ELSEVIER

Brachytherapy ■ (2015) ■

BRACHYTHERAPY

Anthropomorphic phantom to investigate the bladder dose in gynecological high-dose-rate brachytherapy

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ABSTRACT

PURPOSE: This study presents a prototype of a phantom appropriate for experimental bladder dosimetry. This work presents details of the phantom construction and dosimetric results obtained using radiochromic film and optically stimulated luminescence dosimeters (OSLDs).

METHODS AND MATERIALS: The phantom was constructed of polymethyl methacrylate. Two artificial bladders were three-dimensional printed using previous computed tomography images. Radiochromic films and OSLDs were positioned on the artificial bladder walls, and the applicators were placed according to the original computed tomography image.

RESULTS: The prototype phantom simulated the behavior of the dose on the bladder surface, enabling bladder movement in all directions. The dosimetric study that was performed using radiochromic film and OSLDs exhibited concordance, in most cases, with the results obtained from the planning system.

CONCLUSIONS: The methodology presented offers conditions for researchers to investigate more accurately the behavior of the dose on the bladder surface during intracavitary brachytherapy procedures.

Keywords: Brachytherapy; Bladder; Phantom; Dosimetry; Film

Introduction

Intracavitary brachytherapy (ICBT) is an essential component in the treatment of cervical cancer (1). In external beam therapy, a homogeneous dose distribution can be achieved over the target volume; however, in brachytherapy, the dose distribution exhibits steep gradients over the target volume and organs at risk (OAR) due to the proximity of the sources and the inverse square law. These characteristics make the dose to the OAR difficult to assess and to specify with a single value and in simple terms (2). In the case of the bladder, many studies have demonstrated that the dose delivered to this organ during a course of brachytherapy is significantly different to that estimated by the International Commission on Radiation Units and Measurements (ICRU) reference point (3–5). In contrast, other studies found that the doses of the ICRU reference point for the bladder correlate strongly with the maximum delivered dose in this organ (6, 7). Recently, the American Brachytherapy Society recommended that a point located 1.5 cm above the ICRU bladder point may be more representative (8). For these reasons, in a general context, there is no consensus of a point capable of estimating the dose to this organ and predicting later complications.

Actually, images from computed tomography (CT) and magnetic resonance imaging obtained with compatible intracavitary gynecological applicators are being used in several countries for three-dimensional (3D) image-based treatment planning, optimizing the dose prescriptions in the target volume and the dose volume histogram (DVH), thereby improving the quality of treatment (9). However, in a large number of countries, the use of ICRU reference points obtained from orthogonal radiographs persists (10, 11).

Several researchers have suggested in vivo dosimetry to check dose delivery to the bladder and rectum; however, the main difficulty with this procedure is defining and localizing the appropriate positions in the OAR, where dosimeters, such as diodes, thermoluminescent dosimeters (TLDs), or others, can be positioned. The position must be relevant to predicting the side effects of the dose (12).

Received 19 January 2015; received in revised form 6 May 2015; accepted 7 May 2015.

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1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2015.05.005

The recommendation to report at least three values ($D_{0.1\ cc}$, $D_{1\ cc}$, and $D_{2\ cc}$ of 0.1, 1, and 2 cm^3, respectively) for the minimum dose in the most irradiated tissue volume adjacent to the applicator was proposed in 2005 by the Groupe Européen de Curiethérapie/European Society for Therapeutic Radiology and Oncology (GEC-ESTRO) (13). The doses at these volumes have been termed hotspots. The GEC-ESTRO guidelines also recommend estimation of the absolute doses in the volumes of the OAR by adding DVH parameters from each fraction; this estimation is named the ''worst-case assumption.'' This definition assumes that the location of a given hotspot volume is identical in each brachytherapy fraction (13). However, factors that may occur closer to the applicator between imaging and dose delivery, such as intrafraction motion related to OAR, which could result in doses that are even higher than those calculated under the so-called worst-case assumption (13).

