Design of a Heterogeneous Thorax Phantom for Remote Verification of Three-Dimensional Conformal Radiotherapy

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Abstract

The recent proliferation of clinical trials using three-dimensional conformal radiotherapy (3DCRT) has created a need for the Radiological Physics Center (RPC) to remotely evaluate the planning and delivery of 3DCRT treatments. The RPC has developed a heterogeneous, anthropomorphic phantom as a quality assurance tool for tumor dose delivery in 3DCRT. In response to the RTOG 3D lung trials, the designed phantom simulates a thorax. The phantom's dimensions have been determined from a sample of cases submitted to RTOG 3D lung protocol 93-11 by the University of Texas M. D. Anderson Cancer Center. Commercially available materials have been evaluated for use as suitable inhomogeneities in the phantom. Radiochromic film and TLD have been evaluated to assess field localization and absolute dose delivery. Expected tolerances are within 3mm for field placement, and within 5% for absolute dose determination. The phantom consists of a water-fillable shell that encloses a simulated spinal column, two simulated lung structures, a heart, and a target within the left lung. Dose contours are measured on two orthogonal planes within the target. Absolute dose is measured in the target, the spinal cord, and the heart. An insert containing the bulk of the phantom’s left lung and a target is used for imaging. To verify the treatment, the imaging insert is replaced with a treatment insert, which contains dosimeters and is indexed so that position will be reproducible.

Introduction – The Radiological Physics Center

- RPC is responsible for the quality assurance of institutions participating in clinical trials
- Modern 3D treatment planning systems are complex[1] – traditional QA techniques are unable to reliably assure the quality of the treatments
- Conformal treatment protocols are becoming popular in inter-institutional clinical trials – e.g. RTOG 93-11 (lung) and 3D/OG 94-06 (prostate)[2]
- RPC must devise a method to ensure the accuracy of conformal treatments

Introduction – Phantom Project

- Challenge conformal radiotherapy imaging, treatment planning, and dose delivery systems approximately the same as a human patient
- Efficient to mail, compatible with CT imaging, and representative of a lung cancer patient
- Provides absolute and relative dose to verify protocol specifications
- Based on prior RPC experience (head phantoms for remote monitoring of stereotactic radiosurgery[3])

Materials and Methods – Phantom Dimensions

- Dimensions determined from a survey of treatment plans submitted to RTOG protocol 93-11
- Data from the treatment plans was compared to anatomical information[4] presented in ICRU report 48
- Generalizations were made about the size and shape of the anatomical structures to simplify construction

Materials and Methods – Phantom Construction

- Absolute dose to points in the target and dose distribution throughout the target are measured
- Cork and commercial lung substitute considered for lung
- Gypsum, acrylic, and commercial bone material considered for spinal column

Materials and Methods – Dose Localization and Measurement

- For proper contouring, tumor within lung must be visible on CT images
- Point doses are measured using thermoluminescent dosimeters (TLD)
- Point doses normalize the dose profiles
- Dose distributions measured using radiochromic film

Phantom Structures

- Heart – Nylon
- Lung – Commercial Lung Material
- Tumor – Polystyrene
- Spine – Acrylic

Dose Measurement

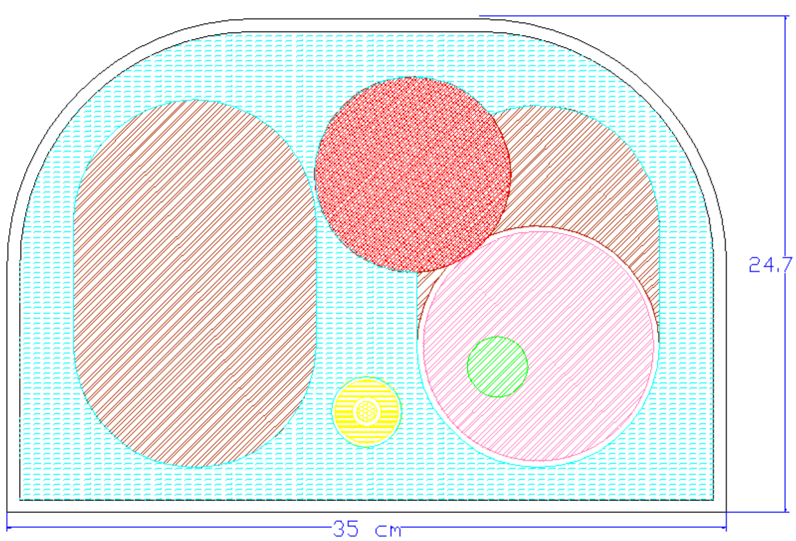
- Point Dose – TLD in tumor, heart, spine
- Dose Contours – Radiochromic film in lung - axial and coronal plane

