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Evaluation of air cavities on dose distributions with air-filled apparatuses having different volumes using Gafchromic EBT3 films in brachytherapy

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Abstract

Aim: The data used in brachytherapy planning are obtained from homogeneous mediums. In practice, the heterogeneous tissues and materials affect the dose distribution of brachytherapy. It is aimed to investigate the effect of air cavities on brachytherapy dose distribution using a specially designed device. *Material and methods:* In this study, the special device designed with different volumes of air and water to be irradiated and measured at different depths using EBT3 Gafchromic films. EBT3 Gafchromic films were preferred for this study because they can be cut to the shape of the experimental geometry, are water resistance and double directional usability. *Results:* In our study, sudden dose increases and decreases were observed at the water–air–water interfaces. Increases were 9, 11·8 and 15% in the 13, 18 and 22 mm apparatus, respectively. These effects were expected and the results were consistent with the literature and within the tolerance limits stated in the clinical dose guidelines. The most important result is that the percent depth–dose curve of the radiation passing through the air to the water and only passing through the water medium is different. The average differences were 1·97, 2·97 and 2·31% for the 13, 18 and 22 mm apparatus, respectively. *Conclusion:* Although the effect of heterogeneity may be neglected according to clinical guidelines, it is suggested that the dose effect of heterogeneity is taken into account so that the dose can be estimated sensitively. Brachytherapy plans using dose data without considering air gaps may cause erroneous dose distributions due to heterogeneity of tissue.

Introduction

Brachytherapy (BT) plays an important role in the curative management of cancers in a variety of disease sites, most prominently, gynaecological malignancies, breast cancer and prostate cancer.[1] BT provides advantages over external beam radiotherapy in that the tumour can be treated with very high doses of localised radiation, while reducing the probability of unnecessary damage to the surrounding healthy tissues. The successful and effective treatment with lesser side effects for healthy tissue strongly depends on the dose distribution in the tumour and surrounded healthy tissues. Dose distributions depend on photon energies, atomic number, density and electron density in BT.[2–4]

The human body is not homogenous. It consists of different types of tissues like bone, liver, lung, spleen, muscle, air cavities, etc. But TG-43 formalism for treatment planning arise from the neglect of applicator, shielding and contrast solution perturbations, scatter dose changes in the absence of a full scatter medium, and tissue heterogeneity effects.[5–8] In these circumstances the dose distribution in the patient cannot be accurately assessed.[9,10] Actually the isodose distribution is affected by the heterogeneous tissues and materials, because backscatter electrons increase the dose between different density mediums.[11]

Although recently, three-dimensional computed tomography based treatment planning for BT applications has been popularly adopted, as it shows more realistic dosimetric outcomes in patient anatomy, there are only a few study that have considered the impact of tissue heterogeneity in BT.[11] Qualitative recognition of the effect of the heterogeneous medium in BT is very useful in assessing the dose distribution in the patient. Therefore, in this study, a special designed device was constructed and irradiated with Iridium-192 (Ir-192), a radioactive source of high dose rate (HDR) BT, and the effects of body air cavities on dose distributions were evaluated with air-filled apparatuses having different volumes using EBT3 Gafchromic films. EBT3 Gafchromic film is water resistant, has double directional usability, weak energy dependent, improved film uniformity, short time period of post-exposure optical density growth, high dose sensitivity, requires no chemical processing and is insensitive to ambient light. The most important feature of EBT3 Gafchromic film is that it can be cut to the exact shape of the experimental geometry. Therefore EBT3 Gafchromic film was used in the study.[12,13]

Materials and Method

Design of experimental setup

A special designed device was prepared and was constructed, the polypropylene has a close density to water (0·909 g/cm^3) and considered water equivalent, between the tubes were air gaps. The cylindrical apparatus was prepared with fixing proper junctions and adding inside styrofoam size of 2 × 20 × 30 cm and separately into 13, 18 and 22 mm. Each catheter which has 2 mm diameter was placed 1 cm laterally from the apparatus surface inside styrofoam. The styrofoam was used for immobilised the catheters and apparatuses. And then, a special device was placed in the water-filled plastic box (Figure 1).

