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Dose variation between Monte Carlo and ray-tracing algorithm for Lung tumors using anthropomorphic digital phantom

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INTRODUCTION

Stereotactic body radiotherapy (SBRT) with CyberKnife are clinically widely used in lung tumor treatment, and Cyberknife reduces the errors caused by respiratory movement through synchronous respiratory tracking technology. Tumor movement synchronized with respiratory motion can be truly tracked, by implanting gold fiducials in or around the tumors, more accurately giving the tumor higher doses, while reducing the dose to normal tissues.

Precision treatment planning system provides the option of using either Monte Carlo or ray-tracing dose calculation algorithm in treatment planning.

Monte Carlo dose calculation algorithm are known as most accurate in predicting dose, especially in a heterogeneous medium, e.g., lung. And this is especially important in the high precision treatment like radiosurgery where hypofractionation dose schedules are used.

AIM

It is known that ray-tracing dose calculation algorithm calculation generally overestimates dose in low density lung tissue and ignores changes to scatter due to local heterogeneities, and thus may result in inaccuracies of organ and tumor doses near density interfaces. Monte Carlo dose calculation algorithm is known for better accuracy, but Monte Carlo calculations are not yet widely available in the clinic. This study focuses on the clinical implications of quantitively comparing Monte Carlo and ray-tracing in digital anthropomorphic phantom and gives the dose differences of PTV and organ doses so that its application have the potential to measurably improve clinical practice

METHOD

- The simulation study was accomplished using 4D XCAT anthropomorphic phantom. The phantom has been developed to simulate the shapes and structures of complex organs in human body along with motion of dynamic organs such as respiratory system.
- Each tumor(GTV) was modeled as a cylinder of *1, 2, or 3-cm diameter/length*, and at three different tumor locations (*close to spine(SP), chest wall(CW), and left wall(LW)*), with center at the same CT slice.
- OARs including chest walls, spine, and heart, were contoured.
- Clinically acceptable plans(60 Gy to 95% PTV coverage) were first developed using the ray-tracing using VOLO optimizer.
- The same beam sets were then recalculated with Monte Carlo; each dose calculation utilized the same beam orientations. The Monte Carlo prescription was then normalized to achieve the same PTV coverage as the ray-tracing plan.

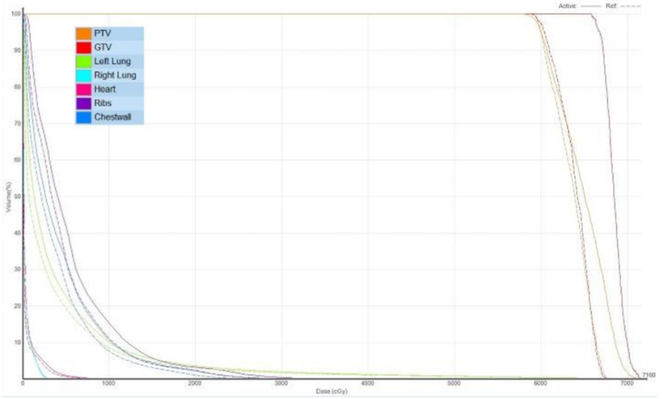
RESULTS

- In the comparison of ray-tracing and Monte Carlo for lung plans, monitor units in Monte Carlo plans were *7.5-14.5% higher* than ray-tracing plans to maintain same PTV coverage.
- Under this circumstance, ray-tracing algorithm consistently *underestimated* the target and the organ dose.
- For the 1-cm diameter tumor, the maximum target dose dropped *6.76±1.7%* from Monte Carlo to ray-tracing. For the organ maximum dose comparison, from Monte Carlo to ray-tracing, an 8 to 18% drop for chestwall, and *4 to 11 %* drop for heart were observed.
- For the large tumor, organ doses were similar. The mean dose difference in organs such as the chestwall and heart did not vary greatly with tumor location, while max dose has more location-dependency.

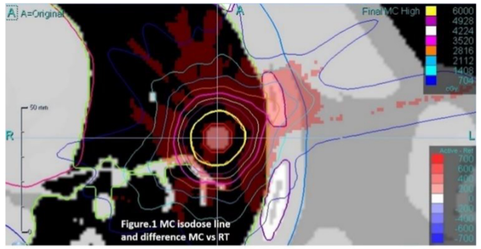
Tumor Location	PTV		Chestwall		Heart	
	MC	Ray-tracing	MC	Ray-tracing	MC	Ray-tracing
Spine	7389	6969	4196	3881	2412	2265
Chestwall	7317	6726	3046	2724	3310	2973
Left Wall of Lung	7160	6787	3490	2957	991	951

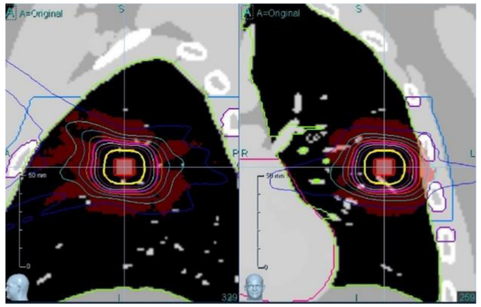
Comparison of the PTV maximum dose and organ doses (cGy) from Monte Carlo and ray-tracing calculation of the 1-cm tumor

DVH comparison between Monte Carlo and ray-tracing, solid line: MC, dotted line: ray-tracing



- The ray tracing algorithm uses effective path length based correction for the heterogeneity. The effective path length doesn't take into account the lateral electronic scatter components from the surroundings. Lateral electronic disequilibrium and steep dose gradient exist in larger portions of the smaller field sizes causes dose calculation deviate, especially in a heterogeneous medium.
- For smaller collimators (12.5mm diameter and smaller), the contribution by electronic disequilibrium, which is significant, is not taken into account by the correction based algorithms. These algorithms account only for the heterogeneity in the primary beam.
- The Monte Carlo algorithm takes into account all these factors and is expected to provide an accurate dose calculation.





Isodose lines of Monte Carlo dose calculation from 1-cm diameter and length cylinder tumor located at mid lung. Color map: Monte Carlo subtracts ray-tracing dose calculation

CONCLUSIONS

Significant differences between Monte Carlo calculations versus ray-tracing can influence dose accuracy, due to the improved ability of Monte Carlo algorithms for photon and electron transport at interfaces between lung/soft tissues or lung/tumors.

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