5). Dose was measured with a pinpoint chamber (PTW Frieburg 31014), corrected for daily output variation. The measured dose/MU was then compared with the TPS dose/MU.

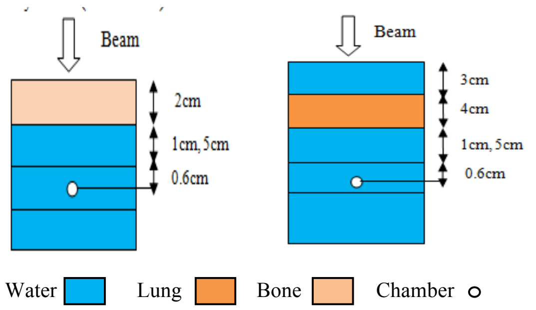

Figure 1; **Phantoms simulating intracranial (left) and lung (right) cases**

Results

The % error in measured and planned dose/MU were calculated after applying corrections for the control results (Table 1)

Case	Field Size (mm)	Chamber depth from (mm)	% Error measured v planned dose/MU
Intracranial	60	56	0.9
Intracranial	30	56	1.5
Intracranial	60	16	2.0
Intracranial	30	16	1.1
Lung	60	56	-1.6
Lung	30	56	-1.1
Lung	60	16	-4.1
Lung	30	16	-4.0

Table1. **% error: measured v planned dose/MU, corrected for control for the bone and lung simulation cases**

The dose calculation in Multiplan for the simulated intracranial cases, replicate the measured doses to within 2%. Due to the higher electron density of bone relative to water, there was a decrease in measured and calculated dose distal to bone compared to the control setup. The largest error in TPS dose calculation was for the case with the measurement point closer to the heterogeneity.
For most of the lung cases, there is an increase in deviation of the TPS result compared with the measured result. The worst case is with the chamber closer to lung interface (4.1 % for the 60 mm collimator size).

Conclusion

The Ray-Tracing algorithm accurately predicts the increase in dose distal to lung heterogeneity and the decrease in dose distal to bone. It appears to perform more accurate dose calculations for the intracranial cases compared with the lung cases.
The largest discrepancy is seen for the lung case closer to the heterogeneity which is expected. These results are considered sufficiently accurate for RT to be used clinically. An attempt was made to repeat the experiment with 5mm and 10 mm collimator sizes which proved difficult due to the large dose gradients (of the order 10%) across the chamber volume. This lead to difficulty in comparison of the control and test CT sets with the TPS due to strong dependence on beam placement accuracy. MC is currently being commissioned and will be tested using the same method. Further studies to evaluate 2D dose distributions with EBT film will also be performed especially for verification of the MC model [2].

References

[1] Accuray, Inc. Physics Essentials Guide. Sunnyvale, CA: Accuray; 2006.
[2] Wilcox EE, Daskalov GM. Medical Physics, 2008; 35(6): 2259-2266