Physica Medica 48 (2018) 119–126

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Establishment of postal audit system in intensity-modulated radiotherapy by radiophotoluminescent glass dosimeters and a radiochromic film

Hiroyuki Okamoto[a,*], Toshiyuki Minemura[b], Mitsuhiro Nakamura[c], Hideyuki Mizuno[d], Naoki Tohyama[e], Teiji Nishio[f], Akihisa Wakita[a], Satoshi Nakamura[a], Shie Nishioka[a], Kotaro Iijima[a], Daisuke Fujiyama[a], Jun Itami[a], Yasumasa Nishimura[g]

[a] Department of Radiation Oncology, National Cancer Center Hospital, 104-0045 Tokyo, Japan
[b] Center for Cancer Control and Information Services, National Cancer Center, Tokyo 104-0045, Japan
[c] Division of Medical Physics, Department of Information Technology and Medical Engineering, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto 606-8507, Japan
[d] Department of Radiation Measurement and Dose Assessment, National Institute of Radiological Sciences (NIRS), National Institutes for Quantum and Radiological Science and Technology (QST), Chiba 263-8555, Japan
[e] Division of Medical Physics, Tokyo Bay Advanced Imaging & Radiation Oncology Makuhari Clinic, Chiba 261-0024, Japan
[f] Department of Medical Physics, Graduate School of Medicine, Tokyo Women's Medical University, Tokyo 162-8666, Japan
[g] Department of Radiation Oncology, Kindai University Faculty of Medicine, Osaka 589-8511, Japan

ARTICLE INFO

Keywords:
Audit
Radiophotoluminescent glass dosimeter
Radiochromic film
IMRT
QA/QC

ABSTRACT

We developed an efficient postal audit system to independently assess the delivered dose using radiophotoluminescent glass dosimeters (RPLDs) and the positional differences of fields using EBT3 film at the axial plane for intensity-modulated radiotherapy (IMRT). The audit phantom had a C-shaped target structure as a planning target volume (PTV) with four measurement points for the RPLDs and a cylindrical structure as the organ at risk (OAR) for one measurement point. The phantoms were sent to 24 institutions. Point dose measurements with a 0.6 cm^3 PTW farmer chamber were also performed to justify glass dosimetry in IMRT. The measured dose with the RPLDs was compared to the calculated dose in the institution's treatment planning system (TPS). The mean ± 1.96σ of the ratio of the measured dose with the RPLDs to the farmer chamber was 0.997 ± 0.024 with no significant difference (p = .175). The investigations demonstrated that glass dosimetry was reliable with a high measurement accuracy comparable to the chamber. The mean ± 1.96σ for the dose differences with a reference of the TPS dose for the PTV and the OAR was 0.1 ± 2.5% and −2.1 ± 17.8%, respectively. The mean ± 1.96σ for the right-left and the anterior–posterior direction was −0.9 ± 2.8 and 0.5 ± 1.4 mm, respectively. This study is the first report to justify glass dosimetry for implementation in IMRT audit in Japan. We demonstrate that our postal audit system has high accuracy with a high-level criterion of 3%/3 mm.

1. Introduction

Treatment processes with highly developed systems exhibit complication in modern radiotherapy [1,2]. Hence, quality management is important for safer radiotherapy, and robustness of the framework of the treatment process against radiotherapy errors is desirable. High-risk events associated with severe radiotherapy toxicity should be actively eliminated from these processes, as suggested by the new concept guideline provided by the American Association of Physicists in Medicine (AAPM) Task Group (TG) 100 [2]. TG-100 provides the methodology and useful quality management tools, such as process map, incident reporting system, and risk assessment. In addition, TG-100 describes the importance and the role of external audits in radiotherapy. Audit has aspects and approaches that are different from the usual quality assurance/quality control (QA/QC) program routinely performed in hospitals. Its goal is to independently assess the institution's treatment process and treatment accuracy.

