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In vivo dosimetry in prostate RT

Two-dimensional *in vivo* rectal dosimetry using an endorectal balloon with unfoldable radiochromic film during prostate cancer radiotherapy

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ABSTRACT

Background and purpose: The present study aims to investigate the feasibility of two-dimensional (2D) *in vivo* rectal dosimetry using an endorectal balloon for the radiotherapy of prostate cancer.

Materials and methods: The endorectal balloon was equipped with an unfoldable radiochromic film. The film was unrolled as the balloon was inflated, and rolled as it was deflated. Its mechanical and imaging properties were tested, and the dosimetric effectiveness was evaluated in clinical photon and proton beams.

Results: The size of the endorectal balloon including the film was linearly proportional to the volume of water filled in the balloon, and its position could be identified by X-ray radiography. The loss of dose information due to film cutting was within ±1 mm from the cutting line. Applying linear interpolation on cut film, the gamma passing rate was more than 95% for 2%/2 mm criteria. The measured dose profiles agreed with the plan within 3% and 4% for the photon and proton beams, respectively. A dose–volume histogram of the anterior rectal wall could be obtained from the measured dose distribution in the balloon, which also agreed well with the plan.

Conclusions: 2D *in vivo* rectal dosimetry is feasible using the endorectal balloon with a radiochromic film in the radiotherapy of prostate cancer.

It is widely known that dose escalation improves biochemical failure survival in patients with localized prostate cancer in the era of three-dimensional (3D) conformal radiotherapy (3D-CRT) [1,2], but there are limitations owing to toxicity to normal tissues. In addition, sexual, urinary and bowel function can be affected by the treatment [3–5]. Advanced treatment techniques have been developed to prevent the adverse effects of radiation on normal tissues while delivering a high dose to the tumor. Examples of such techniques include intensity-modulated radiotherapy (IMRT) [6,7], volumetric-modulated arc therapy (VMAT), and helical tomotherapy (HT) [8,9]. Recently, intensity-modulated proton therapy (IMPT) using a beam scanning technique [10] has received attention. Moreover, traditional radiotherapy combined with image-guided radiotherapy (IGRT) [11,12] is also being used to reduce setup and target positioning errors. Despite these state-of-the-art techniques being highly conformal techniques, dose uncertainty due to intrafractional motion of the prostate during treatment still exists.

In light of this, a rectal balloon has been used to reduce the dose uncertainty of the prostate and rectum by suppressing the intrafractional motion of the prostate and fixing the prostate in the same position for each treatment session [13–15]. Moreover, this rectal balloon can protect the posterior rectal wall by distancing it from the high-dose area [16–18]. One of the most effective methods for directly predicting the adverse effects of radiation on the rectum and for verifying the accurate delivery of the prescribed dose on the target is *in vivo* dosimetry in the anterior rectal wall (ARW). The verification is possible since a part of the ARW is included in the planning target volume. There have been a number of attempts at accurate *in vivo* measurement of the dose on the rectum. For example, Hardcastle et al. used a metal-oxide-semiconductor field-effect transistor (MOSFET) in a rectal balloon [19] to measure the rectal dose in 3D-CRT and IMRT. Additionally, Hsi et al. attached a thermoluminescent dosimeter (TLD) directly

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onto the rectal balloon [20] to measure the rectal dose in IMRT and proton therapy.

However, *in vivo* dosimetry that uses such point dosimeters cannot provide 2D dose distribution in the ARW. In order to obtain the 2D dose distribution and dose–volume histogram (DVH) in the rectal wall, a 2D dosimeter that incorporates radiosensitive film is required. In the present study, a new endorectal balloon equipped with radiochromic film was developed, and its clinical applicability for the radiotherapy of prostate cancer was evaluated.

Materials and methods

Fabrication of an endorectal balloon for in vivo dosimetry

The 2D dosimetric endorectal balloon (2DD-ERB) can measure the dose distribution delivered to the ARW during radiation therapy owing to a radiosensitive film that is wrapped on top of a conventional, inflatable ERB. The radiosensitive film used in the 2DD-ERB is a radiochromic film (GafChromic EBT3, Ashland ISP Advanced Materials, NJ, USA), which unfolds or folds according to the expansion/contraction of the balloon. The 2DD-ERB is primarily composed of two parts: a balloon component and a dosimetry component.

The balloon component consists of silicon material, which is non-toxic to humans. Unlike conventional rectal balloons, this balloon surface has two small, protruding film holders, and inside each holder, a fiducial marker was inserted. The marker used was a gold micropowder-polymer (GPP) marker that was developed in-house, which showed little streak artifacts on CT images and little dose perturbation of the treatment beam [21].

