Development of a novel endorectal balloon for two-dimensional in-vivo rectal dosimetry

Young Kyung Lim [a*], Eun Hee Jeang [a], Soonki Min [a], Kwan Ho Cho [a], Ui-Jung Hwang [b], Sang Hyoun Choi [c], Jungwon Kwak [d]

[a]*Proton Therapy Center, National Cancer Center, Goyang, Gyeonggi, Korea*
[b]*Department of Radiation Oncology, National Medical Center, Seoul, Korea*
[c] *Department of Radiation Oncology, Korea Cancer Center Hospital, Seoul, Korea*
[d] *Department of Radiation Oncology, Asan Medical Center, Seoul, Korea*
[*]*Corresponding author: yklim@ncc.re.kr*

1. Introduction

A metal-oxide-semiconductor field-effect transistor (MOSFET) was used in a rectal balloon [1] to measure the rectal dose in 3D-CRT and IMRT. Additionally, a thermoluminescent dosimeter (TLD) was attached directly onto the rectal balloon [2] 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 a rectal wall (RW). In order to obtain the 2D dose distribution 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 dosimetric property was evaluated.

2. Methods and Results

2.1 Fabrication of an endorectal balloon for 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 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 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 marker that was developed in-house, which showed little streak artifacts on CT images and little dose perturbation of the treatment beam [3].

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 several pieces that were connected to each other without any gaps. Two small holes were made in the film so that it could be affixed to the film holder. The position of the film was then determined by finding the position of the markers inside the film holders. The size of the EBT3 film on the expanded balloon surface was 70×78 mm^2, which was wide enough to measure the dose distribution in the ARW (Fig. 1).

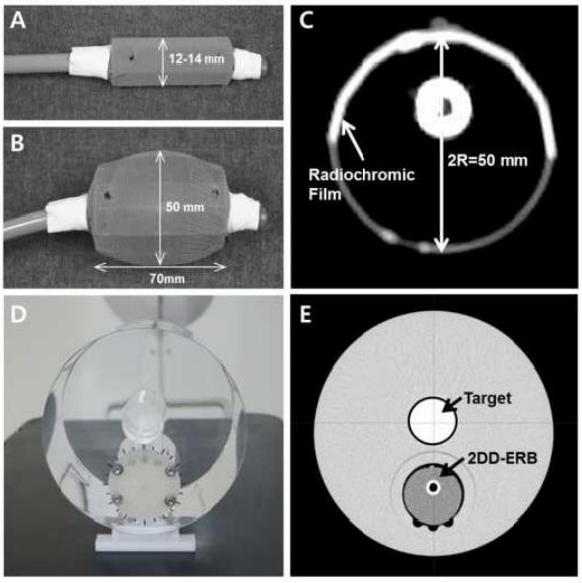

Fig. 1. Top views of 2DD-ERB (A) before and (B) after expansion, and (C) CT image of that filled with air are shown. The 2DD-ERB is inserted into (D) a fabricated rectal phantom and is scanned into (E) CT images.

2.2 Dosimetric evaluation

2.2.1 Photon dosimetry

The rectal phantom with the inserted 2DD-ERB was scanned using a CT scanner (Somatom Definition, Siemens, Forchheim, Germany). In the treatment planning system (TPS, Eclipse 10, Varian Medical Systems, Palo Alto, CA, USA), a plan was established to deliver 500 cGy to the center of the prostate in the rectal phantom via a 15 MV photon beam. The anteroposterior beam was used for simple validation with the parameters, 100 cm of SSD and 4×4 cm^2 of field size and the dose was calculated using a calculation grid of 1.0 mm. In accordance with the plan, after inserting the 2DD-ERB into the phantom, 100 ml of water was injected so as to make the EBT3 film touch the ARW. After irradiation, the film was removed and scanned using a flatbed scanner (Expression 10000XL, Seiko Epson Corp., Nagano, Japan). The

absorbed dose distribution was measured from the optical density distribution of the scanned film, and this dose distribution was considered to be that in the rectal wall.

