DOI: 10.15669/pnst.6.39

Progress in Nuclear Science and Technology
Volume 6 (2019) pp. 39-42

ARTICLE

Direct radiation dose measurement of rectum during High-Dose-Rate ^{192}Ir brachytherapy for cervical cancer treatment

Emi Tomita[a,f*], Hiroaki Hayashi[b,f], Takashi Asahara[b], Kanako Sakuragawa[c], Yasufumi Shitakubo[c], Hiroshi Saegusa[c], Hitoshi Ikushima[b,c], Yuki Kanazawa[b], Sota Goto[a,f], Tohru Okazaki[d], Takuya Hashizume[d] and Vergil Lorenzo E. Cruz[d]

[a]*School of Health Sciences,Tokushima University, 3-18-15 Kuramoto, Tokushima, Tokushima, 770-8509, Japan;* [b]*Graduate School of Health Sciences, Tokushima University, 3-18-15 Kuramoto, Tokushima, Tokushima, 770-8509, Japan;* [c]*Tokushima University Hospital, 3-18-15 Kuramoto, Tokushima, Tokushima, Japan;* [d]*Nagase Landauer, Ltd., Block C22-1, Suwa, Tsukuba, Ibaraki, Japan;* [f]*College of Medical, Pharmaceutical and Health Sciences, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa, Ishikawa, 920-0942, Japan*

High-Dose-Rate (HDR) brachytherapy using ^{192}Ir is widely used for the treatment of cervical cancer. During brachytherapy the radiation dose of organs at risk, such as rectum, should be properly managed, but actual dose measurement is not performed in clinics. In this study, we developed a new dosimetric system using an optically stimulated luminescence (OSL) sheet to measure rectum doses during treatment. Our new dosimetric system was made as follows; the cut OSL sheet was sealed with black vinyl to shield it from visible light, and attached to a Nelaton catheter. Then, we measured the rectum doses of patients during brachytherapy clinical situations (n=3). The catheter was directly inserted into the rectum, and treatment was performed. After irradiation, three disk shapes of the OSL sheet were made and they were analyzed using a commercial reader. In addition, using a clinical planning system, we derived the planning dose to the rectum where our dosimeter was inserted. Then we compared the measured value and doses derived from the planning system. We found that the measured doses using our rectum dosimeter and that derived by the planning system was almost equal, and verified that our new dosimetric system worked well.

***Keywords:** brachytherapy; cervical cancer; organ dose; in-vivo dosimetry; optically stimulated luminescence dosimeter; direct dose measurement*

1. Introduction

The American Brachytherapy Society recommends to apply High-Dose-Rate (HDR) brachytherapy for the treatment of cervical cancer because of its positive results [1-3]. During the brachytherapy, the radiation doses of organ at risk, such as rectum and bladder, which should be properly managed to reduce various side effects that may occur in normal tissues [4,5]. During the actual clinical treatment, radiation doses to target (abnormal tissues) and organs at risk are generally evaluated by therapeutic planning systems [6]. This can distribute doses under various source dwelling points in applicators. We focused our attention on actual *in-vivo* dosimetry using optically stimulated luminescence (OSL) dosimeters [7]. The OSL dosimeter was used for quality assurance and quality check (QA/QC) of HDR brachytherapy [8]. There is also a report concerning *in-vivo* dosimetry during breast cancer treatment [9]. In these previous studies, commercially available dosimeters (nanoDot OSL dosimeters) were used. However, there is a case in which the nanoDot OSL dosimeter cannot be applied to *in-vivo* dosimetry. Although the outer size of the nanoDot OSL dosimeter is 1 cm × 1 cm × 0.2 cm, the detector region is a small disk shape, sized 0.5 cm$^{\phi}$ × 0.02 cm. We considered that if only the detector region can be separated from the nanoDot OSL dosimeter, it is possible to perform *in-vivo* dosimetry. Furthermore, use of an OSL sheet which is the same element used in the nanoDot OSL dosimeter is more feasible to fabricate for use as a new rectum dosimeter. The OSL sheet is easy to use because the sheet can be cut to an appropriate size.

In this study, we propose a novel rectum dosimetric system in which a simply-constructed dosimeter using a thin OSL sheet was attached to a catheter. Using the dosimeter, rectum doses of patients during the ^{192}Ir brachytherapy were measured for the first time.