BT planning

Before starting the BT planning, computer tomography (CT) images of special designed device were obtained with 5 mm slice thickness for using BT planning system (Asteion, TSX-021B, Toshiba, Japan) and CT images were transferred to treatment planning system (TPS-Oncentra, Elekta, The Netherlands). The length of each catheter was measured with a check ruler. The starting point of the catheters was marked and the irradiation distance was determined as 4 cm with 5 mm steps. The origin was defined at the centre of the catheter on the *X*, *Y*, *Z* coordinates. A dose normalisation point was marked at a distance of 2·5 cm from the midpoint of the 4 cm catheter length (origin) to the periphery and the dose was optimised to give 700 cGy to evaluate the change in water–air–water interfaces on a single film. And then, the BT planning was loaded on the BT (MicroSelectron HDR, Nucletron, The Netherlands) (Figure 2).

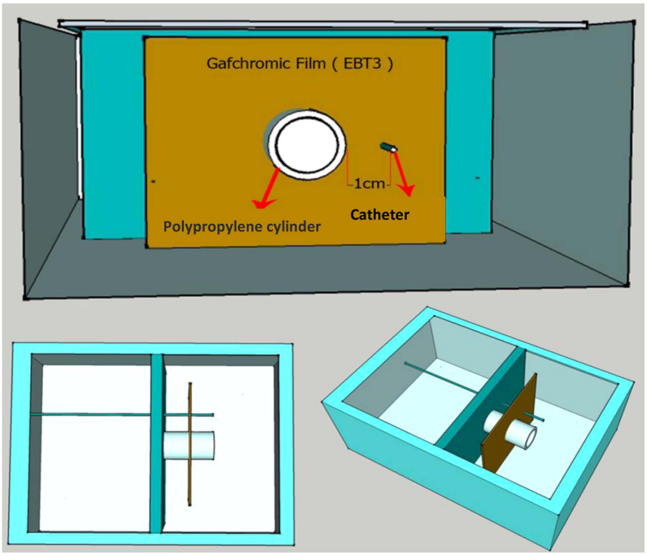

Figure 1. Special designed device for measuring the effect of air cavities on brachytherapy dose distributions.

Irradiation

On the Gafchromic EBT3 films, the holes were opened to fit the diameters of the apparatus and catheter. The film was placed in the centre of the 4 cm catheter length. According to the plan made in the TPS, the special designed device was irradiated with Ir-192 source (Figure 3). The measurement was repeated three times to increase accuracy for each apparatus.

Acquisition of data

The irradiated films were scanned using the Landscape method and red colour channel mode using a film scanner (Epson Perfection V750 Pro, Epson, USA). The 'OmniPro IMRT' programme was used to generate percent depth dose (PDD) curves from the scanned films. The average values of the three measurements were


[redacted]

Figure 3. Irradiation of the special designed device.

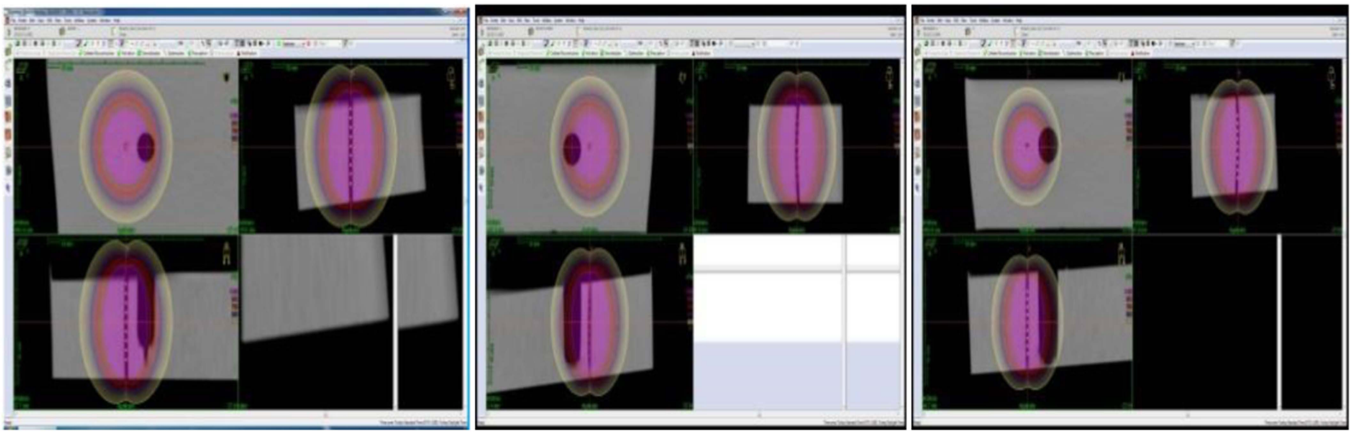

Figure 2. Dose distributions on the *X*, *Y* and *Z* axes (for the 13, 18 and 22 mm apparatuses, respectively).

