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

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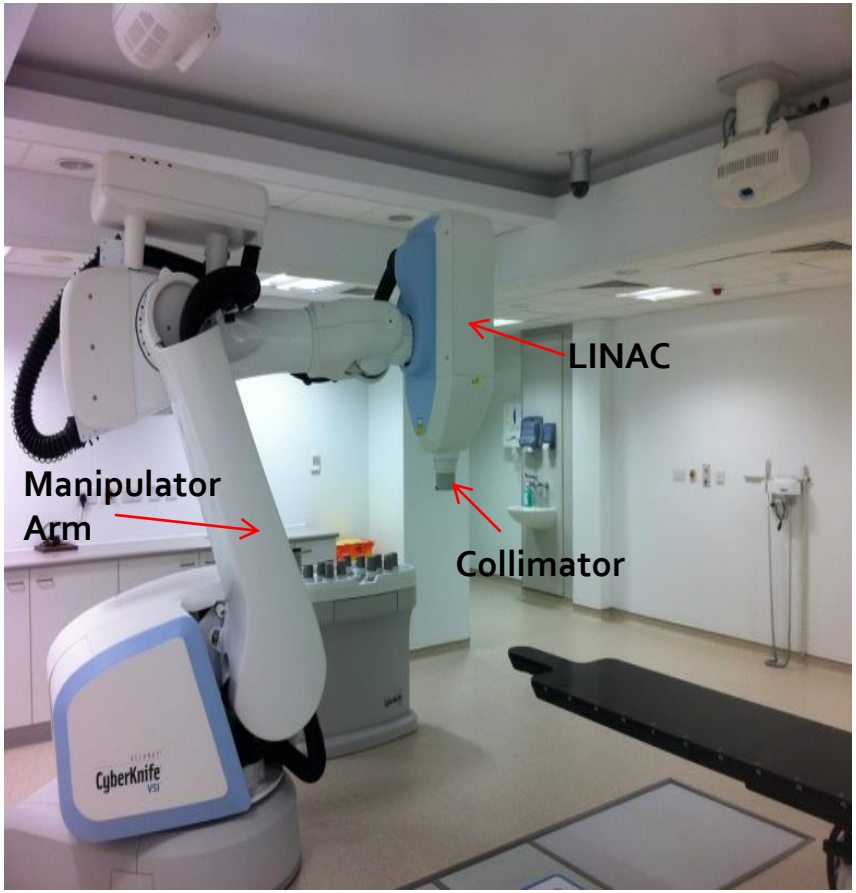
Cyberknife Robotic Radiosurgery System



- Flattening filter free 6MV LINAC mounted on a robotic manipulator arm with six degrees of freedom.
- 12 interchangeable fixed collimators (5 to 60 mm) and IRIS.

