Radiation Measurements xxx (2017) 1–5

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Time-resolved plastic scintillator dosimetry in a dynamic thorax phantom

Patrik Sibolt [a, b, *], Claus E. Andersen [a], Wiviann Ottosson [b], Claus F. Behrens [b]

[a] Technical University of Denmark, Center for Nuclear Technologies, Risø Campus, Frederiksborgvej 399, DK-4000, Roskilde, Denmark
[b] Herlev Hospital, Radiotherapy Research Unit, Herlev Ringvej 75, DK-2730, Herlev, Denmark

HIGHLIGHTS

- A novel dynamic thorax phantom with reproducible respiratory motion was developed.
- Dynamic thorax phantom and scintillator dosimetry system was synchronized.
- Time-resolved scintillator dosimetry of complex dynamic radiotherapy was enabled.
- Need for quality assurance of motion managed lung cancer radiotherapy was stressed.
- The role of scintillator dosimetry in a dynamic thorax phantom was demonstrated.

ARTICLE INFO

Article history:
Received 29 September 2016
Received in revised form
7 March 2017
Accepted 24 April 2017
Available online xxx

Keywords:
Dynamic thorax phantom
Time-resolved
Plastic scintillator dosimetry
Quality assurance
Lung cancer
Radiotherapy

ABSTRACT

Motion managed and dynamic radiotherapy of lung cancer patients is increasingly complex and subject to challenges related to respiratory motion and heterogeneous tissue densities. This puts high demands on methods for quality assurance and especially time-resolved dose verification of the treatment delivery. The aim of this study was to develop a novel dynamic thorax phantom for time-resolved plastic scintillator dosimetry. The in-house developed phantom has a well-known geometry mimicking a lung cancer patient with a reproducible (within 0.04 mm), respiratory-like motion of a tumor embedded in a lung. The phantom motion was controlled by a script in-house developed using LabVIEW (National Instruments) and synchronized with the in-house developed ME40 scintillator dosimetry system (DTU Nutech). The dose in the center of the tumor was measured, using a BCF-60 plastic scintillator detector (Saint-Gobain Ceramics & Plastics Inc.), during dynamic 6 MV half-arc treatments on a TrueBeam linear accelerator (Varian Medical Systems). Deviations of ~2% from the corresponding dose calculated by the treatment planning system (TPS) were detected. The results emphasize the shortcomings of commercial TPSs to handle respiratory motion and lack of lateral charged particle equilibrium, motivating quality assurance based on a system like the one presented in this study. It has specifically been demonstrated that reliable time-resolved scintillator dosimetry in a dynamic thorax phantom can play an essential role in dose verification of lung cancer radiotherapy.

1. Introduction

Dynamic radiotherapy of lung cancer patients is subject to challenges related to breathing motion and heterogeneities. The report of AAPM Task Group 76 presents recommendations on respiratory motion management during radiotherapy (Keall et al., 2006). The report includes guidelines motion-encompassing methods, respiratory gated techniques, breath-hold techniques, and respiration-synchronized techniques and it moreover stresses the need for quality assurance (QA) of the devices and methods. The demands on reliable QA methods are increasing, as for example gating and tracking methods are becoming more and more complex. It is furthermore known that commercial treatment planning systems (TPSs) have difficulties with accounting for lack of charged particle equilibrium (CPE) in volumes of the body encompassing heterogeneities such as lung, air cavities and bone (Papanikolaou et al., 2004; Knöös et al., 2006; Behrens, 2006; Ottosson et al.,

* Corresponding author. Technical University of Denmark, Center for Nuclear Technologies, Risø Campus, Frederiksborgvej 399, DK-4000, Roskilde, Denmark.
E-mail address: pasi@dtu.dk (P. Sibolt).

http://dx.doi.org/10.1016/j.radmeas.2017.04.016
1350-4487/

2015a). Thus, reliable verification of dose calculation and delivery is critical. Not only is the accumulated dose of relevance but for motion managed radiotherapy the dose delivered as a function of time should be considered. This is especially the case if one is interested in finding the underlying cause of a failed treatment delivery. The benefit of time resolved dosimetry over accumulated dose measurements lies in the increased likelihood of separating errors due to for example MLC motion, gantry motion and interplay effects. Such methods for time-resolved dose verification has previously been presented based on the use of electronic portal imaging device (EPID) (McCurdy and Greer, 2009; Bakhtiari et al., 2011; Liu et al., 2013), fiber-coupled aluminum oxide crystals (Damkjær, 2011), as well as the Scandidos Delta[4] diode array (Sadagopan et al., 2009). However, to the authors' knowledge, there is a lack of systems providing time-resolved measurements in a geometry mimicking the heterogeneous anatomy and respiratory motion of the thoracic part of a patient. A detector suitable for dosimetry in that kind of complex geometry is the fiber-coupled plastic scintillator detector (PSD) as its characteristics make it suitable for time-resolved radiation dosimetry in small, complex and dynamic megavoltage (MV) photon beams (Beddar et al., 1992; Beierholm et al., 2011, 2013, 2015). This study aimed to develop a novel dosimetry system, combining and synchronizing an in-house developed dynamic thorax phantom with an in-house developed PSD dosimetry system. It furthermore aimed to verify the reliability of the system and to test its applicability on clinically relevant dynamic arc treatments.