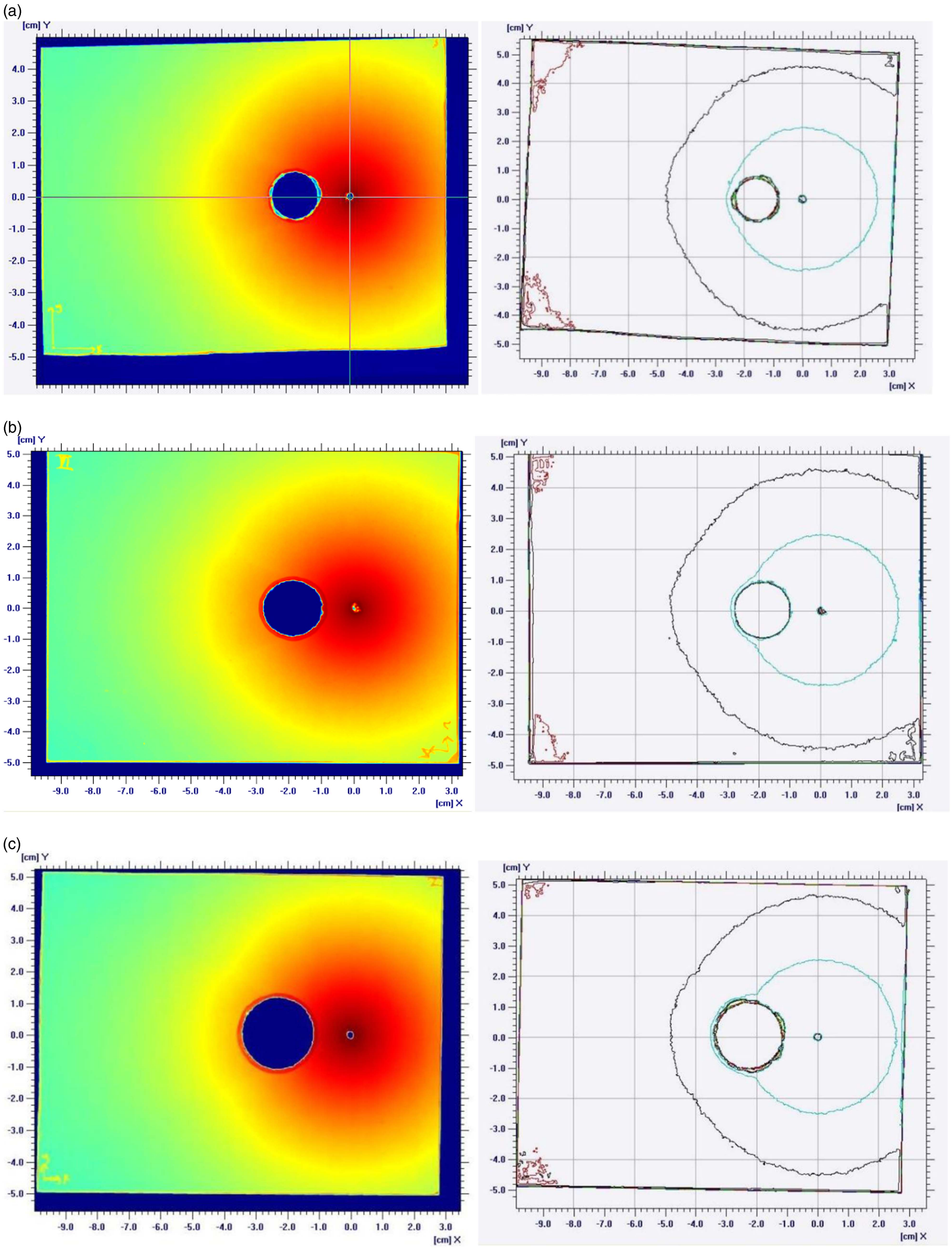

Figure 4. Isodose distributions according to air spaces simulated with 13 mm (a), 18 mm (b) and 22 mm (c) cylinders.