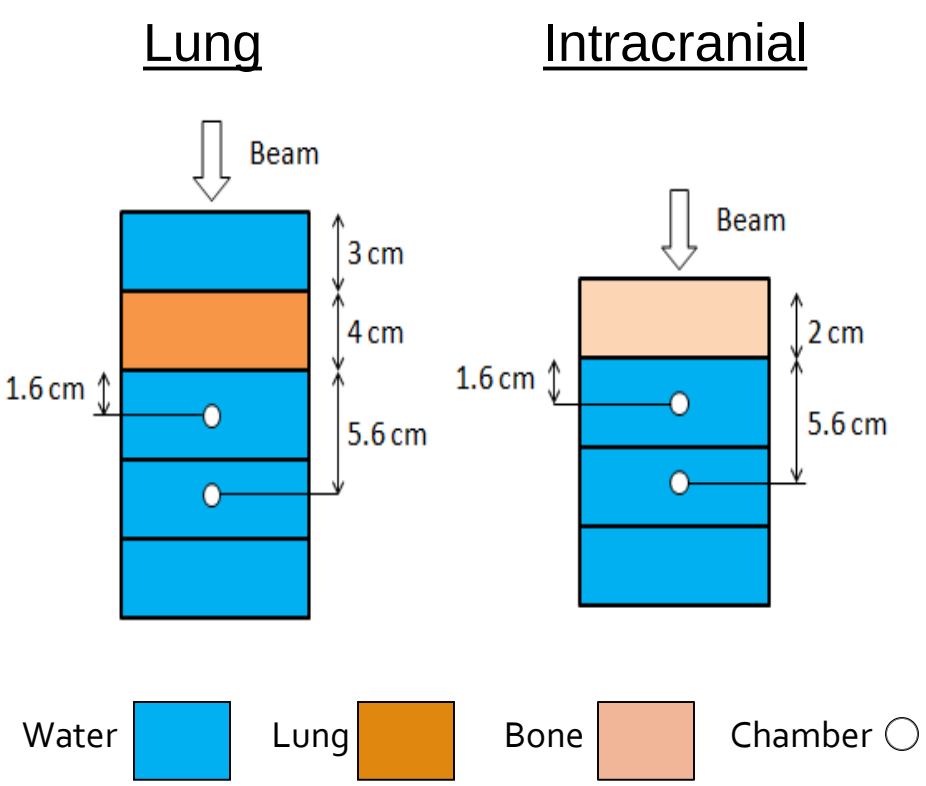
Treatment Planning System Algorithms

- CyberKnife (CK) Treatment Planning System is called Multiplan and uses two dose calculation algorithms: Ray Tracing and Monte Carlo
- Ray Tracing: 1D algorithm which uses an effective depth calculation to correct for tissue heterogeneities. Currently being used clinically at Barts.
- Monte Carlo: Particle by particle simulation of the transport and interactions in matter. More accurate but also increases computational time. Currently being commissioned at Barts.

Project Aim

- CK is currently being used for treating a larger number of intracranial and some body cases at Barts.
- Verification of the accuracy of heterogeneity algorithms used in treatment planning is largely untested in the UK due to the use of water equivalent phantoms for patient specific QC.
- Here the accuracy of the Ray Tracing algorithm in computing doses beyond bone and lung heterogeneity has been established.

Method - Phantom Design



- Phantoms built using Barts custom-made bone (ρ_e = 1.6), lung (ρ_e = 0.2) and solid water equivalent blocks.
- Detector placed at 2 depths beyond heterogeneity: 1.6cm and 5.6cm.
- Controls: Heterogeneity block replaced with water equivalent blocks.

