Physica Medica 31 (2015) 414–419

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Technical notes

A novel method for dose distribution registration using fiducial marks made by a megavoltage beam in film dosimetry for intensity-modulated radiation therapy quality assurance

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A R T I C L E I N F O

Article history:
Received 3 October 2014
Received in revised form
28 January 2015
Accepted 2 February 2015
Available online 25 February 2015

Keywords:
Film dosimetry
Radiochromic film
Quality assurance
Dose distribution

A B S T R A C T

Purpose: Photographic film is widely used for the dose distribution verification of intensity-modulated radiation therapy (IMRT). However, analysis for verification of the results is subjective. We present a novel method for marking the isocenter using irradiation from a megavoltage (MV) beam transmitted through slits in a multi-leaf collimator (MLC).
Methods: We evaluated the effect of the marking irradiation at 500 monitor units (MU) on the total transmission through the MLC using an ionization chamber and Radiochromic Film. Film dosimetry was performed for quality assurance (QA) of IMRT plans. Three methods of registration were used for each film: marking by irradiating with an MV beam through slits in the MLC (MLC-IC); marking with a fabricated phantom (Phantom-IC); and a subjective method based on isodose lines (Manual). Each method was subjected to local γ-analysis.
Results: The effect of the marking irradiation on the total transmission was 0.16%, as measured by a ionization chamber at a 10-cm depth in a solid phantom, while the inter-leaf transmission was 0.3%, determined from the film. The mean pass rates for each registration method agreed within $\pm$1% when the criteria used were a distance-to-agreement (DTA) of 3 mm and a dose difference (DD) of 3%. For DTA/DD criteria of 2 mm/3%, the pass rates in the sagittal plane were 96.09 $\pm$ 0.631% (MLC-IC), 96.27 $\pm$ 0.399% (Phantom-IC), and 95.62 $\pm$ 0.988% (Manual).
Conclusion: The present method is a versatile and useful method of improving the objectivity of film dosimetry for IMRT QA.

Introduction

Photographic film is widely used for the dose distribution verification of intensity-modulated radiation therapy (IMRT). A more recent development is the use of a multi-dimensional detector and an electronic portal imaging device (EPID) [1–2]. For example, there are diode detector arrays of MapCheck2 (Sun Nuclear) and ion chamber detectors of MatiXX (IBA Dosimetry) or OCTAVIUS 729 (PTW) in two-dimensional detectors. And there are detector arrays of ArcCHECK (Sun Nuclear) or Delta4 (ScandiDos) in three-dimensional detectors. However, because of its low-introduction cost and high spatial resolution, photographic film is still useful for dose distribution verification. Moreover, photographic film can be used even in facilities that lack a film processor because radiochromic film (RCF) can be used under lighted conditions and needs no processing. In addition to requiring less know-how than radiographic films (RGFs), such as Kodak extended dose range 2 (EDR2) and XV2 film, RCF has lower energy dependence,

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http://dx.doi.org/10.1016/j.ejmp.2015.02.003

and its wide energy range and composition are similar to human soft tissue, compared with RGF. The Gafchromic EBT2 and EBT3 could also be applied to the electron and proton beams as well as photon beams [3,4,5]. RCF or RGF has, however, uncertainties of film characteristics or scanning. van Buttum et al. [6] reported RGF has an uncertainty of 2% even when an integrated protocol is used. Also, Borca et al. [7] reported Gafchromic EBT3 has an uncertainty of 1.7%.

To verify the obtained dose distribution it is necessary to register the dose distribution from the treatment planning system with the dose distribution of the film. Two common methods include marking the film during measurement to identify the isocenter and manual registration performed by comparing isodose lines and dose profiles. In the former case, the positional location of the film can change with respect to the phantom after marking. In the latter case, subjectivity of the observers can lead to different results of analysis, even using the same data set. Also, there are a couple of methods to make it objective (like e.g. automated registration algorithms).

Here, we present a method of isocenter marking that uses a megavoltage (MV) beam to irradiate the film through four small slit-like fields made by a multi-leaf collimator (MLC). This method eliminates the subjectivity of the observers while facilitating marking. Winkler et al. [8] reported that the uncertainty of phantom positioning is 0.5 mm, while the uncertainty of using fiducial marks is 0.4 mm. In this study, the uncertainty of phantom positioning could be decreased because marking with the MV beam was conducted after the phantom was set. This means that the marking was also independent of the quality control of the lasers used for the phantom setup. However, MV beam transmission through the MLC could potentially affect the dose distribution verification.

