Radiation Physics and Chemistry 141 (2017) 251–256

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Feasibility study of silica bead thermoluminescence detectors (TLDs) in an external radiotherapy dosimetry audit programme

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ARTICLE INFO

Keywords:
Dosimetry audit
Radiotherapy
SABR
Thermoluminescent detectors

ABSTRACT

Purpose: Investigating the feasibility of using low-cost commercially available silica beads as novel thermoluminescence dosimeters (TLD) for postal dosimetry audit.
Methods: A mail-based dosimetry audit was designed to assess the positional and dosimetric accuracy of SABR-lung treatment delivery using alanine and EBT3-film, placed in a CIRS-anthropomorphic thorax phantom. In conjunction, the silica beads were dosimetrically characterised as TLDs and cross-calibrated against the alanine. A CT-scan of the phantom with pre-delineated volumes was sent to 20 RT centres and used to create a SABR plan using local current protocols and techniques. The silica beads were held in an insert, designed to match that of the alanine holder and ionisation chamber to give the same measurement length. The doses determined by the silica beads were compared to those measured by alanine, the local ionisation chamber, film and the TPS calculation.
Results: The mean percentage difference between the doses measured by the silica beads and the calculated doses by the TPS was found to be 0.7% and differed by 0.6%, 0.7%, and 1.3% from the alanine, film and local ionisation chamber measurements respectively.
Conclusions: Results obtained with the silica beads agree well with those obtained from conventional detectors including alanine, film and ionisation chambers. This together with the waterproof and inert characteristics and minimal dose fading associated with silica bead TLDs confirm their potential as a postal dosimetry audit tool in both water and plastic phantoms which could withstand challenges of temperature and humidity variation, as well as postal service delays.

1. Introduction

Radiotherapy audit provides an external independent assessment of the dosimetry and can help to identify possible improvements and also find issues which may need addressing immediately (Nisbet and Thwaites, 1997; Thwaites et al., 1995; Izewska et al., 2003; Clark et al., 2014, 2015; Ibbott and Thwaites, 2015, Clark et al. 2015).

Although the use of thermoluminescence dosimeters (TLD) as the standard tool for postal dose audits is common practice (Aguirre et al., 2002; Ferreira et al., 2000; Izewska et al., 2003; Izewska and Andreo, 2000) TLDs require improvements to face the new challenges introduced by advanced radiotherapy techniques, and recently several other types of detector have been used for audit including *seven29 array* (PTW-Freiburg GmbH, Germany) and *InLight® nanoDot OSLD system* (Clark et al., 2014; Ibbott and Thwaites, 2015; Hussein et al., 2013). Advanced radiotherapy techniques very often use small radiation fields with high dose gradients (Benedict et al., 2010; Jain et al., 2013) which introduce further challenges in dosimetry. The common and well-established small TLDs, such as 1 mm^3 LiF: Mg, Ti have been designed for traditional radiotherapy practice with an upper dose range limit of approximately 10 Gy and therefore are not suitable for dose evaluation of high dose advanced techniques such as SABR. Furthermore, for postal dosimetry audit of such techniques, especially when complex dose distributions and field arrangements are used, the best detector would be a micro detector with a linear response to a large dynamic dose range and ideally be a detector that also has a very low fading,

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http://dx.doi.org/10.1016/j.radphyschem.2017.07.021
Received 8 May 2017; Accepted 25 July 2017
Available online 29 July 2017
0969-806X/

non-hygroscopic nature and is robust, as irradiation and postage return may take some time (Jain et al., 2013; Izewska et al., 2002).

Silica beads have previously been characterised as novel high spatial resolution micro TLDs (Jafari et al., 2014a, 2014b, 2014c, 2014d, 2016). The particular silica beads employed have several potentially favourable physical characteristics as dosimeters in postal dosimetry audit of advanced radiotherapy. They are small in size (2 mm diameter and 1 mm thickness), chemically inert, inexpensive, readily available, and reusable. They exhibit minimal fading compared with LiF: Mg, Ti TLDs, have a high sensitivity and a large dynamic dose range that remains linear ($R^2 \geq 0.999$) from 1 cGy to 50 Gy (i. e. the investigated dose range). The dose response has been found to be independent of dose rate and incidence of beam angle which makes it suitable for delivery techniques such as VMAT and non-coplanar beams. Although silica beads are silicon based TLDs and not soft-tissue equivalent, they have shown a close to uniform response over the MV photon energy range which is commonly used in advanced radiotherapy techniques. These properties suggest their practical use as TL dosimeters for radiotherapy dosimetry.

In this work the feasibility of using silica bead TLDs for the lung radiotherapy postal dosimetry audit is assessed in conjunction with the UK SABR Lung Consortium dose audit run by the Consortium QA group. Silica beads were placed in the CIRS phantom where heterogeneity is present and the performance of the silica beads in a non-equilibrium condition (near the tissue/lung interfaces) was evaluated.