2. Materials and methods

2.1. Development of a rectum dosimetric system

Our dosimetric system uses a thin OSL sheet provided by Landauer Inc. (Glenwood, Illinois, U.S.A.).

*Corresponding author. Email: emitomita.15@gmail.com

The main component of the OSL sheet is Al_2O_3:C [7-9]. The advantage of using this material is to achieve relatively small energy dependence; in this study we evaluated the water equivalent dose, therefore to use a material having a relatively low atomic number is suitable for this study. **Figure 1** shows a schematic drawing of the construction and analysis method our rectum dosimeter. First, the OSL sheet was cut into a 1 × 2 cm square. Second, it was wrapped with black vinyl to shield it from visible light, and then it was attached to a catheter (6.0 mm$^{\phi}$) using a heat-shrink tube at a position of 3 cm from the tip. In this way, we produced the rectum dosimeter and applied it to a clinical study. How the dosimeter was applied to the clinical study is described in the next section. Third, after radiotherapy treatment using ^{192}Ir, the OSL sheet was removed from the rectum dosimeter, and three disk shapes (5 mm$^{\phi}$) of the OSL sheet were made. In this paper, these three discs are named A, B, and C. Finally, they were inserted into commercial dosimeter cases and a microStar™ reading device (Landauer, Glenwood, Illinois, U.S.A) was used to carry out analysis. To convert the response of the read value to a dose value a calibration curve proposed by Asahara et al. was applied [10].

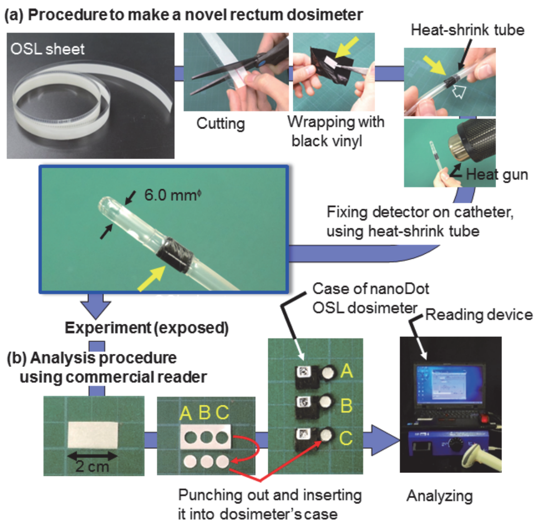

Figure 1. Procedure to make a novel rectum dosimeter and analytical method. (a) Our rectum dosimeter was developed using the OSL sheet, heat-shrink tube, and catheter. (b) The exposed OSL sheet was punched out discs (named A, B and C), and then they were inserted into the dosimeter's case to use a commercial reading device.

2.2. Clinical study

We measured rectum doses of patients during brachytherapy in actual clinical situations (n=3). A flowchart of the brachytherapy is shown in **Figure 2.** First, applicators named "ovoid" and "tandem" were set into the vagina and uterus. At the same time, our rectum dosimeter was inserted directly into the rectum of a patient. Second, to adjust these applicators and rectum dosimeter, a fluoroscopy procedure was carried out using X-ray angiography systems (Infinix Celeve™-I INFX-8000C, Toshiba Medical Systems, Otawara, Japan). Third, cone beam computed tomography (CBCT) examination was performed to obtain three dimensional images. Typical irradiation conditions were as follows: tube voltage 100 kV, tube current 500 mA, frame rate 30 f/s, total examination time 20 s, and total tube current time product 2000 mAs. Next, therapeutic planning was made based on CBCT images [11]. The calculation was performed using a therapeutic planning system (Oncentra Brachy ver. 4.0, Elekta, Stockholm, Sweden) which is based on a Task Group 43 (TG-43) algorithm proposed by the American Associate of Physicists in Medicine [6]. According to the Manchester method [2], generally adopted dose distribution was calculated based on actual positions of the applicators. Prescribed dose was determined to be 5-6 Gy at "point A". Finally, source positions and dwelling times were remotely controlled by the irradiation system (micro Selectron HDR-V2™, Elekta, Stockholm, Sweden) and treatment was performed. Activity of ^{192}Ir source was 140-150 GBq, and total irradiation time was 14-18 min.