calculated. PDD curves at various 2-mm increment distances from the centre of the catheter, depending on the diameter lengths of the cylinders, were obtained from films with and without apparatus and the differences in PDD values between the air–water interface were calculated. This process repeated for each apparatus of 13, 18 and 22 mm. Due to damage to the film that occurred when creating

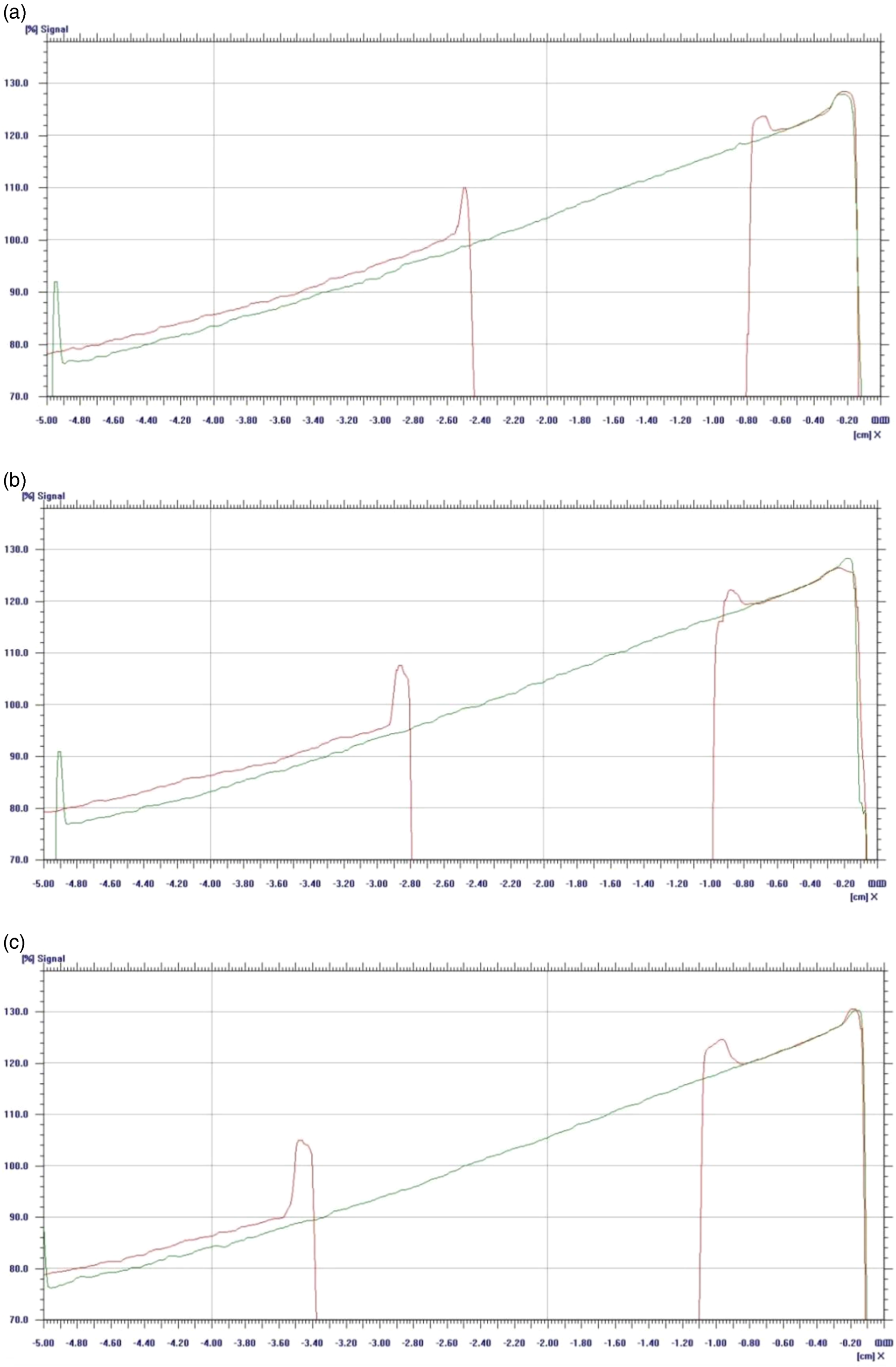

Figure 5. The per cent depth–dose curves in devices with simulated air gaps using 13 mm (a), 18 mm (b) and 22 mm (c) cylinders [*X* axes: length from the centre of catheter (cm), *Y* axes: per cent depth dose].

openings for their insertion through the polypropylene apparatus, the dose values obtained from the vicinity of the hole as well as the dose densities originating from the scattered on the sides of the hole were not included in the measurements.

