Dose verification of radiotherapy for lung cancer by using plastic scintillator dosimetry and a heterogeneous phantom

W Ottosson[1,2], C F Behrens[2] and C E Andersen[1]
[1]Center for Nuclear Technologies, Technical University of Denmark, DTU Risø Campus, DK-4000 Roskilde, Denmark
[2]Department of Oncology, Radiotherapy Research Unit, Herlev Hospital, University of Copenhagen, DK-2730 Herlev, Denmark

E-mail: wiot@dtu.dk

Abstract Bone, air passages, cavities, and lung are elements present in patients, but challenging to properly correct for in treatment planning dose calculations. Plastic scintillator detectors (PSDs) have proven to be well suited for dosimetry in non-reference conditions such as small fields. The objective of this study was to investigate the performance of a commercial treatment planning system (TPS) using a PSD and a specially designed thorax phantom with lung tumor inserts. 10 treatment plans of different complexity and phantom configurations were evaluated. Although the TPS agreed well with the measurements for the least complex tests, deviations of tumor dose > 4% were observed for some cases. This study underpins the dosimetric challenge in TPS calculations for clinically relevant heterogeneous geometries. The scintillator system, together with the special phantom, provides a promising tool for evaluation of complex radiotherapy dose calculations and delivery.

1. Introduction

Fiber-coupled organic plastic scintillator detectors (PSDs) feature advantages suitable for complex and dynamic radiation dosimetry in megavoltage photon beams [1-3]. When it comes to heterogeneous setups with lack of charged particle equilibrium (CPE), there are recognized calculation challenges for most commercial treatment planning systems (TPSs). Thus, volumes containing bone, air passages, cavities and lung may deteriorate the TPS dose calculation accuracy [4, 5].

The objective of this study was to investigate the performance of a TPS dose calculation algorithm by using a PSD in a heterogeneous setup, analogous to the geometry of a lung cancer patient, while delivering clinical relevant treatment plans of varying complexity.

2. Material and methods

2.1. Phantom design

A thorax phantom, analogous to a lung cancer patient, was constructed to perform PSD dosimetry in a well-defined heterogeneous geometry. The body of the phantom is made of PMMA, 34 cm in width (W), 23 cm in height (H) and 40 cm in length (L) (figure 1). It contains three hollow cylinders of L:50 cm, and a diameter (Ø) of 10 cm. These cylinders can be filled with several inserts of various materials to simulate different homo- and heterogeneous geometries. The various inserts are made of the copolymer polyoxymethylene (POM-C), balsa wood, and PMMA representing bone, lung and soft

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

tissue, respectively (figure 1, table 1-2). The lung inserts were 15 cm long with a Ø of 9 cm, mimicking a human lung in size. PMMA spheres of various sizes (1-8 cm in diameter) embedded in balsa wood are available to simulate tumors in lung (figure 1 (d)). In the lower part of the body, two smaller cylindrical holes of Ø:2 cm and Ø:3 cm (which also can be altered to Ø:2 cm) are positioned at different distances from the phantom center, i.e. 6.5 cm and 9.5 cm (table 2). These holes can, one at a time, be filled with a POM-C rod to simulate the spinal column at different diameters and position from the center of the phantom (table 2).

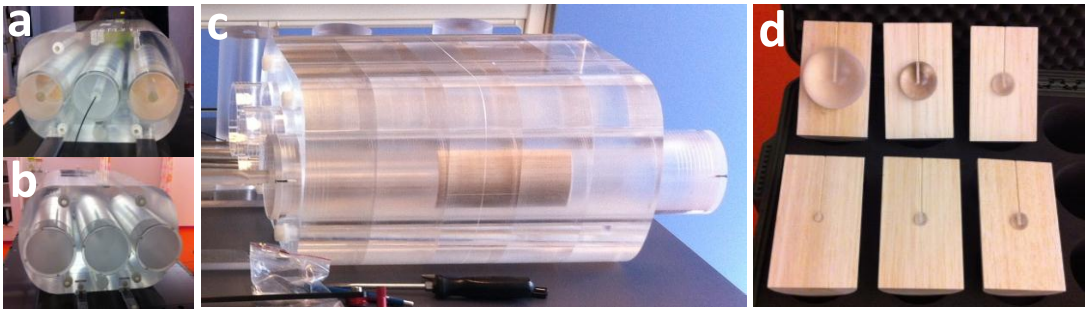


Figure 1. (a) A heterogeneous setup where the two lateral body cylinders are filled with balsa wood inserts. (b) A homogeneous setup, where the whole phantom are filled with PMMA inserts. (c) The heterogeneous setup described in (a) viewed from the side, where the lateral body cylinder containing the lung insert is longitudinal shifted from the central position in the phantom. (d) Balsa wood lung insert with associated tumors, ranging from 1-8 cm in diameter. (Color version of figure is available online.)