Because it is possible that hotspots within an organ may alter their positions as they shift from fraction to fraction, some studies have proposed techniques to estimate and evaluate the dose by taking into account this behavior (14–17). But, these studies show, in general, results from new algorithms that are only compared with the planning system and validated using nonanthropomorphic objects, such as phantoms that do not represent the real and complex bladder size (e.g., balloons with radio-opaque markers on their surfaces). One of the most realistic studies was performed by Wognum *et al.* (18), who determined the spatial accuracy of different deformable image registration algorithms using CT images of ex vivo porcine bladders; however, the results were only compared using virtual analysis, and difficulties to determine the dose accumulation also were related. In a practical form, there are, in fact, no methodologies described in the literature using experimental procedures capable of investigating the real behavior of the dose on the bladder surface during ICBT.

Considering all the difficulties related to the determination of the dose delivered at the bladder surface in an ICBT procedure for cervical cancer, this study presents a prototype of a phantom using artificial bladders printed by a 3D printer, which is able to simulate the dose behavior on the walls of this organ. This work presents details of the phantom construction and preliminary dosimetric results obtained using radiochromic film and optically stimulated luminescence (OSL) dosimetry. The dosimetric study was performed to confirm the capacity of the phantom to simulate the dose distribution on bladder surface during real clinical situations of ICBT for cervical cancer. Besides, were evaluated the mass attenuation coefficient for the thermoplastic used to print the artificial bladders, the bladder volumes based on different delineations, and the DVHs from the treatment planning system (TPS) for real and artificial bladders.

Methods and materials

Phantom preparation

The main box of phantom was constructed using polymethyl methacrylate with useful dimensions of 280 mm × 300 mm and a wall thickness of 12 mm. Figure 1 shows the main parts and dimensions and the complete phantom. A millimeter scale was placed on two sides of the box and on part C for user viewing. In part C, a protractor was also placed to assess angulation.

Two bladders were 3D printed to evaluate the phantom properties. To conform these artificial bladders, planning

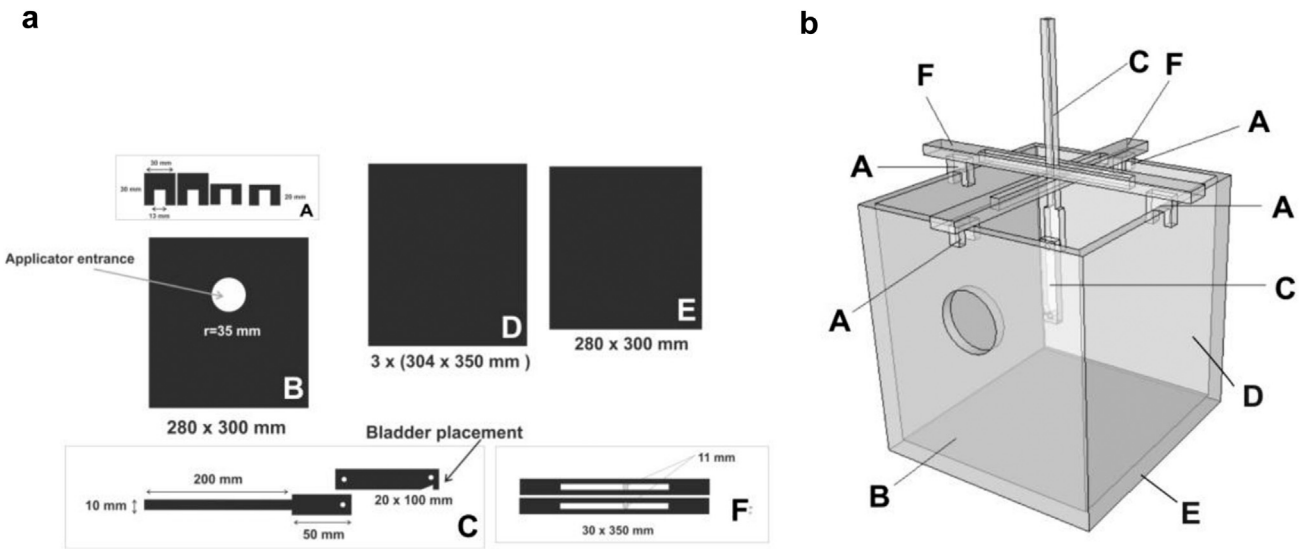

Fig. 1. (a) Parts of the phantom and their respective dimensions; (b) complete phantom.