Results

Isodose distributions according to air spaces simulated with 13 mm (a), 18 mm (b) and 22 mm (c) cylinders are showed in Figure 4. As can be seen from the Figure 4, when the air gap increases, the deformation in the shape of the circle becomes more pronounced. The PDD curves in the *X* direction are given for 13 mm (a), 18 mm (b) and 22 mm (c) cylinders in Figure 5. In Figure 5, *X* axes show the axis length from the centre of the catheter and *Y* axes represent the PDD. According to these PDD distributions, the radiation emitted from the Ir-192 source is less than the dose calculated according to the inverse square law. The intensity of a wave transitioning from water to air is increased by the backscattering of radiation at the interface. The dose increases are 2, 3 and 4% for 13, 18 and 22 mm cylinder devices, respectively. Hence, the dose increased as the air gap widened. The signal plateaued after the first transitional increase; the plateau distances were 0·10, 0·12 and 0·14 mm for the 13, 18 and 22 mm devices, respectively, when including the air-equivalent polypropylene. These values were small and negligible. When a wave travels from air to water, the higher density of water slows the wave and thereby increases its interaction with the medium. We found that a plateau formed at the interface between the air and water (0·06 mm for the 13 mm device, 0·07 mm for 18 mm device and 0·10 mm for 22 mm device); however, even when neglecting this plateau zone, the wave was exponentially absorbed by the sudden change in medium; these increases were 9, 11·8 and 15% in the 13, 18 and 22-mm devices, respectively, indicating that the signal increased in direct proportion to the air gap.

When the radiation transverses through the air medium and reaches the water medium, the exponential decrease in the depth dose is different from that of the water medium. The average differences were 1·97, 2·97 and 2·31% for the 13, 18 and 22 mm devices, respectively.

Discussion

When radiation beams travel through a homogenous medium, the dose decreases in inverse proportion to the square of the distance from the source. However, when radiation passes through mediums of different atomic number, density and electron density, dose fluctuations are caused. If radiation passes through an interface between materials with low atomic number and a high atomic number, a significant fraction of the secondary electrons is backscattered toward the interface by the tissue with the high atomic number. This effect considerably increases the dose at the interface.[14] Such changes in dose intensity are most apparent at the interfaces between mediums of different densities. Transitioning from a low-density medium (air) to a dense medium (water) causes a sudden drop in dosage at the interface. The reverse situation results in dose increases at the interface. Anatomically, such disruptions cause a breakdown in dose distribution by increasing the PDD values within the BT treatment area.[15,16]

Zabihzadeh et al.[17] have found air heterogeneity dose increases as 9·11–10·2, 9·11–10·0, 8·62–10·08 and 8·5–10·07%, respectively, for 5, 10, 20 and 30 mm distances from the source. In a study by Terribilini et al.,[18] air at a distance of 10 mm from the source produced heterogeneity that was 7% higher than the corresponding value of the control water medium. In a similar study, Chandola et al.[19] have found that the corresponding doses behind heterogeneities were 5·5–6·5% higher and 4·5–5% lower than water phantom values in the presence of air and cortical bone, respectively. Graf et al.[20] have showed a heterogeneous dose increase of 10% at a distance of 2 mm above the water–air interface and a dose decrease of 30% in the homogeneous medium at distances of under 2 mm.

In our study, sudden dose increases and decreases were observed at the water–air–water interfaces. These effects were expected and the results were consistent with the literature and within the tolerance limits stated in the clinical dose guidelines. The most important point of our results is that the PDD curve of the radiation in the air medium through to the water medium is different from the only water medium.

Conclusion

Even if the heterogeneous dose changes according to the AAPM TG-43 protocol are neglected but according to results of our study, heterogenity changes in dose distributions should be taken into consideration in BT plannings. It is recommended that the dose effect of air gaps be considered so that the dose can be accurately estimated.

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