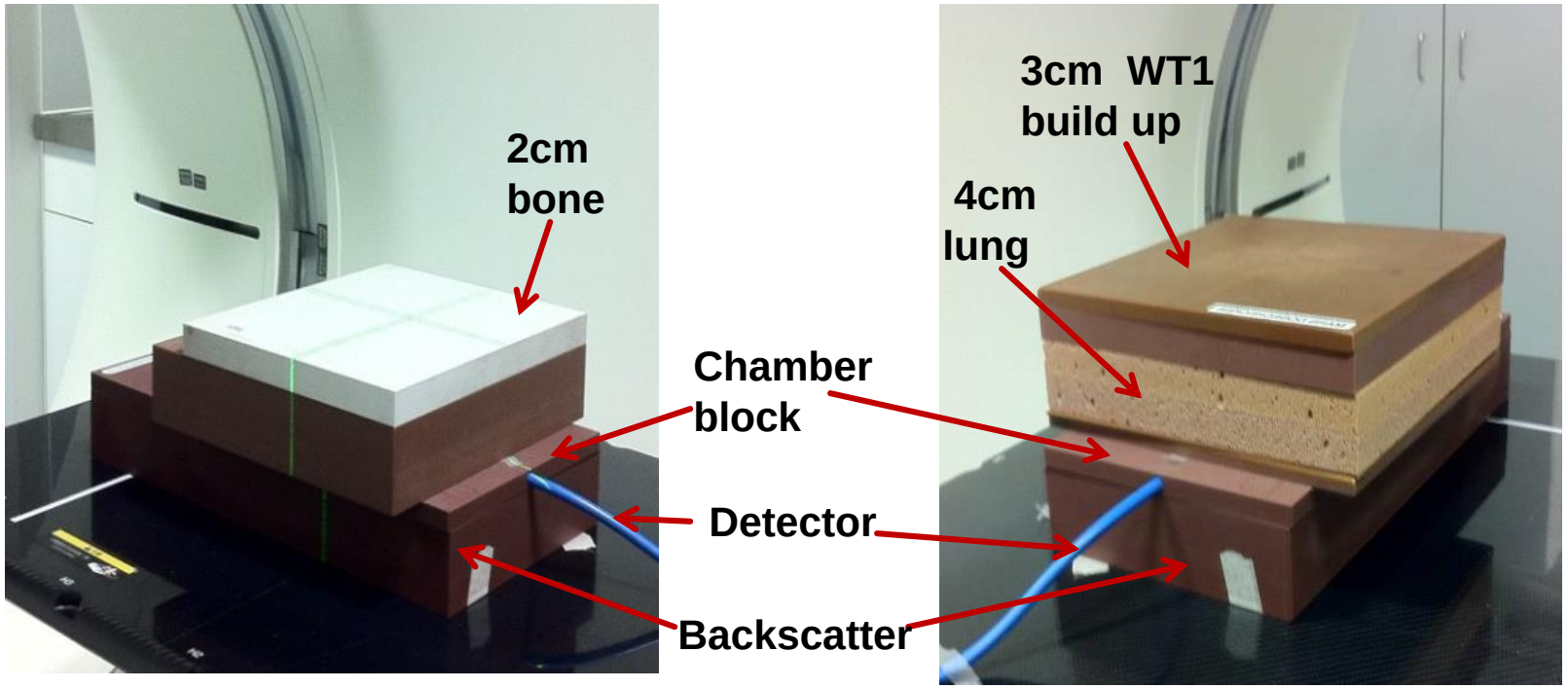
Choice of Detector

- Small volume detector compared to the field size to avoid signal averaging over a peaked distribution.
- Water equivalent and not perturb the beam.
- PTW Pinpoint Chamber(15 mm^3 active volume) chosen for this experiment has most of these characteristics.

