Evaluation of Lung Treatment Deliveries Using the Radiological Physics Center's (RPC) Thorax Phantom: Monte Carlo vs. All Other Modern Heterogeneity Correction Algorithms.

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Introduction

The Radiological Physics Center (RPC) was established as a resource in radiation dosimetry and physics for cooperative clinical trial groups and radiotherapy facilities that deliver radiation treatments to patients entered onto cooperative group protocols. The RPC's primary responsibility is to assure NCI and the cooperative groups that the participating institutions deliver radiation treatments that are clinically comparable to those delivered by other institutions in the cooperative groups. One of the remote audit techniques used by the RPC to assure NCI is to credential institutions using its anthropomorphic phantoms, i.e. an end to end test from imaging to planning to final dose delivery as if the phantom were an actual patient. One of the phantoms that the RPC employs is it's thorax phantom with a 3 cm target located in the center of the left lung. With the recent the implementation of several lung protocols requiring heterogeneity corrected target doses, the RPC, through its credentialing activities has evaluated numerous heterogeneity correction algorithms as used in various treatment planning systems.

Materials & Methods

The thorax phantom (figure 1) is a water–filled plastic shell that simulates a patient not only in dimensions but also in densities for imaging and treatment purposes. This design includes two lungs with density of 0.33 g/cm^3 and a target centrally located in the left lung with density near 1.000 g/cm^3. TLD and radiochromic film were used as dosimeters within and near the target region (figure 2). Institutions that received the phantom are requested to image, plan and treat the phantom as if it was a patient. The institutions are asked to submit the heterogeneity corrected treatment plan electronically for comparison to the measured dose distributions. The various planning system heterogeneity correction algorithms analyzed include Elekta Pinnacle superposition convolution (SC) (adaptive convolve and collapsed cone) algorithms, Varian Eclipse AAA algorithm, TomoTherapy planning station SC algorithm, Accuray Multiplan Monte Carlo (MC) algorithm, CMS XiO SC and Monaco MC algorithms, and BrainLab MC algorithm.

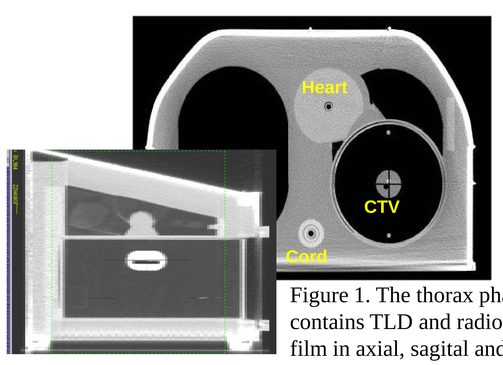

Figure 1. The thorax phantom contains TLD and radiochromic film in axial, sagital and coronal planes.

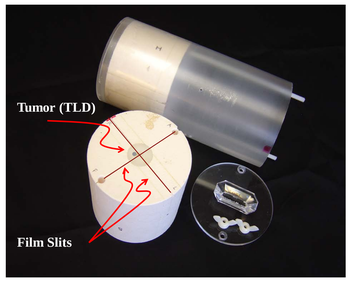

Figure 2. The thorax phantom dosimetry insert showing the location of the TLD and the film slits for the radiochromic film.

Criteria for credentialing:

Lung Phantom

RPC/Institution PTV TLD dose: 0.92-1.02

Dist. to Agree: 5mm (high gradient region)

Results

Over the past 7 years, the thorax phantom has been mailed to 430 institutions (figure 3) wanting to be credentialed to participate in lung clinical trials. Criteria for passing the thorax phantom irradiation test were developed from a pilot study of 12 initial thorax phantom irradiations choosing the 90% confidence interval as the acceptance criteria.

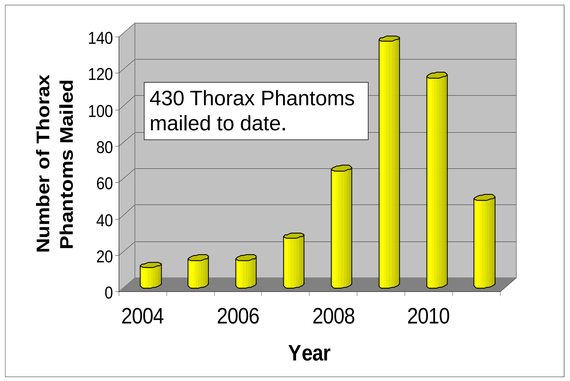

Figure 3. Number of thorax phantoms mailed to institutions.

To date there have been 236 irradiations analyzed that used the Eclipse AAA or CMS/Pinnacle/TomoTherapy SC heterogeneity correction algorithms. The dose to the center of the PTV for the 236 irradiations is shown in Figure 4. The average of all of the RPC/Institution dose ratios for the AAA and SC algorithms was **0.963** with a standard deviation of **2.6%**. That is, the RPC measured almost 4% less delivered dose than predicted by the institution. A total of 26 irradiations were analyzed that used a MC heterogeneity correction algorithm as shown in figure 5. The average of the RPC/Institution dose ratios for the MC algorithms was **0.997** with a standard deviation of **2.9%**.