In this study, we evaluated the effect of the marking irradiation on the dose distribution and performed a γ-analysis of three registration methods for IMRT QA.

Materials and methods

Equipment and materials

For dose distribution verification, we used a four-dimensional radiation therapy system, Vero4DRT (Mitsubishi Heavy Industries, Tokyo, Japan), with an RT-3000-New phantom (R-Tech, Tokyo, Japan) and Gafchromic EBT3 film (batch number A02061302, International Specialty Products, Wayne, NJ, USA). A flatbed scanner, the Epson ES-10000G (Seiko Epson Corporation, Suwa, Nagano, Japan), was used to read the irradiated film, and the digitized images were analyzed using the DD-system software (R-Tech, Tokyo, Japan).

The MLC of the Vero4DRT has 30 pairs of leaves (5-mm width and 110-mm height) under a fixed jaw (15×15 cm^2). The MLC is a single-focus type with tongue-and-groove construction. Nakamura et al. [9] reported the maximum inter- and intra-leaf transmission is 0.21% and 0.12%, respectively, and the mean transmission is 0.11%.

Fiducial marking using an MLC

As illustrated in Figs. 1 and 2, fiducial marks were produced on the film by irradiation through four tiny slits in the MLC before or after the treatment planning irradiation. With this setup, there was no need to pay particular attention to the film orientation because the marking could be performed after the phantom setup. Errors in the laser-mediated setup of the phantom could also be decreased. The fiducial marks make it possible to determine the right-left (RL) axes and superior-inferior (SI) axis coordinate in the coronal plane, or the anterior-posterior (AP) axis and the SI axis in the sagittal plane of MLC independently of the observers' positions. However, random errors from the variability in MLC positioning remained. Nakamura et al. [9] reported the leaf position accuracy was 0.0 ± 0.1 mm, ranging from -0.3 to 0.2 mm at four gantry angles of 0°, 90°, 180°, and 270°.

Effect of the marking irradiation on the total transmission through the MLC

Scattering of the marking irradiation may contribute to the total transmission through the MLC and affect the IMRT dose distribution. Therefore, we evaluated the effect of the marking irradiation on the total transmission through the MLC using a Farmer-type ionization chamber and RCF. A PTW 30013-Farmer ionization chamber (PTW, Freiburg, Germany) was set at a source axis distance (SAD) of 100 cm and at a 10-cm depth in a water-equivalent solid phantom (TM phantom, Taisei Medical Co, Osaka, Japan), and then given 500 monitor units (MU) of fiducial marking irradiation. As a control, the measurement was repeated with 500 MU of irradiation through a completely open MLC (15×15 cm^2). The percentage of the marking irradiation that reached the phantom was

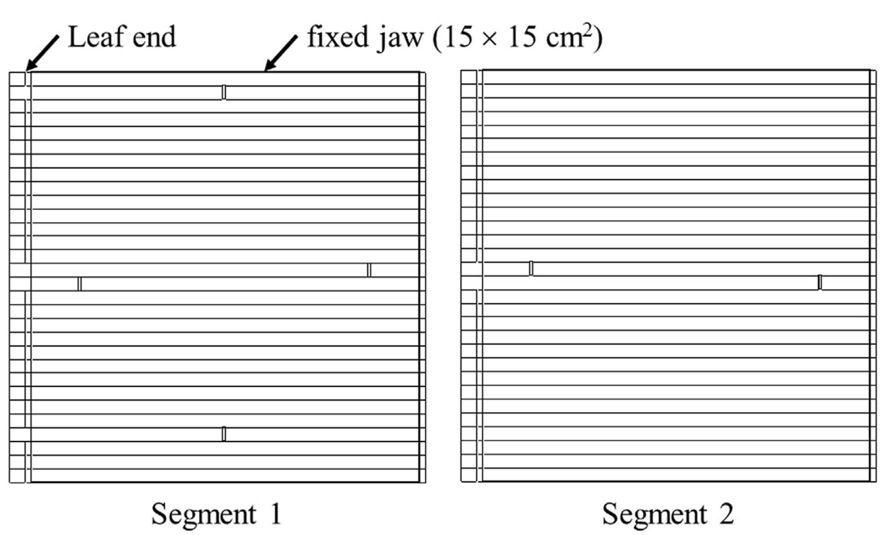

Figure 1. Leaf sequence for fiducial marking using a multi-leaf collimator (MLC). Slit-like fields (1-mm gap width) were created using two segments, each delivering 250 monitor units (MU). The beam angles for the coronal and sagittal planes were 0° and 90°, respectively.