RESULTS – PHANTOM DIMENSIONS

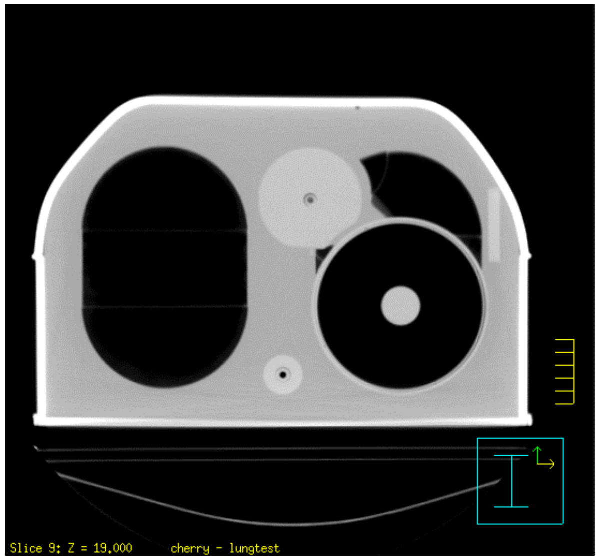
Results of the treatment plan survey to determine phantom dimensions are given in this table. The dimensions of the phantom were chosen based on these measurements. In some cases, such as the location of the heart, the average measured value was used. In other cases, such as the dimensions of the phantom body, lungs, and tumor, a representative value was chosen that was not exactly equal to the average, but still lies within one standard deviation. This was done to simplify the specifications for the phantom, and to ensure that all of the components maintained the proper proportion to each other.

Average dimensions from treatment plan survey

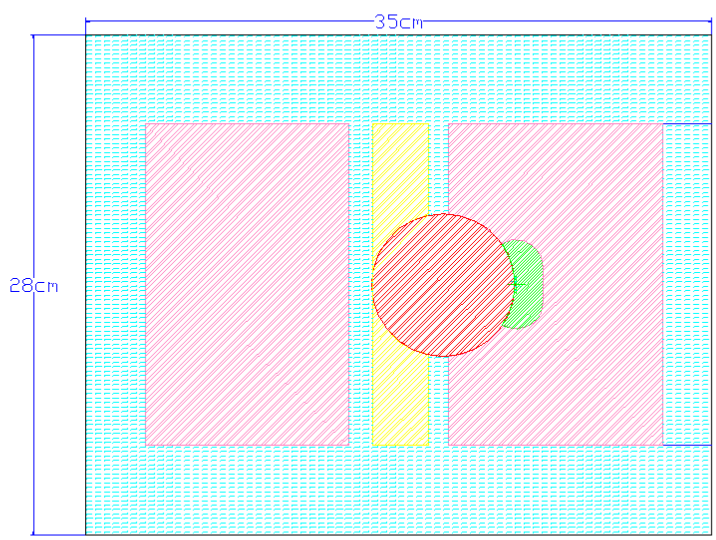
	Average Patient	Phantom		Average Patient	Phantom
Width (X)	35.0 ± 2.2	36.0 cm	Heart Location	(-2.3,10.8) ± (1.6,2.7)	(-2,12.8)
Height (Y)	24.6 ± 2.9	slope from 21cm to 28 cm	Heart Size	4.6 ± 1.7	12 cm
Tumor Location	(1.8,3.8,4.5) ± (6.2,5.0,7.2)	Center of lung 3 x 5 cm	Lung Diameter Left	13.8 ± 2.1	12 cm
Diameter	2.8 ± 0.9		Right	14.1 ± 3.0	12 cm



An axial view through the center of the phantom. Structures include left and right lungs (brown), heart (red), spinal column (yellow), imaging insert (pink), and tumor/target (green).



An axial CT slice through the center of the phantom with the imaging insert in place.



An anterior-posterior view of the phantom. Film is placed in this plane within the dosimetry insert.