2. Material and methods

2.1. Dynamic thorax phantom

2.1.1. Phantom description

The dynamic thorax phantom was developed to enable time-resolved dosimetry of complex dynamic radiotherapy using an organic plastic scintillator detector (PSD) in a geometry resembling a lung cancer patient. The phantom design has previously been described, why only a brief description is given here (Ottosson et al., 2015b). A thorax phantom, mimicking a lung cancer patient, was designed and built with a well-defined geometry consisting of a PMMA body (34 cm in width, 23 cm in height, 40 cm in length) with three hollow cylinders (50 cm in length, 10 cm in diameter) (Fig. 1). The cylinders can be filled with various inserts in order to simulate either hetero- or homogeneous geometries. The inserts mimicking bone, lung or soft tissue are constructed out of high density delrin, low density balsa wood, and PMMA, respectively. The dimensions of the inserts were chosen based on data on the human anatomy and PMMA spheres of various diameters (1–8 cm) were embedded inside the lung inserts (15 cm in length and 9 cm in diameter) in order to simulate tumors in the lung. The design of the inserts enables PSD measurements in the center of the tumor.

2.1.2. Dynamic motion of the phantom

In order to replicate the respiratory motion of a lung cancer patient, the thorax phantom, described in section 2.1.1, was connected to a motorized linear stage (A-LST0250B-C, Zaber Technologies Inc.) (Fig. 2). The connection was constructed using a PMMA rod mounted to the stage and attached to the end wall of one of the lateral cylinder inserts. This enabled one dimensional motion of the cylinder through the length of the body of the thorax phantom. In order to simulate a complex realistic dynamic breathing motion of the tumor and lung insert, a script for controlling the motion of the linear stage was in-house developed using LabVIEW (National Instruments). This was partly based on a library of LabVIEW instrument drivers provided by the stage vendor. Communication between the script (local PC) and the linear stage was conducted through a 115 200 baud RS232 serial port. The script operates by first moving the cylinder insert to the center position for an optimal position of the lung insert and tumor before initiating the accelerator beam and scintillator measurements. It thereafter requires an input file describing the desired motion of the cylinder. This motion input should include the expected position as a function of time and can be either manually generated or for example based on monitored respiratory motion of a lung cancer patient using a respiratory monitoring/gating system. As the linear stage is set in motion the script starts to acquire the position of the stage in real-time. Knowing the actual and expected position, the script continuously updates the velocity of the stage in order to continue along the desired motion pattern.

2.2. Time-resolved fiber-coupled plastic scintillator dosimetry

In order to use the PSD measured radiation dose for time-resolved verification of the treatment, the motion of the phantom was required to be linked to the measured dose as a function of time. The motion of the phantom was therefore synchronized with the in-house developed ME40 scintillator dosimetry system (DTU Nutech) (Beierholm et al., 2011) using an external 10 V ramp signal (period: 6 s) which was simultaneously recorded by both systems. The synchronization between measurements and phantom motion furthermore imply a synchronization with the linear accelerator log files as the ME40 system is triggering on the sync pulse from the linear accelerator. It is therefore, for example, possible to use the described dynamic thorax phantom dosimetry system as an input to four-dimensional Monte Carlo simulations, opening up for a solid solution for complete quality assurance of complex lung cancer radiotherapy.

All measurements in this study were carried out using a BCF-60 PSD (Saint-Gobain Ceramics & Plastics Inc.), with a diameter of 1 mm and a length of 2 mm. The system has previously been described and further studied for its potential use in time-resolved verification of dynamic radiotherapy (Beierholm et al., 2011, 2015). With 0.1 ms readout and mm spatial resolution it is well suited for

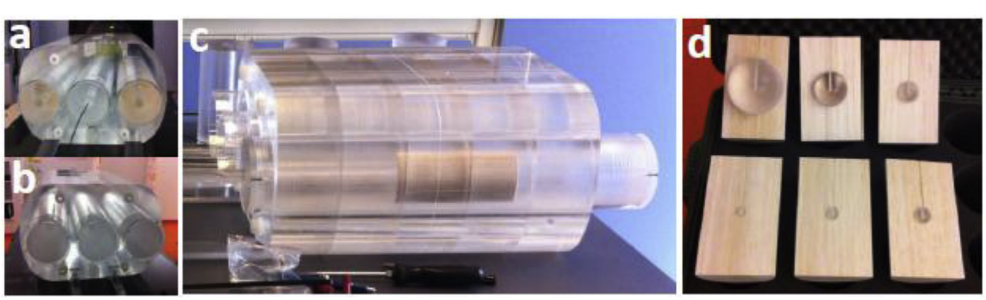

Fig. 1. a) A heterogeneous setup where the two lateral cylinders are filled with balsa wood inserts. b) A homogeneous setup with everything in PMMA. c) The heterogeneous setup described in a) viewed from the side. d) Balsa wood lung inserts with associated tumors. (Figure adopted with permission from Ottosson et al., 2015b).