IMRT Heterogeneity dose calculation algorithm accuracy using anthropomorphic thorax phantom

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Introduction

The accuracies of heterogeneity dose calculation algorithms from two commercially available IMRT treatment planning systems (TPS) were assessed using an anthropomorphic thorax phantom. The TPS used for this study were:

1) Pinnacle, ADAC 2) Corvus, Nomos

Pinnacle's dose calculation algorithm is based upon superposition-convolution while Corvus employs the pencil-beam algorithm with an effective pathlength (EPL) correction. The AAPM Task Group No. 65 report on tissue inhomogeneity corrections for megavoltage photon beams suggests that superposition-convolution or Monte Carlo based dose calculations may better determine the dose in the presence of heterogeneities.

Clinically relevant IMRT treatment plans were created and delivered to an anthropomorphic thorax phantom that simulated realistic patient anatomical and geometrical conditions (Fig. 1). The phantom is part of the Radiological Physics Center's (RPC) family of phantoms that are used in credentialing clinical trials sponsored by the Radiation Therapy Oncology Group (RTOG).

In order to isolate the optimization algorithms from each TPS dose calculation, direct dose comparisons were made. This was accomplished by importing the Corvus MLC files into Pinnacle, then allowing Pinnacle to recalculate the dose distribution.

Film and TLD measurements were made for comparisons to each of the TPS dose calculations.

Fig. 1. Anthropomorphic phantom and axial CT image.

Material & Methods

Anthropomorphic phantom

- Constructed from polyvinyl chloride (PVC) to form outer shell and designed to provide a water tight seal.
- Internally, materials and shapes represent the lung ($\rho = 0.21 g/cm^3$), heart, spinal cord and tumor target.
- Target was located within the lung, anteriorly toward the mediastinum.
- Remaining space filled with water to simulate the surrounding tissue.

Dosimeters

- TLD: Capsules located in the target center, heart and spine.
- Film: MD-55 2 radiochromic film positioned in three anatomical planes (axial, coronal, sagittal) through the center of the target and located via registration pin marks .
- Ion chamber: CC04 type ion-chamber used to determine absolute dose from delivery of hybrid treatment plans to an IMRT QA water phantom.

Treatment Planning Systems (TPS)

- Pinnacle 7.4f /7.6c – *calculation: superposition-convolution*
- Corvus 5.0 – *calculation: pencil-beam algorithm w/ EPL correction*

Treatment plans

Treatment plans were created on both planning systems. Equivalent plans were based on the dose to the PTV. The PTV was defined as the GTV plus one centimeter margin. Plan equivalency was defined from the dose volume histogram where 66 Gy covered 96% of the PTV.

Additionally, because of the optimization algorithms, evaluation of only the dose calculation was difficult. To address this, the Corvus MLC files were imported into Pinnacle where they were recalculated.

Delivery

The two treatment plans were delivered to the anthropomorphic phantom using a Varian Linac 21EX linear accelerator. The monitor units were rescaled to deliver 20Gy in one fraction. The parameters included:

- 6MV photons
- 5 beams
  - Gantry angles of 35°, 90°, 150°, 190°, and a 90° couch kick with a gantry angle of 30°
- Monitor units
  - Pinnacle: 4090 MU
  - Corvus: 5288 MU
- Control points
  - Pinnacle: 63 pts
  - Corvus: 204 pts

Measurements

Each plan was delivered three times to account for film and TLD reproducibility.

TLD: Dose measured in the center of the target, heart and spine. Corrected for the measured machine output.

Radiochromic film: 2D dose distributions measured in the axial, coronal, and sagittal planes located in the target center. Optical density (OD) converted to dose and then normalized to the target TLD dose.

Ion chamber: IMRT QA hybrid plans created for delivery to a QA water phantom. Single point dose was read in a low gradient region of the PTV. TPS dose distributions within the anthropomorphic thorax phantom were then corrected using this ion chamber measurement.

Evaluation Criteria

±5% of normalization point (target TLD) or 3mm distance-to-agreement (It is the expectation of TG-53 for TPS to meet criteria that lie within ±5% or 7mm.)

