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Original Article

Dosimetric characterization and commissioning of a superficial electronic brachytherapy device for skin cancer treatment

Han Beom Park [a], Hyun Nam Kim [a], Ju Hyuk Lee [a], Ik Jae Lee [b], Jinhyun Choi [b], Sung Oh Cho [a], *

[a] Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong, Yuseong, Daejeon 305-701, South Korea
[b] Department of Radiation Oncology, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul 146-92, South Korea

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ABSTRACT

Background: This work presents the performance of a novel electronic brachytherapy (EBT) device and radiotherapy (RT) experiments on both skin cancer cells and animals using the device.
Methods and materials: The performance of the EBT device was evaluated by measuring and analyzing the dosimetric characteristics of X-rays generated from the device. The apoptosis of skin cancer cells was analyzed using B16F10 melanoma cancer cells. Animal experiments were performed using C57BL/6 mice.
Results: The X-ray characteristics of the EBT device satisfied the accepted tolerance level for RT. The results of the RT experiments on the skin cancer cells show that a significant apoptosis induction occurred after irradiation with 50 kVp X-rays generated from the EBT device. Furthermore, the results of the animal RT experiments demonstrate that the superficial X-rays significantly delay the tumor growth and that the tumor growth delay induced by irradiation with low-energy X-rays was almost the same as that induced by irradiation with a high-energy electron beam.
Conclusions: The developed new EBT device has almost the same therapeutic effect on the skin cancer with a conventional linear accelerator. Consequently, the EBT device can be practically used for human skin cancer treatment in the near future.

1. Introduction

The incidence of skin cancers is constantly increasing [1,2]. Several options are available to treat skin cancers, such as simple surgery [3], Mohs surgery [4], chemotherapy [5], cryotherapy [6], photo dynamic therapy [7], and radiotherapy (RT) [8–11]. Among the available options, RT is a favored procedure particularly for patients who have difficulty in undergoing surgery because of aging and who do not want to develop cosmetic defects from surgery.

RT for skin cancers includes external RT and brachytherapy. External RT uses a megavolt electron beam as a radiation source and, thus, requires a high-cost linear accelerator facility and large space for the installation and radiation shielding [12]. Furthermore, external RT has a problem related to local radiation borders. Brachytherapy using radionuclides such as Ir-192 and Re-188 is another option [13]. However, radionuclide-based brachytherapy has a few disadvantages: constant production of radiation, fixed radiation energy, and difficulty in storage and management of the radionuclides. An alternative RT to overcome these drawbacks is electronic brachytherapy (EBT) based on a superficial X-ray (<100 kVp) tube. On/off controllable X-ray production, variation of X-ray energy, minimal shielding requirements, and low cost are the advantages of using the EBT. At present, a few electronic brachytherapy systems, such as Xoft Axxent [14], Intrabeam [15,16], and Esteya [17] devices, have been commercialized.

Recently, we have developed a novel EBT device. In this study, we characterized the performance of the new EBT device and conducted commissioning tests on both cells and animals to examine the therapeutic effect of the device on skin cancers.

2. Methods and materials

2.1. The superficial EBT device

The developed EBT device is shown in Fig. 1A. One of the main features of the EBT device is that a miniature X-ray tube [18] operating with a carbon nanotube (CNT) field emitter was used as an

* Corresponding author.
E-mail address: socho@kaist.ac.kr (S.O. Cho).

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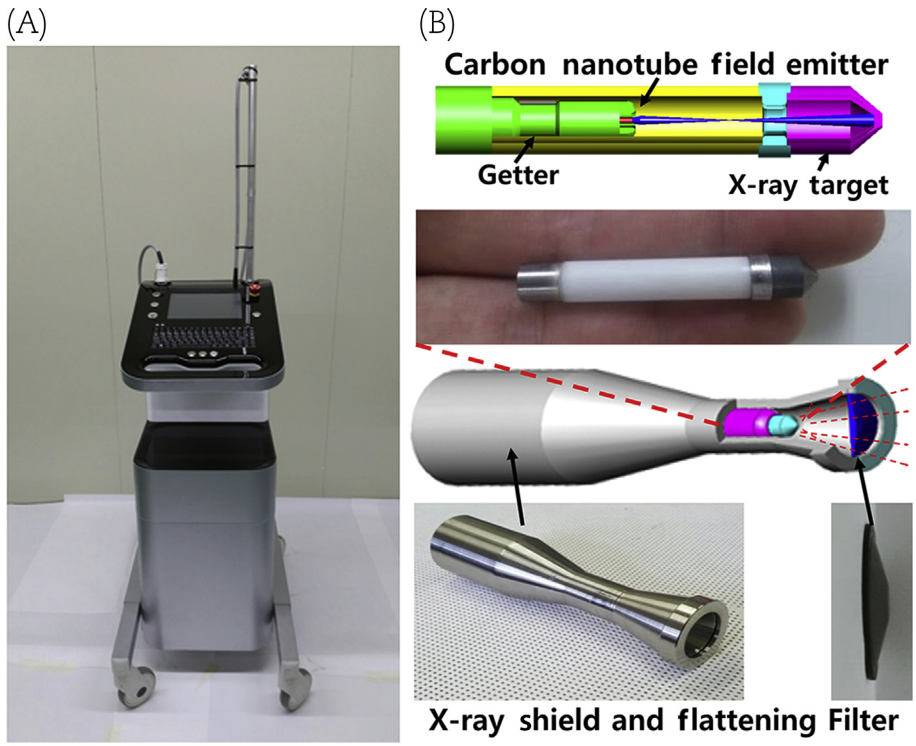