RESULTS – DOSE MEASUREMENT TECHNIQUE

TLD:

- The RPC can measure dose with an accuracy at the $1\sigma = \pm 2\%$ level[5]

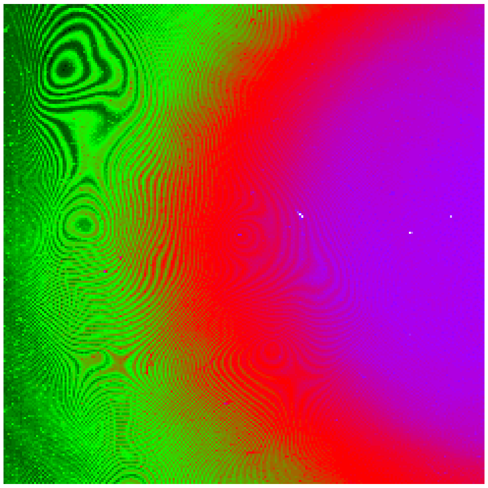
FILM:

- Radiochromic film has many of the advantages of verification film without some of the disadvantages
- Insensitive to visible light, tissue equivalent, will not require a beam-specific calibration
- Properties of radiochromic film[5] match our requirements

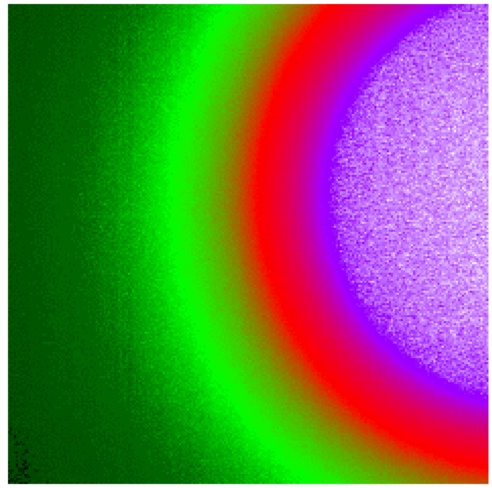
RADIOCHROMIC FILM

- Special techniques to overcome limitations inherent in radiochromic film[7]
- Most significant problem is presence of the “Newton’s rings” interference phenomenon
- Ring artifact created when coherent light from the scanning laser undergoes multiple reflections in the polished glass scanning bed and between the layers of the film
- Replacing polished glass bed with custom ground-glass significantly reduces artifact
- Wiener filter removes noise from raw data

REMOVAL OF INTERFERENCE DUE TO MULTIPLE LASER REFLECTIONS



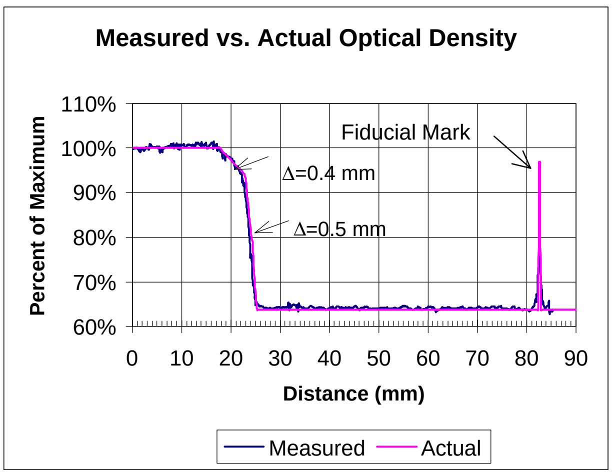
Polished glass scanning tray



Diffusing glass scanning tray

RESULTS – THE SPATIAL ACCURACY OF THE FILM-SCANNING SYSTEM

Our film dosimetry system must be able to identify the misplacement of a given isodose line with an accuracy of 3 mm in the clinic. In the laboratory, we must achieve an accuracy of 1 mm. To demonstrate this ability, several test films containing known contours were generated using a programmed array of film density values and a film printer. Fiducial marks were also printed on the films. The films were then scanned and analyzed. The results show the ability of our system to localize the 95% and 80% isodose lines within 0.5 mm.



Conclusions

Criteria and design of an anthropomorphic phantom that will serve as a QA tool for 3DCRT treatments have been presented. The anatomy is modeled after actual patients that have participated in the RTOG 93-11 lung protocol. The structures within the phantom are made out of materials that simulate the radiological properties of the tissues they represent at both diagnostic and therapeutic energies. The modular design of the phantom makes it possible to thoroughly test the treatment planning and delivery process. An insert containing the bulk of the left lung and a simulated tumor is placed in the phantom for imaging. Then, that insert is replaced with one containing dosimeters for measuring absolute dose and dose distributions. This phantom allows us to verify absolute dose within 5%, and dose localization within 3 mm.

Acknowledgement

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The RPC thorax phantom

The phantom lungs, spine, heart, and imaging insert.