The 3D dose distribution of the rectum in the plan can be formed by accumulating 2D dose distributions in a slice-by-slice manner. To display the position of the rectal wall in each of the 2D dose distributions, the radial vector **R** was defined as $x=R\cdot\cos\theta$, $z=R\cdot\sin\theta$, and R = 2.4 cm, and the dose values were derived at 1° increments with the azimuthal angle θ ranging from 0° to 180°. The derived values were arranged in order to obtain the dose distribution on a 2D plane, which was then compared to the dose distribution measured from the EBT3 film (Fig. 2). The red lines represent the planned dose profiles, whereas the black lines represent the measured dose profiles. The 2DD-ERB demonstrated a high resolution dose distribution, which was consistent with the dose distribution of the treatment plan. When 500 cGy was delivered on the center of the target, the calculated dose in the plan was 414 cGy at the film center, whereas that measured by the 2DD-ERB was 404 cGy.

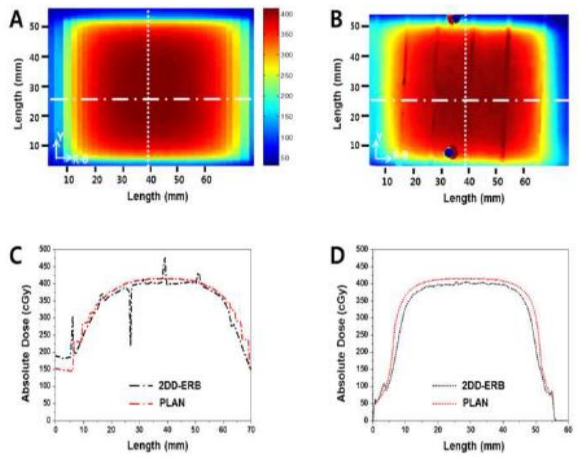

Fig. 2. Dose distributions for anterior rectal wall in (A) treatment plan and (B) EBT3 film of 2DDERB, and their dose profiles along (C) azimuthal direction (dash-dot line) and (D) longitudinal direction (dot line) in the rectal wall

2.2.2 Proton dosimetry

Proton plans with double scattering (DS) and pencil beam scanning (PBS) were made using a volumetric prescription (500 cGy to 95% volume of a virtual target) for the phantom used in photon dosimetry. Plans that used both single (RT) and bilateral (RT-LT) fields were established for each beam delivery mode, and the treatment dose was delivered from a Proteus 235 system (IBA, Louvainla-Neuve, Belgium). The EBT3 films irradiated with the proton beam were scanned in the same manner as photon dosimetry. For the proton beam, the calibration curve was created using irradiated films in a plateau region of a pristine Bragg peak. The measured physical dose was converted to a biological dose by considering the therapeutic proton beam's relative biological effectiveness, which was 1.1. The central dose values of the dose profiles from the plan and measurement for a single field beam in DS mode were 253.4 cGy and 249.1 cGy, respectively. The values for the bilateral beam were 507.3 cGy and 490.4 cGy, respectively. In the PBS mode the central dose values from the measurement were same as those of the plans by compensating the effect of the field size. The dose value was 273.2 cGy for single beam and 541.5 cGy for bilateral beam (Fig. 3).

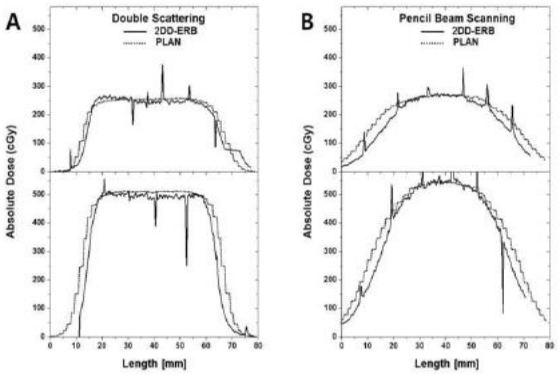

Fig. 3. Comparison of dose profiles measured in the 2DD-ERBs along azimuthal direction with proton plans using (A) double scattering: single- (up) and bilateral-beam (down), and (B) pencil beam scanning: single- (up) and bilateral-beam (down).

3. Conclusions

A new endorectal balloon capable of 2D *in vivo* rectal dosimetry was developed. Unlike conventional ERBs, this 2DD-ERB was equipped with a radiosensitive film on the outside of the balloon to directly measure the 2D dose distribution delivered to the ARW by the treatment beam. The dosimetric properties of the 2DD-ERB were measured, and the results showed that the measured dose distributions agreed well with their respective treatment plans within 4%. The film-equipped endo-rectal balloon is expected to be used as an *in vivo* dosimeter for measuring the dose distribution in the rectal wall in the modern radiotherapy techniques, such as IMRT, VMAT, HT, and IMPT.

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