2.2. Image acquisition and target definition

Four phantom configurations ('Homo.', 'Hetero.', '3 cm tumor' and '5 cm tumor') scanned in a 16 slice Philips Brilliance CT Big Bore, version 3.5.17001 (Philips Medical Systems, Cleveland, OH) using a standard thorax scanning protocol were used in this study (illustrated in table 2). Table 1 presents the CT image characteristics of the phantom materials of 10 CT series of the phantom compared to corresponding human tissue data for 10 randomly picked lung cancer patients.

Table 1. CT image characteristics of the phantom materials compared to human tissue. Mean HU values and (range) for 10 CT series of the phantom and corresponding tissue data for 10 randomly picked lung cancer patients. Paired t-tests were performed for each tissue type, to check for differences in the mean HU value between the phantom material and the patient tissue data. No significances were found, using $p < 0.05$, i.e. there are good agreement between human tissue and the phantom materials.

Tissue	Phantom Material		HU[b]	
		Density / [g/cm^3]	Phantom	Patients
Bone	POM-C	1.40	319 (309;327)	313 (210;413)
Lung	Balsa wood	0.10	-913 (-917;-888)	-901 (-977;-770)
Soft tissue	PMMA[a]	1.18	116 (103;123)	118 (84;143)

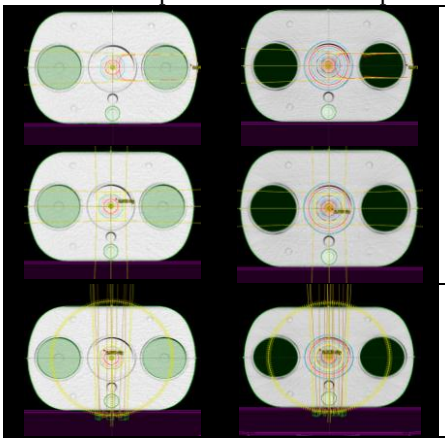
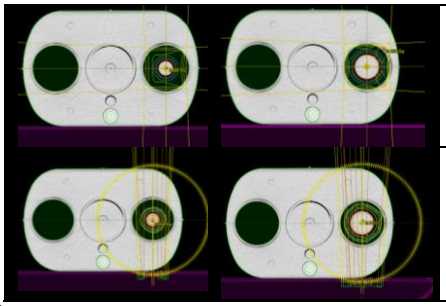
[a.] Poly(methyl methacrylate)
[b.] Using a standard thorax CT scanning protocol by Philips.

Delineations of the anatomical structures GTV, CTV, PTV, medulla, lung and body were performed on all image sets in the treatment planning system (TPS) Eclipse v. 10 (Varian Medical Systems, Palo Alto, CA, USA). CTVs and PTVs were defined as a 5 mm and 10 mm symmetrical expansion of GTV, respectively.

2.3. Experimental setup and calibration conditions

The scintillator used was the BCF-60 (Saint-Gobain Ceramics & Plastics Inc.) with Ø:1 mm and L:2 mm, described by Beierholm *et al* [1]. The PSD was calibrated according to the procedure (method C) described by Guillot *et al* [6] in a solid water calibration phantom. Measurements were carried out using the ME40 scintillator dosimetry system (DTU Nutech) [2]. The reference dose (100 MU, 10x10 cm^2 field) was measured by a Farmer ionization chamber, type 30011 (PTW, Freiburg, Germany) at a depth of 10 cm in the PMMA phantom QUASAR Multi-Purpose Body Phantom (Modus Medical Devices Inc., London, ON, Canada). Irradiation was delivered by a Varian Clinac iX 2300 linear accelerator (Varian Medical Systems), with a beam energy of 6 MV at a dose rate of 600 MU/min [7]. The accumulated PSD dose for the various treatment plans were compared with corresponding TPS calculated point doses (table 2).

Table 2. TPS calculated isocentric point doses compared with corresponding PSD measured dose. (Color version of figure is available online.)

