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Microfocus X-ray imaging of the internal geometry of brachytherapy seeds

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HIGHLIGHTS

- The internal geometry of brachytherapy seeds was evaluated nondestructively.
- A novel microfocus X-ray imaging method was used for the first time for this purpose.
- The two ^{125}I seed models commercially available in Japan were evaluated.
- The microfocus X-ray imaging method was found to be useful for this purpose.
- Geometrical size parameters were obtained for the two seed models.

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ABSTRACT

Precise and reliable geometrical data on the internal structure of seeds are indispensable for dosimetric calculation in brachytherapy. We used a novel microfocus X-ray imaging technique for observing the internal structure of brachytherapy seeds. Two popular ^{125}I seed models were evaluated. Obtained high precision images enabled us to observe the internal structure of seeds qualitatively. Geometrical size parameters were evaluated quantitatively with uncertainty of 0.01–0.04 mm (k=2).

1. Introduction

The dosimetry of low-energy low-dose-rate (LDR) interstitial brachytherapy sources has been based on the Task Group No. 43 (TG-43) report and its update (TG-43U1) with a supplement (TG-43U1S1) (Nath et al., 1995; Rivard et al., 2004, 2007). In the standard two-dimensional (2D) framework recommended for cylindrically symmetric sources, the dose-rate at a distance of r (the distance from the center of the active source to the point of interest) and a polar angle of θ (the polar angle specifying the point-of-interest relative to the source longitudinal axis) is represented as follows

$$\dot{D}(r) = S_K \times \Lambda \times \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \times g_L(r) \times F(r,\theta), \quad (1)$$

where r_0 is the reference distance (1 cm), θ_0 is the reference polar angle ($\pi/2$), S_K is the air kerma strength, Λ is the dose rate constant, $G_L(r, \theta)$ and $G_L(r_0, \theta_0)$ are called geometry factors, $g_L(r)$ is the radial dose function, and $F(r, \theta)$ is the anisotropy function. In general, these parameters and functions depend on the geometrical parameters of brachytherapy seeds. Although the

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responsibility of offering reliable data on seed geometry is primarily on the manufacturers and vendors (DeWerd et al., 2013), it is important that medical physicists assess available data on seed geometry and estimate the uncertainties associated with each dimension independently (DeWerd et al., 2011).

While brachytherapy treatment of prostate cancer has been practiced since the early 20th century, the first permanent seed implant using ^{125}I was performed in the 1970s by a retropubic technique (Butler and Merrick, 2005; Lief, 2005; Thomadsen et al., 2008). It was not until the modern techniques of transperineal interstitial implant and transrectal ultrasound guidance were introduced that permanent brachytherapy has become a common treatment option for localized prostate cancer in the United States (Davis et al., 2012; Nag et al., 1999; Nath et al., 2009). The TG-43U1 and TG43U1S1 reports described dosimetric data of sixteen types of seeds. In Japan, permanent interstitial brachytherapy with ^{125}I seeds was approved in 2003 for treatment of prostate cancer. Currently two types of seeds, the model 6711 (GE Healthcare/Oncura, Arlington Heights, IL) and the model STM1251 (C. R. Bard, Inc., Murray Hill, NJ), are available (Hanada et al., 2010; Saito et al., 2007; Sumida et al., 2009).

The model 6711 seed has been the subject of many dosimetric studies for nearly 30 years (Ali et al., 2009; Capote et al., 2001; Duggan, 2004; Ling et al., 1983; Mobit and Badragan, 2004; Rodríguez et al., 2005; Sakelliou et al., 1992), ever since it was introduced in the early 1980s. A set of currently standard dosimetry and geometry data of the model 6711 are described in the TG-43U1 report. The geometry was more realistically evaluated by Dolan et al. (2006), where refined dosimetric data were presented considering possible geometrical uncertainty. X-ray radiographs of overall internal structure and electron microscopic images of an end part of an encapsulated source component were used to extract geometric data. However, the spatial resolution of the conventional X-ray radiography is not sufficient for precise evaluation. On the other hand, the model STM1251, which was introduced more recently, is also a well-documented seed model. A set of currently standard dosimetric data is described in the TG-43U1S1 report, where the geometry data for the model STM1251 are based on previous articles (Kirov and Williamson, 2001, 2002). Also a comprehensive Monte Carlo simulation study (Taylor et al., 2007; Taylor and Rogers, 2008; Yegin, 2003) for various types of seeds including the two models referred to those geometrical data.