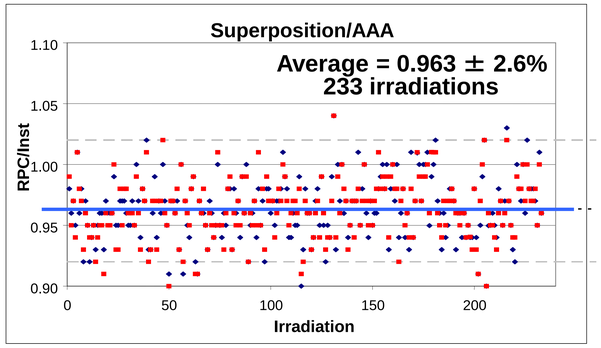

Figure 4. RPC/Inst. dose ratios for AAA and SC heterogeneity correction algorithms. Measured Jdoses are ~4% lower than predicted

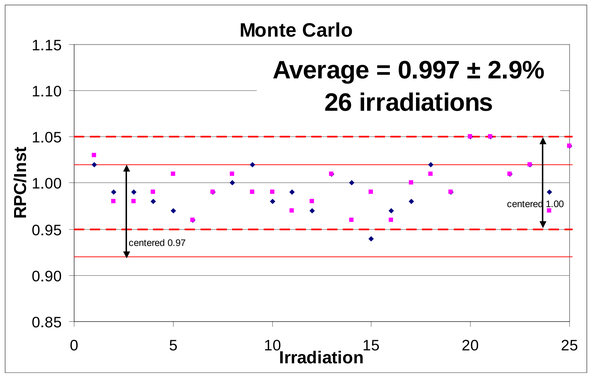

Figure 5. RPC/Inst. dose ratios for MC heterogeneity correction algorithms.

Histograms of the RPC/Institution dose ratio in the PTV are shown in Figure 6 for the MC algorithms, the three SC algorithms and the Eclipse AAA algorithm. The average ratio for the MC data is very near unity, whereas the other algorithms had averages ranging from 0.956 – 0.970 with the average being 0.963 (as was seen in the original pilot study). The Pinnacle and TomoTherapy SC algorithms appeared to have better results (average of 0.969) overall than the XiO and AAA results (average of 0.958). However, these averages have overlapping uncertainties and are not statistically different. The MC results are distinctly different from the SC and AAA algorithms ($p<0.0001$) and represent better agreement with measurements. Reasons for the difference between the MC results and the other algorithms are not fully understood at this time but they are believed to be due to the calculation approximations that the AAA and SC algorithms use to speed up the dose calculations. Evidence to this is that if the Pinnacle SC Fast Convolve, the agreement with measurement is poorer than observed with the other Pinnacle SC algorithms.

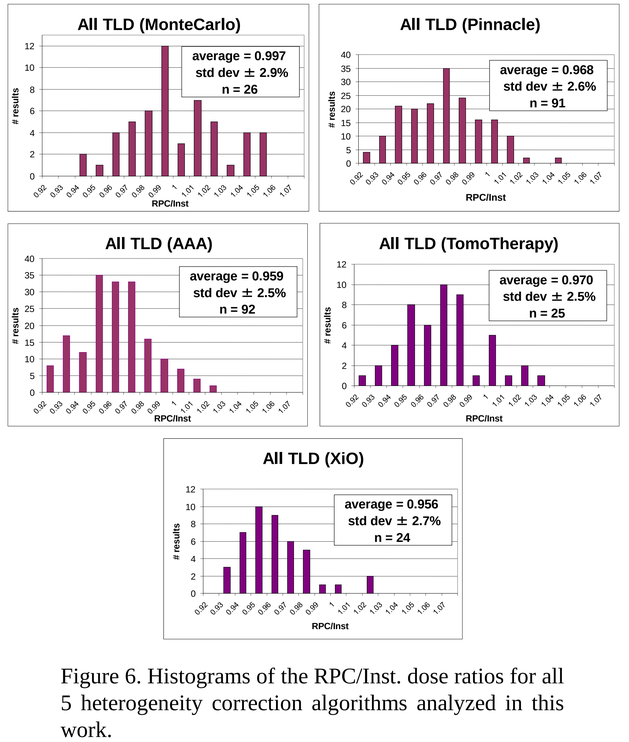

Figure 6. Histograms of the RPC/Inst. dose ratios for all 5 heterogeneity correction algorithms analyzed in this work.

Conclusions

1. The Monte Carlo heterogeneity correction algorithm agrees better with the measurements in the RPC's thorax phantom than SC or AAA algorithms.
2. The Superposition Convolution (SC) algorithms and the Analytical Anisotropic Algorithms (AAA) are good heterogeneity correction algorithms that are consistent appropriate for use in clinical trials.
3. A separate criterion of 1.00 ± 0.05 for the RPC/Inst PTV dose ratio will be used for the MC calculated treatment plans in addition to the 0.97 ± 0.05 for the SC and AAA calculated treatment plans.
4. Further analysis of the differences between the SC/AAA and the MC algorithms is needed to better understand why the SC and AAA algorithms over-predict the dose to the PTV in lung heterogeneous media.

Support

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