The EBT3 film in the dosimetry component has two polyester sheets laminated on both sides of the active layer. However, the polyester sheet encounters separation issues when rolled up with a small radius of curvature. In order to prevent this, the film was cut into three $70 \times 10\,mm^2$ pieces and four $70 \times 12\,mm^2$ pieces that were connected to each other without any gaps by a thin, flexible, non-expandable tape. Two small holes were made in the film so that it could be affixed to the film holder. Since there was no gap between the holder and the hole in the film, the film did not move or rotate with respect to the balloon. The position of the film was then determined by finding the position of the markers inside the film holders. The whole balloon was wrapped up with a thin elastic fabric after putting the film in a nylon pocket and fixing that to the film holder by sewing; as a result, the film unfolded or folded smoothly when the balloon was inflated or deflated. The size of the EBT3 film on the expanded balloon surface was $70 \times 78\,mm^2$, which was wide enough to measure the dose distribution in the ARW (Fig. 1).

Fabrication of rectal phantom

A rectal phantom was fabricated in order to assess the dosimetric properties of the 2DD-ERB (Fig. 1). The phantom was fabricated with acrylic material into a cylindrical shape, with a size of $20 \times 20\,cm^2$. A non-transparent polyoxymethylene cylinder with a size of 4 cm (diameter) × 5 cm (length) was located inside the phantom to simulate the prostate. Directly below was a hole with a diameter of 5 cm that simulated the rectum. Owing to the transparency of the phantom, it was possible to visually verify whether the inserted 2DD-ERB was situated in the proper position and direction.

Mechanical evaluation

An expansion test was performed on the 2DD-ERB equipped with the EBT3 film. When 60, 80, and 100 ml of water were

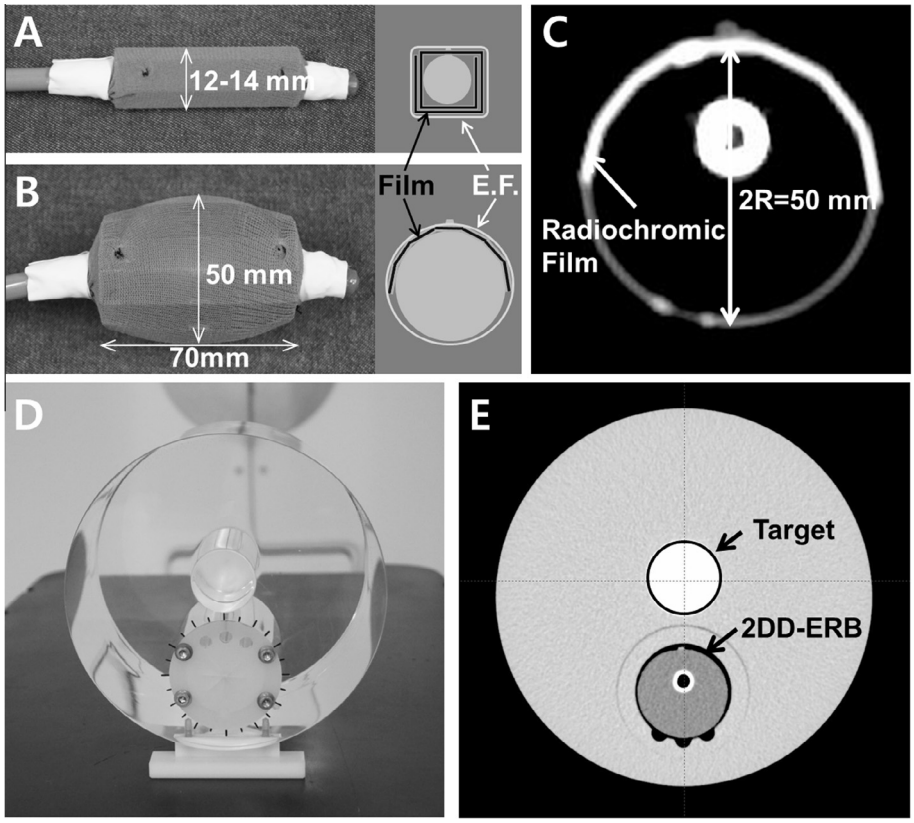

Fig. 1. Top views (photograph) and cross sections (schematic) of 2DD-ERB (A) before and (B) after expansion, and (C) CT image of that filled with air are shown. The 2DD-ERB is inserted into (D) a fabricated rectal phantom and is scanned into (E) CT images. Abbreviation: E.F. = elastic fabric.