To this end, several audit systems that have been established globally are successful in external beam radiotherapy [3–12] and brachytherapy [13–16]. The role of the typical audit methodology is to independently assess dosimetric accuracy through measurements using the dedicated phantom. The delivery in the audit intends to involve

* Corresponding author at: Department of Radiation Oncology, National Cancer Center Hospital, 5-1-1 Tsukiji, Chuo-ku, 104-0045 Tokyo, Japan.
E-mail address: hiokamot@ncc.go.jp (H. Okamoto).

https://doi.org/10.1016/j.ejmp.2018.03.013
Received 9 November 2017; Received in revised form 24 February 2018; Accepted 23 March 2018
Available online 24 April 2018

overall clinical treatment processes, such as planning computed tomography (CT) scans, treatment planning, setup, and delivery, mimicking a scenario of an actual patient undergoing radiotherapy.

The Imaging and Radiation Oncology Core (IROC) group earlier explored the establishment of an audit system in radiotherapy [3–5]. They demonstrated the effectiveness of the audit in intensity-modulated radiation therapy (IMRT) using a head and neck anthropomorphic phantom with a thermoluminescent dosimetry (TLD) and a radiochromic film. They found that failures in the audit system were associated with incorrect data being input into the treatment planning system (TPS), inaccuracy of beam modeling in the TPS, and instances of software and hardware failure [5].

The postal audit system in Japan began in 2007 for a reference condition in external radiotherapy [8] and in 2014 for a non-reference condition (e.g., wedge fields) [9]. The on-site system for external audit in IMRT mainly began in institutions participating in clinical trials conducted by a multicenter clinical study group, called the Japan Clinical Oncology Group (JCOG) [10]. However, certain issues, including lack of manpower and time-consuming procedures, were encountered while conducting the on-site audit. The use of IMRT is no longer limited to clinical trials, but has been extended to clinical practice, which has dramatically increased. To address these issues, the need of a postal audit system for IMRT in Japan has been considered in domestic intersociety meetings since 2015. In fact, a project team composed of more than a dozen qualified medical physicists in Japan was established to start the postal audit system for IMRT in the country.

This study aims to establish an efficient postal audit system in IMRT using radiophotoluminescent glass dosimeters (RPLDs) and a radiochromic film. Only a few studies were performed to implement glass dosimetry in radiotherapy [17–19]. To the best of our knowledge, this study is the first to report on justifying glass dosimetry for implementation in postal IMRT audit. We also assess the effectiveness and the efficiency of the postal audit system compared to the ordinary on-site audit system.

2. Materials and methods

2.1. Phantom design

Fig. 1a shows the postal audit phantoms used for treatment planning (left figure) and irradiation (right). Fig. 1b illustrates the cross-section of the two phantoms. Each phantom had a dimension of $16 \times 16 \times 16\ cm^3$. The cross-hairs of the scribe lines can be found on the surface of both phantoms, representing the center position of the phantom indicated by a green cross-hair in Fig. 1c. The treatment planning phantom had a C-shaped target structure as the planning target volume (PTV) and a cylindrical structure as the organ at risk (OAR), which was made of acrylic (Fig. 1b). Hence, they can be identified and delineated on the CT image, as shown in Fig. 1c (left figure).

However, dose calculation should be performed in homogeneous water (Fig. 1c), and the density of acrylic and the phantom material should be set to the density of water because the irradiation phantom had a uniform water-equivalent material (tough water [20], Kyoto Kagaku Co., Ltd, Kyoto, Japan). Four measurement points can be found inside the PTV (i.e., C_1, C_2, C_3, and C_4) and one inside the OAR (i.e., OAR in the figure). Each measurement point had two RPLDs (i.e., GD-302 M (AGC Technology Solutions Co., Ltd., Kanagawa, Japan)) aligned in a longitudinal direction. The five measurement points were delineated to obtain the mean calculated dose for comparison with the dose measured with the RPLDs. The dedicated phantom to the point dose measurements, which was capable of inserting the chamber, was also used to measure the absorbed dose with the chamber in the PTV and the OAR to justify glass dosimetry. In addition, a radiochromic film EBT3 (Ashland Inc., NJ, USA) can be placed inside the irradiation phantom in the axial plane of the central position of the phantom to assess the positional difference of the radiation fields.