Recently, it was demonstrated that a microfocus X-ray imaging technique can be used to investigate the internal geometry of small shielded radioactive sources nondestructively for the purpose of their quality control (Hasegawa et al., 2012). The same technique is expected to be useful for quality control studies on small brachytherapy sources. In this study, a microfocus X-ray imaging technique was used to observe the internal structure of seeds and evaluate their geometrical parameters. To the best of our knowledge, this is the first research article of such an approach.

2. Materials and methods

2.1. Sample seeds

Two types of seed models were examined: model 6711, *OncoSeed*™ (GE Healthcare/Oncura), and model STM1251, *BrachySource*™ (C. R. Bard, Inc.). A model 6711 seed consists of a cylindrical titanium capsule and a silver wire coated with a radioactive layer made of AgI and AgBr (Dolan et al., 2006; Hanada et al., 2010). A model STM1251 seed consists of a cylindrical titanium capsule of a similar size and a cylindrical radioactive part. It consists of a gold core rod and an outer aluminum cylinder, on which thin layers of copper, nickel, and radioactive material are coated (Kirov and Williamson, 2001, 2002). Twenty samples of model 6711 were supplied by Nihon Medi-Physics Co., LTD. (Tokyo Japan) and twenty samples of model STM1251 were supplied by Medicon, Inc. (Osaka, Japan). These 40 samples were mimic samples produced by the same production procedures as the commercial seeds except that radionuclides were not introduced.

2.2. Microfocus X-ray imaging system

The microfocus X-ray imaging system used for obtaining projection X-ray images was SMX-2000 (Shimadzu Co., Ltd., Kyoto, Japan). The system was equipped with an X-ray source viz. MTT-160CL (Shimadzu Co., Ltd.) and a flat panel detector. The nominal focal spot size was 1 μm. The detector nominal sensitive area and matrix size were (52.8×52.8) mm^2 and 1000×1000, respectively. The microfocus X-ray imaging system used for CT imaging was

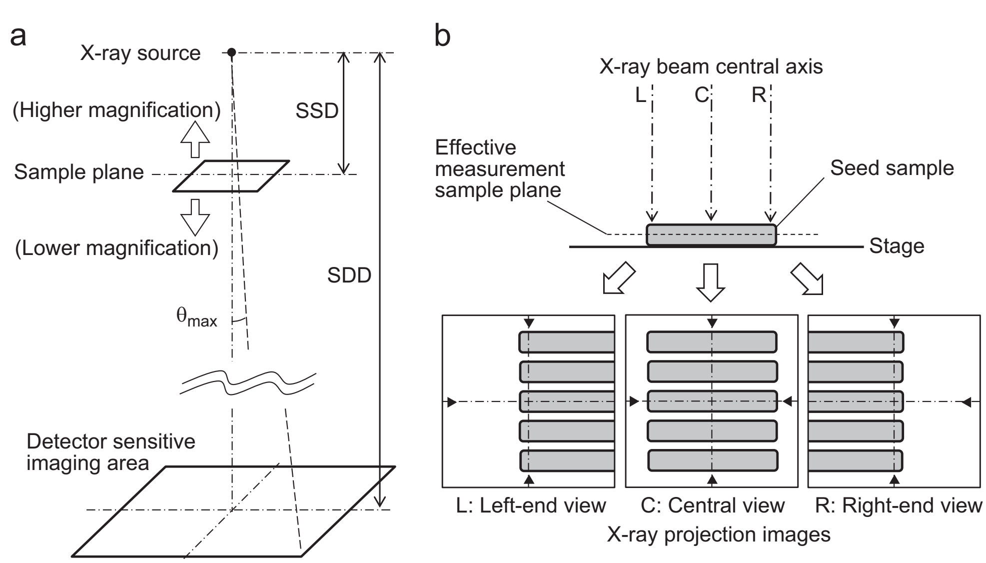

Fig. 1. (a) Measurement geometry; the source sample distance and source detector distance are denoted by SSD and SDD, respectively. The maximum oblique angle at a detector corner, θ_{max}, is 0.12 rad (7°) at SDD = 300 mm for SMX-2000 and 0.09 rad (5°) at SDD = 500 mm for XVA-160. (b) Left-end, central, and right-end views of seed samples in X-ray projection images. The triangle marks indicate the position of the image center.