Isocenter is positioned in the center of the phantom			Fiber dose [Gy]		TPS dose [Gy]		Dose deviation [%]	
Homo. setup	Hetero. setup		Homo.	Hetero.	Homo.	Hetero.	Homo.	Hetero.
		Conv.	2.001	2.005	2.000	2.000	-0.1	-0.3
			2.005	2.006	2.000	2.000	-0.3	-0.3
		RA	1.976	1.953	1.984	1.965	0.4	0.6
Isocenter is shifted laterally 11 cm			3 cm tumor	5 cm tumor	3 cm tumor	5 cm tumor	3 cm tumor	5 cm tumor
3 cm tumor	5 cm tumor							
		Conv.	2.114	2.083	2.000	2.000	-5.4	-4.0
		RA	2.323	2.203	2.268	2.175	-2.4[a]	-1.3

[a] The dose deviation per arc was as large as -7.6%.

2.4. Treatment plans and delivery

In total, 10 treatment plans of different phantom configurations and isocentric field techniques (single field, 4-field conventional and two-arc RapidArc (RA) plans) were created. For each treatment plan the isocenter was positioned in the center of the GTV. For six treatment plans the isocenter was positioned centrally in the phantom. Three of these had a homogenous setup (figure 1 (b), table 2), and three of them had a heterogeneous setup (figure 1 (a), table 2). For the remaining four treatment plans the isocenter were shifted 11 cm laterally, because the GTVs were situated in the left lung of the phantom (table 2). Doses were calculated using the AAA algorithm, with a prescribed dose of 2 Gy to the PTV. The RA plans were normalized to the mean dose of the PTV, while the other plans were

normalized to the isocenter. All treatment plans satisfied the clinical dose coverage criteria. For the tumors situated in the lung 98% of the PTV volume was covered by minimum 90% of the prescribed dose. For the treatment plans not situated in the lung the corresponding dose coverage was 95%. The beam energy and dose rate used were 6 MV and 600 MU/min, respectively.

3. Results/Discussion

Under calibration conditions the PSDs agreed with the TPS calculations to 0.1%.

Deviations less than 1% were observed between calculated and measured doses when the isocenter was located in the middle of the phantom. For the homogeneous configuration, deviations were in the range of (-0.1%;0.4%) and for the heterogeneous configuration, deviations were in the range of (-0.3%; 0.6%) (table 2). The RA plans generally resulted in larger total dose deviation (0.4%;0.6%) compared with the simple conventional techniques (-0.3%;-0.1%). These low discrepancies, for the centrally positioned point in the phantom, probably illustrate that there is enough distance to adjacent heterogeneities in the phantom to be able to establish CPE. Larger TPS dose deviations (-5.4%;-1.3%) were observed when the isocenter was shifted laterally, since the GTV was situated in the left lung of the phantom. These substantial deviations could potentially be due to lack of sufficient spread of lateral radiation to obtain CPE. Even larger dose deviations (-5.4%;-2.4%) were observed for the smallest tumor size investigated (3 cm in diameter). This small size of tumor is not large enough to re-establish the CPE condition, and this is most likely the reason why the smallest tumor size results in the highest dose deviation. For the laterally shifted phantom configuration, the simple conventional technique resulted in a higher total dose deviation (-5.4%;-4.0%) compared to the more complex RA (-2.4%;-1.3%). The lower dose deviation, when using RA, might be due to the spread of incident radiation over the whole phantom compared to limited incident angles through heterogeneous medium, when using conventional technique.

4. Conclusion

Dose deviations of < 1% were observed for isocentric field techniques centered in the middle of the phantom, whereas dose deviations > 4% were observed for some laterally shifted treatment plans. The study confirmed that the smallest tumor size results in the highest dose deviation. The scintillator system and the heterogeneous phantom provide a promising tool for critical evaluations of complex radiotherapy calculations and dose delivery.

5. Acknowledgment

Søren Dalsgaard and the DTU Nutech workshop are thanked for making the phantom. Anders Beierholm is acknowledged for his valuable input to this study. The work was partly carried out within the EMRP: "Metrology for radiotherapy using complex radiation fields" (HLT09). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

6. References

[1] Beierholm A R *et al* 2011 *Phys. Med. Biol.* **56** 3033-45
[2] Beierholm A R *et al* 2013 *Radiat. Meas.* **56** 290-3
[3] Beddar A S *et al* 1992 *Phys. Med. Biol.* **37** 1901-13
[4] Papanikolaou N *et al* 2004 *AAPM Report no. 85: Tissue inhomogeneity corrections for mega voltage photon beams* (Madison, WI, USA)
[5] Knöös T *et al* 2006 *Phys. Med. Biol.* **51** 5785807
[6] Guillot M *et al* 2011 *Med. Phys.* **38** 2140-50
[7] Sjöström D *et al* 2009 *Acta Oncol.* **48** 192-200