After irradiation, we removed applicators and rectum dosimeter. The dosimeter was analyzed in the way previously described, and an experimental value was determined. On the contrary, using the planning system, doses concerning the circumference of the rectum dosimeter were derived. Then, the average value of these planning doses was calculated. We then compared the average values obtained from the experiment and planning system.

This study was permitted by Institutional Review Board of Tokushima University Hospital. We also obtained informed consent for each patient before carrying out the clinical study, and all data were anonymous.

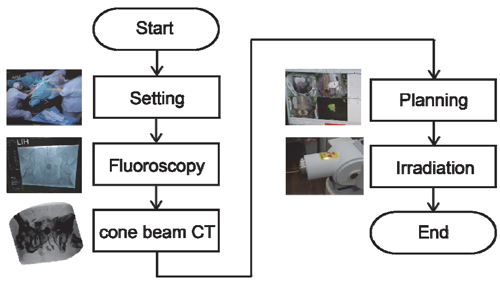

Figure 2. A flowchart of brachytherapy using ^{192}Ir. This procedure is adopted for use in general clinical treatment. At the beginning, our rectum dosimeter was inserted into the rectum when the applicator was placed in the patient.

3. Results and discussions

Figure 3 shows CBCT images used in brachytherapy. The upper and the lower images show axial and sagittal views of the pelvis region, respectively. In the axial image, organs at risk, such as rectum and bladder are located near the applicator in which radioactive sources are transferred. We can clearly identify the position of catheter in the rectum because inside the catheter was filled with air which has a completely different contrast than that of the surrounding tissues. In this case, distance between the radioactive source and the dosimeter was sufficiently long (27 mm). Our rectum dosimeter should be used under the condition in which the distance between the radioactive source and the dosimeter is over 10 mm [10]. We can use the dosimeter in the range of the above stated limitation in all clinical studies. In the sagittal view of the lower image, a contour plot of absorbed dose distribution at each organ was presented; it was calculated by the TG-43 algorithm [6]. Source dwelling points were marked with red circles. Catheter was clearly identified and we can see the place in which the dosimeter was implanted. The enlarged views of Figure 3 a) indicate definition of coordinate and analysis points for evaluating the rectum dose of the catheter circumference. In the coordinate, θ_0 and θ are offset angle and rotation angle, respectively. When θ_0 equals 0, analysis points of P_1, P_2, …, P_8 are obtained at every 45 degrees. The analysis procedure is described in the next session.

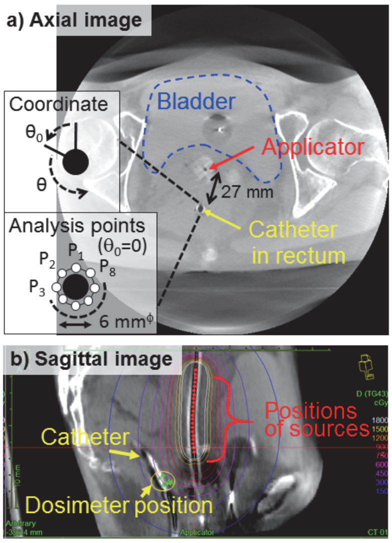

Figure 3. Typical result of X-ray images used in clinical treatment. Upper and lower images indicate axial and sagittal views (see text).

Figure 4 shows results for a) planned dose, b) experimental value, and c) comparison. Notations of Ex01, Ex02 and Ex03 indicate the results for different patients. For planned dose evaluation, we measured A_1 to A_8 positions, and then they were fitted by the spline function $f(\theta)$. Then, we calculated the integrated value of $f(\theta)$. As represented in the definition in Figure 4, A_p is the averaged value of the $f(\theta)$ in the integral range between θ_0 to θ_0+120 degrees; the integrated range of 120 degrees corresponds to the experimental condition, in which three measured points were evaluated and each indicates the averaged value in the range of 120 degrees (see Figure 1). In a similar way, B_p and C_p were calculated. As shown in Figure 3 a), the A_p, B_p and C_p are a function of offset angle θ_0. These data show deviations, because distances between analytic positions of A_p, B_p and C_p and source position were varied. Here, we propose using an averaged value of $(A_p+B_p+C_p)/3$ in order to reduce the impact of differences in distance. The bottom figure in Figure 4 a) shows a comparison between $(A_p+B_p+C_p)/3$ and D_p; D_p is an integrated value for all ranges (0 to 360 degrees) and theoretically the correct value. The fact that $(A_p+B_p+C_p)/3$ and D_p shows good agreement is useful for both for planned dose and experimental value evaluations.