Stereotactic ablative body radiotherapy (SABR) is an advanced radiotherapy technique that uses low fractionation, high dose treatments, stereotactically directed to the tumour. For example, in SABR for lung a prescription dose of 18 Gy/fraction (in 3 fractions) to the 80% isodose is typically prescribed (IPEM Group, 2010). In such a situation where a high dose is delivered in a few fractions, there are fewer opportunities to correct or adapt the treatment dose. An error in any single fraction would have a larger proportional impact and therefore, the dosimetric accuracy is expected to have a greater effect on radiotherapy outcome. It is therefore essential that such treatments be verified by undertaking appropriate quality assurance (QA). Dose errors in such cases of the order of 5% can result in 10 to 20% changes in tumour control probability and up to 20–30% changes in normal tissue complication probabilities (Chetty et al., 2007).

The audit was designed to assess the positional and dosimetric accuracy of SABR lung treatment delivery across UK. This was achieved with the use of alanine pellets and EBT3 GafChromic film dosimetry, placed in a CIRS lung phantom (Distefano et al., 2015; Distefano et al., in press). 20 volunteer centres within the UK collaborated with this feasibility study.

2. Material and methods

2.1. Silica beads

A batch of transparent silica beads, 2 mm diameter and 1 mm thick outer shell (*Petite*: Stock#: G42010, Mill Hill, Japan) with material composition (by weight): C-8.93%, O-42.18%, Na-10.55%, Al-1.3%, Si-33.62%, K-1.09%, Ca-1.92%, Fe-0.37% (Jafari et al., 2014b) was selected for this work. The silica beads were initially produced as jewellery silica beads and preparation was required for them to be used as TLDs. The silica beads were acid washed in an ultrasonic bath in order to remove the surface-applied colouration and were screened for variation in mass using an Ohaus Adventurer Analytical balance. Overall, 280 silica beads of mass 3.4 ± 0.1 mg were used. For each measurement, 20 silica beads were threaded along a cotton yarn, in order to have the same effective length of measurement as a NE2571 graphite-walled cylindrical ionisation chamber (23 mm). In this arrangement, a high resolution dose profile measurement was obtained as well as the mean value of all 20 silica beads were comparable to the dose measured by each centre's local ionisation chambers. They were then loaded into a custom-built insert.

2.2. Silica bead readout

A Harshaw 4500 planchet TLD reader was employed to readout the silica beads at 300 °C at a ramp-rate of 35 °C/s following a preheat treatment of 140 °C for 10 s. To consider the post radiation time delay for a potential postal service, readings were only obtained following a post-irradiation delay of 10 days. Between each use, the beads were subsequently annealed for 1 h at 400 °C and then kept 24 h at room temperature under dark conditions to ensure they were stabilised prior to the next irradiation. A detailed description of the preparation and annealing procedure has previously been published (Jafari et al., 2014a).

2.3. Silica beads holder insert

Given the phantom was designed for film and ionisation chamber dosimetry, custom made inserts matching the external shape of the NE2571 type ionisation chamber were made from tissue equivalent material (PEEK) in order to hold the silica bead TLDs and the alanine in an identical measurement position. All the inserts were coded to keep track of individual silica beads. Three inserts and a stem were packed in a black card box (Fig. 1) and posted to each centre at the same time as the CIRS phantom, alanine and film were sent by the SABR consortium audit team.

2.4. CIRS Lung phantom

Five CIRS IMRT Thorax Phantoms (The CIRS Model 002LFC) (Fig. 1) were used for the Lung SABR dose audit. This is an anthropomorphic phantom with lungs and a spinal cord in a thorax shaped solid water, which can be used for commissioning as well as comparison of TPS calculated plans and measurements.

A CT scan of a CIRS lung phantom was performed by the SABR consortium audit team prior to the national audit with 1.25 mm slice spacing and thickness. Volumes relating to the internal target volume (ITV) and the position of the alanine pellets were pre-delineated. This CT scan set was sent to all centres and was loaded into their respective treatment planning system. The CT calibration curves were sufficiently similar to justify this single scan and uncertainty was estimated to be no larger than 0.5% (Hussein et al., 2013).

2.5. Audit documents

In addition to dosimeters, the following documents, dosimetry protocols and instruction sheets were prepared and sent to each centre:

- A dosimetry audit protocol, which was prepared by the SABR consortium audit team, provided explanation of the phantom description, handling, CT-scanning and planning, EBT3 GafChromic film dosimetry and procedures for returning film for processing, as well as return of the alanine dosimeters to the National Physical Laboratory for readout.
- A GafChromic film irradiation record form
- An alanine irradiation record form
- Silica beads introductory document
- Silica beads dosimetry instructions and irradiation record form

2.6. Measurement procedure

2.6.1. Silica beads calibration

This batch of silica beads has been dosimetrically characterised in the previous studies and the details of characterisation measurements are published in earlier publications (Jafari et al., 2014a, 2014b). Linearity of dose response covering the range of radiotherapy dose levels (1 cGy to 50 Gy), had a correlation coefficient of $R^2 \geq 0.999$; therefore, the large dose differences between reference dose