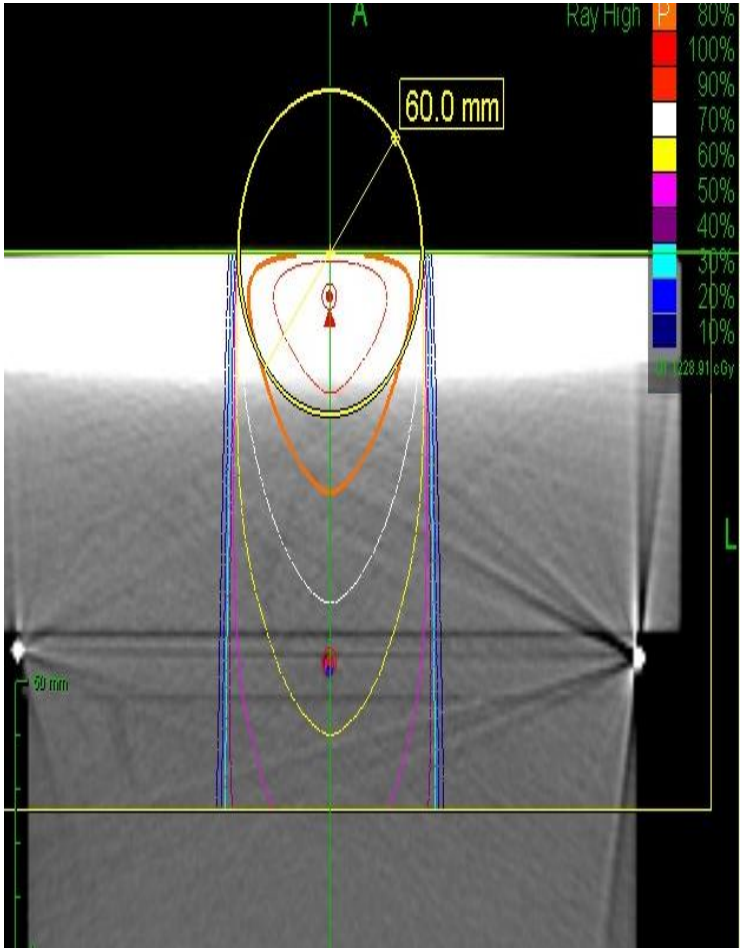
Method - CT scanning

Intracranial

Lung



Multiplan Dose Calculation

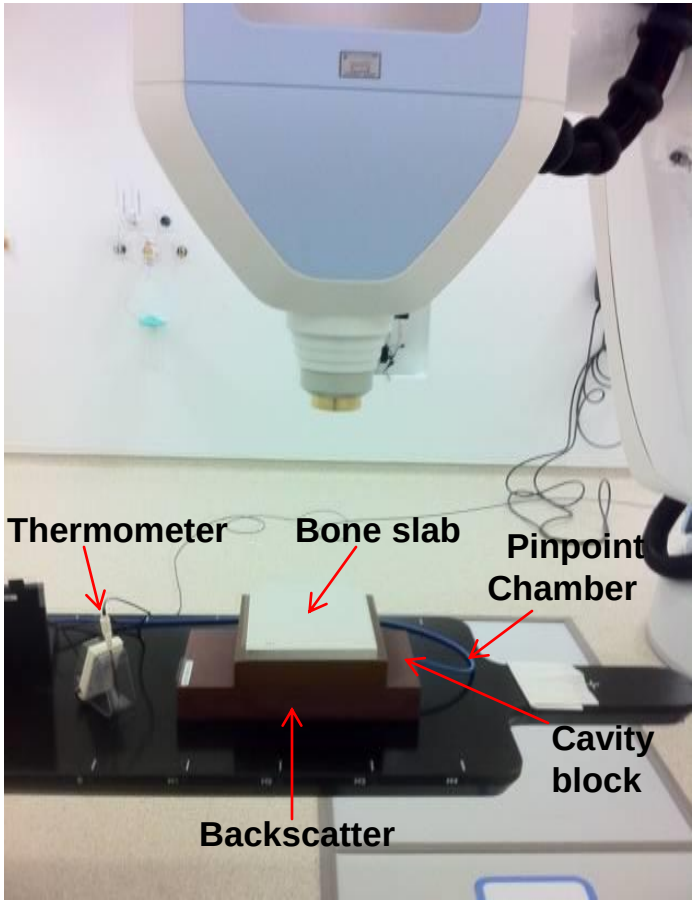


- Treatment plans generated using the single beam (QA mode) option in Multiplan.
- Compute number of monitor units needed to deliver approximately 5Gy to the detector.
- Dose calculation carried out in Multiplan using the following equation

$$\textit{Dose/MU} = (800/SAD)^2 \times TMR \times OF$$

Reference conditions : 800 mm SAD, 60 mm collimator

Method – Dose Measurements



- LINAC normal to the phantom surface (800 mm SSD).
- 60 mm and 30 mm collimator sizes.
- Dose calculated from charge reading R accounts for output drift.

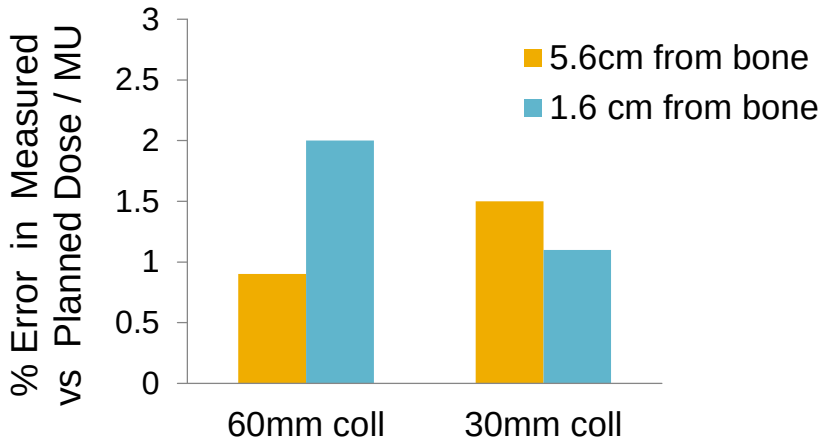
$$Dose = \frac{Rx\ N_{DW}\ x\ f_{ion}\ x\ f_{elec}\ x\ f_{tp}}{Output\ Correction}$$