Next, we will explain the method to analyze the experimental value as follows. As described above, the exposed OSL sheet was analyzed at three positions, A, B and C. These doses are represented in Figure 4 b). Based on the former discussion, we adopted the averaged value of (A+B+C)/3 as the experimental value. In this study, we assumed that uncertainty of experimental values was 15%. This uncertainty was tentatively evaluated with experiments, in which responses of A, B, and C were evaluated as a function of θ_0. These experiments were performed several times for repeatability evaluation, we then found that deviations of these experiments were approximately 15%. A more detailed description of the uncertainty will be available in another study, in which the impact of distance was also simulated in addition to experiments [10].

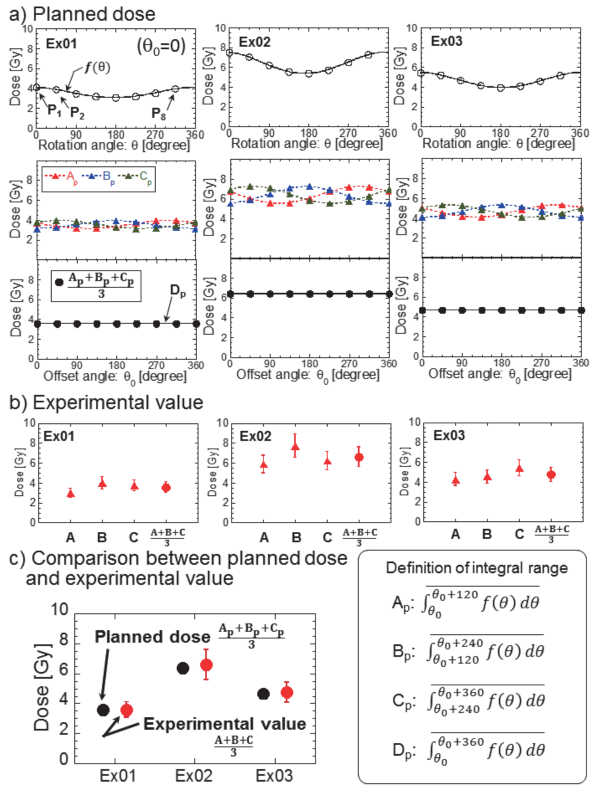

Figure 4. Comparison of doses between the planning system and rectum dosimeter. Figures of a), b), and c) show planned dose, experimental value, and comparison of these data, respectively.

Figure 4 c) shows a comparison of average values between planned doses and experimental values. Black and red circles are planned doses and experimental values, respectively. We found that the experimental value using our rectum dosimeter and average value of planned dose was comparable to each other. In this study, we measured rectum doses under the condition in which the patient's body was filled with water equivalent organs; it is similar to the condition proposed by TG-43 [6]. In this case, the experimental value and planned doses are in good agreement.

The present study has been performed under certain limitations. First, we did not consider the dose during the CBCT; the dosimeter was inserted into the rectum before obtaining the CBCT (see Figure 2), therefore the dose caused by CBCT should be subtracted from the total doses when the experimental value was compared to the planned dose. Kan et al. reported that the dose caused by CBCT is approximately 0.04 Gy when using standard mode and it is thought to be relatively-small for the present case [12].

Second, the planned dose is based on the assumption in which there are no voids in the pelvis region. In the rectum and vagina, there is a possibility that a void exists in the clinical study. The impact of voids should be precisely evaluated. Based on these prospective, further studies will be on going.

4. Conclusions

In this study, we developed the novel rectum dosimeter using an OSL sheet. Then we applied the dosimeter to clinical brachytherapy treatment of cervical cancer using high-dose rate ^{192}Ir. In order to evaluate the performance of our dosimeter, the doses of the places where dosimeters were inserted into were analyzed by a therapeutic planning system; our planning system was based on TG-43 algorithm using a precisely measured cone-beam CT image, therefore we can clearly identify the position of our dosimeter in the rectum. As a result, the measured doses were in good agreement with the planned doses. Further experiments are need for accurate evaluation of our dosimetric system. We hope that our *in-vivo* dosimetric system will help in the safety management of absorbed doses of organs at risk.

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