2.2. Glass dosimetry

As shown in Fig. 2, we established a reading protocol designed to reduce the statistical variations and exclude the outliers in readings. The RPLD can be repeatedly read in a glass dosimetry reader FGD-1000 (AGC Technology Solutions Co., Ltd., Kanagawa, Japan). A dataset had five readings, and a mean value can be calculated from the dataset (Fig. 2). In our protocol, when five mean values were obtained, the maximum difference Δ_{max} for all RPLDs among the five measurements was calculated to estimate the outlier in the readings. The reading process will end if Δ_{max} falls within 0.5%, and the mean values from the five mean values can be used as the RPLD reading corresponding to M_{raw} for the derivation of the absorbed dose, as described in Eq. (1). However, the worst dataset of the five measurements characterized by the greatest deviation is removed, and a new dataset is additionally obtained if Δ_{max} is beyond 0.5%. The five datasets can then be updated with the newly recorded one. Moreover, Δ_{max} is calculated once again for the second round of assessments. The reading process continues until Δ_{max} falls within 0.5%.

Fig. 3a depicts that glass dosimetry (a gray arrow) is contained in a capsule (a white arrow), and we capsule the glass dosimetry in the irradiations. Twenty RPLDs were managed for an examination (Fig. 3b). Four of these were used to assess the background level (without irradiation during postal audit); six were used as a reference to derive the absorbed dose in water; and 10 RPLDs were used for the point dose measurements in the IMRT delivery. A predetermined model number of the read-out magazine should be used for 20 RPLDs (Fig. 3c) because the RPLD showed high sensitivity in reading even toward slight changes in the reading conditions, such as positions and rotations of the RPLD inside the read-out magazine.

Therefore, the same model number of the read-out magazine should be used to maintain constant reading conditions.

The glass dosimetry formula is presented as follows:

$$D^k = M_{raw}^k R^k \cdot C \cdot E_Q \cdot P_Q \quad (1)$$

where D^k and $M_{raw}^k R^k$ represent the RPLD absorbed dose (ID = kth, Fig. 3b) and the reading of RPLD M_{raw}^k with a sensitivity correction factor R^k, respectively. The sensitivity correction R can correct any individual difference in the response of each RPLD and can be derived from the equation $M_{raw}^k/(\sum_{k=1}^{k=20} M_{raw}^k/20)$ by irradiation to 20 RPLDs with a field size of $10 \times 10\ cm^2$ and 6 MV X-rays. Fig. 4 shows an example of the sensitivity corrections for individual differences in the response of 20 RPLDs at three different dates (i.e., Aug 2015, Jun 2016, and Oct 2017). No significant change was observed in the response of the RPLDs in the long term.

We irradiated six reference RPLDs placed at a depth of 10 cm in a water-equivalent phantom (tough water) with a reference beam Q_0 of 6 MV X-rays with a field size of $10 \times 10\ cm^2$ (Varian iX, Varian Medical Systems, Palo Alto, USA) in the reference institution. The absorbed dose D_{ref} in the phantom at a depth of 10 cm was measured in advance with a $0.6\ cm^3$ PTW farmer chamber (30013, PTW, Freiburg Germany). From this result, the calibration factor C can be obtained using D_{ref}/M_{ref}, where M_{ref} represents the mean value of the reference RPLD readings with sensitivity correction. E_Q denotes a correction caused by the energy dependence of the RPLDs, and can be expressed by a function of beam quality, $TPR_{20,10}$, in relation to the reference beam Q_0 with a $TPR_{20,10}$ of 0.665, namely $E_{Q_0} = 1$ (Fig. 5). E_Q was derived from the ratio of the absorbed dose measured with an ionization chamber to the RPLD under a reference condition. P_Q denotes a conversion factor from the absorbed dose in the water-equivalent phantom to that in water, which can also be expressed by a function of the beam quality, $TPR_{20,10}$, which was obtained from a ratio of the absorbed dose in water to that in the water-equivalent phantom measured with the farmer chamber. E_Q and P_Q can broadly cover the beam qualities of ^{60}Co γ-ray and 4, 6, 10, and 15 MV X-rays (Fig. 5).