Results - Intracranial

Field Size (mm)	Chamber depth from bone (mm)	Setup	Measured Dose Ratio (cGy/MU)	Calculated Dose Ratio (cGy/MU)	% Error measured vs. planned dose/MU
60	56	Control	0.687	0.687	0.9
		2cm Bone	0.644	0.638	
	16	Control	0.867	0.878	2.0
		2cm Bone	0.833	0.827	
30	56	Control	0.646	0.648	1.5
		2cm Bone	0.603	0.596	
	16	Control	0.847	0.85	1.1
		2cm Bone	0.799	0.792	

Findings - Intracranial Simulation

- Reduction in calculated dose/MU compared to the control setup.
- The simulated dose calculations in Multiplan for all the intracranial setups replicate the measured doses to within 2% .
- The largest error in TPS dose calculation was for the setup with the chamber closer to the heterogeneity and 60 mm collimator size.

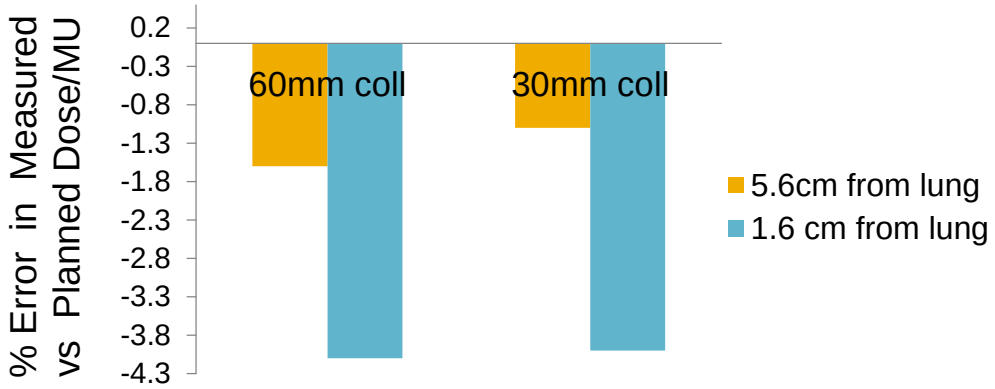


Results - Lung

Field Size (mm)	Chamber depth from lung(mm)	Setup	Measured Dose Ratio (cGy/MU)	Calculated Dose Ratio (cGy/MU)	% Error measured vs. planned dose/MU
60	56	Control	0.486	0.497	- 1.6
		4cm Lung	0.552	0.574	
	16	Control	0.643	0.642	- 4.1
		4cm Lung	0.709	0.738	
30	56	Control	0.452	0.457	-1.1
		4cm Lung	0.523	0.535	
	16	Control	0.604	0.602	- 4.0
		4cm Lung	0.681	0.707	

Findings - Lung Simulation

- At the lung-tissue distal interface, there is an enhancement of dose which is correctly modelled by Multiplan.
- Measured and planned dose/MU within 2% for the chamber 5.6cm from lung.
- Discrepancy of 4% between planned and measured dose/MU with the detector closer to the heterogeneity which is expected. This is 2% worse than the intracranial case.



Experimental Limitations

- Measurements carried out for only two collimator sizes and two depths.

- Strong dependence on geometric set up accuracy. Accurate comparison of measured and calculated doses for the smallest collimator sizes (10 and 5 mm) not possible due to a large dose gradient (worst case of 15%) across the chamber volume.

Conclusions

- The Ray-Tracing algorithm accurately predicts the dose delivered to tissue beyond the interface region to within 2%.
- In the interface region, the largest errors were 4% and 2% for lung and bone respectively.
- These results are clinically acceptable.

References

- Accuray, Inc. Physics Essentials Guide. Sunnyvale, CA: Accuray; 2006.
- Wilcox EE, Daskalov GM. Accuracy of dose measurements and calculations within and beyond heterogeneous tissues for 6 MV photon fields smaller than 4cm produced by CyberKnife. Medical Physics, 2008; 35(6): 2259-2266.
- IJ, Ding GX, Ahnesjo A. Small fields: Nonequilibrium radiation dosimetry. Medical Physics, 2008: 35(1): 206-15.