Results

TLD Corrected Results

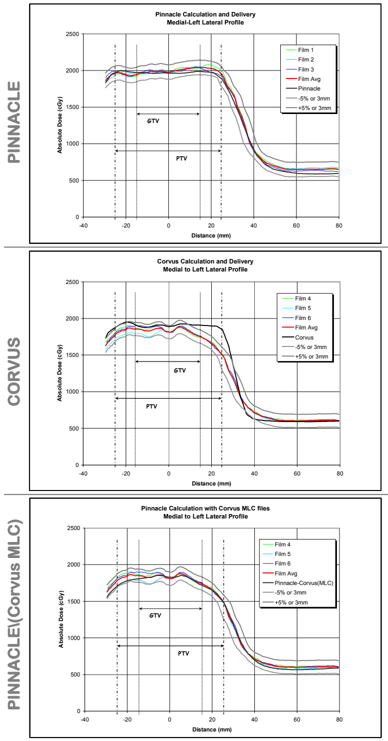
Calculation Algorithm	Treatment Planning System	Delivery method: *MLC files*	Tumor			
			measured		calculated[2] (cGy)	*ratio:* measured/ calculated
			average (cGy)	percent standard deviation		
Superpositon Convolution	**Pinnacle 7.4f**	**Pinnacle 7.4f**	1981.7	0.4%	1966.0	**1.008**
Pencil Beam	**Corvus 5.0**	**Corvus 5.0**	1810.4	2.3%	1900.7	**0.952**
Superpositon Convolution	**Pinnacle 7.6c**	**Corvus 5.0**			1828.0	**0.990**

[1]Corrected for machine output

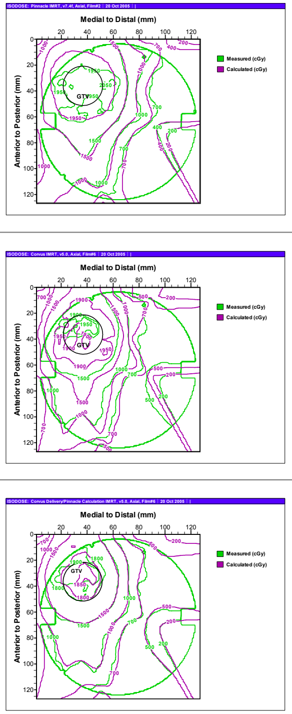
[2]Corrected for IC point dose water phantom measurement

2D Dose Results; single film comparison, inferior-superior view

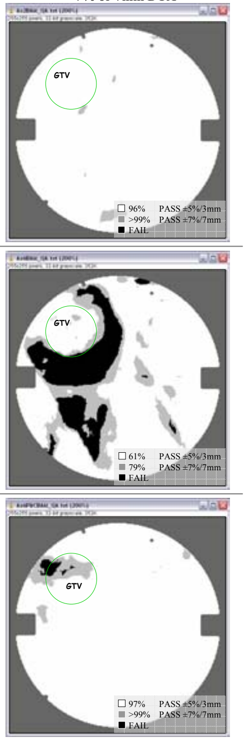
Dose Profile Results



Isodose Distributions



Binary Agreement Map;
Criteria: ±5% or 3mm DTA
±7% or 7mm DTA



Conclusions

- The superposition convolution algorithm used in the Pinnacle IMRT TPS calculated correct doses to the target and surrounding lung tissue heterogeneities using either the Pinnacle or Corvus MLC files.
- The pencil-beam algorithm with effective pathlength correction employed by Corvus was not able to accurately predict target and lung doses. Corvus overestimated the dose in the GTV by nearly 5% and did not account for the extent of lateral spread from secondary particles. This conclusion is consistent with the observations reported in TG-65.[1]
- The superposition convolution algorithm, whether used for forward planned 3D conformal radiotherapy (3D CRT) (Fisher)[3] or inverse planned IMRT, calculates the dose correctly within lung heterogeneity.
- The introduction of intensity maps comprising of many small beamlets for IMRT treatment did not increase any dose calculation errors over those found with 3D CRT (Fisher)[3] for the Pinnacle TPS.

References

[1]N. Papanikolaou, et.al., "Tissue Inhomogeneity Corrections for Megavoltage Photon Beams," American Association of Physicists in Medicine Radiation Therapy Committee Task Group 65, AAPM Report No. 85 (2004): 104-105.

[2]B. Fraass, et al., "Quality Assurance for Clinical Radiotherapy Treatment Planning", American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53, AAPM Report No. 62 (1998): 1804.

[3]G. Fisher, "The Accuracy of 3-D Inhomogeneity Photon Algorithms in Commercial Treatment Planning Systems using a Homogeneous Lung Phantom", (master's thesis, University of Texas – Houston), 2005.