Fig. 1. The developed EBT device. (A) Full assembly photo. (B) Schematic drawing and photo of the treatment unit in the EBT device.
EBT, electronic brachytherapy.

X-ray source of the device. The miniature X-ray tube has an outer diameter of 7 mm and a length of 47 mm and is normally operated at 50 kVp. X-rays are generated from a transmission-type X-ray target. The miniature X-ray tube is wrapped with a surface applicator (Fig. 1B). The surface applicator consists of an X-ray shield (2-mm–thick stainless steel) and a conical-shaped graphite flattening filter. The miniature X-ray tube equipped with the surface applicator produces spatially uniform X-rays over the desired skin region while almost completely shielding X-rays outside of the region.

2.2. Evaluations of the EBT device performance

2.2.1. X-ray spatial distribution

To investigate whether the EBT device is suitable for skin cancer treatment, X-ray dosimetric characteristics such as flatness, symmetry, and penumbra were evaluated. The three parameters were characterized by analyzing the X-ray spatial dose distribution following the definitions in the International Electrotechnical Commission 60976 criteria [19]. The X-ray spatial dose distribution was measured using a radiochromic film (Gafchromic EBT3 film; International Specialty Products, USA), which has a color-changing property when irradiated with X-rays. After scanning the irradiated films with a scanner (Epson 11000XL; Seiko Epson Corp., Japan), dose distribution was obtained by analyzing the red channel values in the scanned image. For the calibration of the film dose, the variation of the red channel value as a function of X-ray dose was premeasured using the miniature X-ray tube and a soft X-ray parallel-plate ionization chamber (PTW T34013; PTW Freiburg GmbH, Freiburg, Germany). The film dose measurements were carried out following the American Association of Physicists in Medicine (AAPM) TG-55 protocol [20].

2.2.2. Half value layer

Half value layers (HVLs) of the generated X-rays were measured to identify the absorbed doses at the skin surface. Measurement of the HVL was conducted following the TG-61 protocol [21]. For the HVL measurement, high-purity (>99.9 %) aluminum (Al) slabs of varying thicknesses ranging from 0.1 mm to 1.0 mm, Al foils with 18 μm thickness, and an ionization chamber (PTW T34013) were used. The distance between the X-ray tube and ionization chamber was 25 cm, and the Al attenuation materials were placed at the middle position between the tube and ion chamber. The HVL values were obtained through measuring the air kerma rates of X-rays passing through the Al materials by changing the thickness of the materials. The air kerma rates were determined by averaging five results measured with the ionization chamber.

2.2.3. Absorbed dose rate at the skin surface

The absorbed dose rate at the skin surface was identified following the in-air method in the AAPM TG-61 protocol [21]. First, the absorbed dose at the water surface is given by

$$D_{w,z=0} = MN_K B_w P_{stem,air}\left[\left(\overline{\mu}_{en}/\rho\right)^{w}_{air}\right]_{air}, \quad (1)$$

where M is the corrected reading value of the ionization chamber and N_K is air kerma calibration factor. M value was measured using an ionization chamber (PTW T34013). N_K value was provided by the PTW laboratory and adjusted through the measurement of HVL. Backscatter factor B_w and mass energy coefficient ratio of water to air $\left[\left(\overline{\mu}_{en}/\rho\right)^{w}_{air}\right]_{air}$ were determined from the Table 1 of TG-61 protocol. $P_{stem,air}$, chamber stem correction factor, is normally taken as unity [21]. Second, the absorbed dose at the medium surface is calculated from the absorbed dose at the water surface by the following relation [21]:

$$\dot{D}_{med,z=0} = C^{med}_{w}\dot{D}_{w,z=0}, \quad (2)$$

where C^{med}_{w} is the conversion factor to find the dose to medium from the dose to water. The C^{med}_{w} value for skin can be obtained from the Table 2 of TG-61 protocol if HVL value is specified.

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