

Comparative skin dose measurement in the treatment of anal canal cancer: Conventional versus conformal therapy

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The subject of this work was to compare the effect of Conventional and Conformal techniques, used for anal canal cancer treatments, on the skin dose deposition. Skin dose was measured on a Rando phantom using XR-T GAFCHROMIC® film. A skin surface dose histogram was constructed and a skin dose profile in the sagittal direction of the perineal region was measured, for both techniques. The measured skin dose in the anterior and posterior region of the skin exposed to radiation is from two to ten times higher when using a conventional technique. In the perineal region, an 85% of the prescription isodose line spreads over 25% of the perineum for conformal technique as compared to 65% with conventional techniques. In addition, conformal technique dose profiles confine better the anatomical position of the anal verge than conventional techniques. Results presented in this work confirm clinically observed improvement in the radiation-induced dermatitis when using the conformal technique. © 2004 American Association of Physicists in Medicine.

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Key words: GafChromic film dosimetry, anal canal cancer treatment, skin dose measurement

I. INTRODUCTION

Radiotherapy combined with chemotherapy is a mainstay of the anal canal cancer treatment, resulting in the preservation of anal sphincter function in 65%–70% of the patients.^{1,2} However, radiation treatment is often associated with acute skin, hematological, and gastrointestinal toxicities requiring treatment interruption and this was reported as a negative factor in the local tumor control.^{3–7}

For treatment of the anal canal carcinoma, the Radiation Therapy Oncology Group (RTOG) recommends a specific radiotherapy technique described in the RTOG 98-02 protocol. The use of the RTOG conventional technique was associated with a severe skin dermatitis requiring a mandatory break during the course of treatment. As a result, an increased rate of tumor reappearance was reported in the form of 23% two-year colostomy recurrence.⁴ We developed a conformal treatment technique⁸ that, in comparison with the RTOG technique, reduces the dose to the skin in the perineal region. By using a three-dimensional (3-D) treatment planning system (TPS) we optimized the shielding of normal tissues in order to deliver the radiotherapy course with concurrent chemotherapy in an uninterrupted fashion.

Conventional DVH tools available in our TPS (CadPlan, Varian) are not suitable for a quantitative comparison of the impact of the RTOG conventional and our conformal technique on the skin dose deposition. Similarly to other existing forward-based TP systems our TPS calculates dose distributions using beam data at the depth of dose maximum and

beyond. Consequently, TPS can only calculate the exit doses but not the entrance skin doses. Monte Carlo-based TP systems are increasingly used in complex treatment set-ups, however, a well known discrepancy between Monte Carlo dose calculations and experimental measurements in the build-up region for high energy photon beams, 18 MV in particular,^{9–11} prevented us from using Monte Carlo simulations to calculate accurately the skin dose for two techniques.

Since electronic equilibrium is not established in the build-up region, the choice of the measurement device is important. Several radiation dosimeters can be used^{12,13} for dose measurements in the build-up region: fixed-separation parallel-plate ionization chambers, extrapolation ionization chambers, diodes, TLDs, radiographic film, and radiochromic film. Measurement of skin dose with conventional detectors such as ionization chambers^{14–16} is a tedious task as dose integration is required at each position and the detector needs to be repositioned for each measurement point. The wide diameter of parallel-plate ionization chambers also provides poor spatial resolution in the penumbra region and other high dose gradient areas. Thermoluminescent dosimeters (TLDs)¹⁷ provide better spatial resolution, but require batch calibration and provide only point-by-point data.

Radiochromic film, on the other hand, provides a complete surface dose profile data set that is limited only by the spatial resolution of the readout densitometer. Near water equivalency of radiochromic film reduces the possible perturbations caused by primary and backscatter fluence and makes radiochromic film a very convenient tool for the col-

lection of off-axis and peripheral skin doses in phantoms as well as *in vivo*.^{18–24} In order to compare the skin dose deposition for two techniques used in the anal canal cancer treatments, we measured the skin dose on a Rando phantom using the XR-T model GAFCHROMIC® film. The surface of the Rando phantom in the irradiated region was covered with film pieces affixed to the phantom surface with a narrow tape in order to provide firm contact with the phantom surface. The exposed film was then used to construct the skin surface dose histogram (SDH) as well as the skin dose profile in the sagittal direction of the perineal region for both techniques.

To compare the quantitative impact of the RTOG and conformal technique on the skin dose, we carried out an experimental measurement of the skin dose, simulating the clinical setup for each of two techniques. Pieces of film have been positioned on the Rando anthropomorphic phantom (Alderson Research Laboratories) surface in the region exposed to radiation during treatment delivery. The skin dose histograms (SDH) as well as the dose distribution in the perineal region with and without bolus have been determined and compared for two techniques.

II. MATERIALS AND METHODS

A. Radiochromic film

XR-T model GAFCHROMIC® film, with batch number 30198-1B was used in our experiments. The active layer of the film is sandwiched between two sheets of yellow, transparent polyester, having a thickness of 97 μm and a density of 1.38 g/cm^3 . The active layer is about 28 microns thick with a physical density of 1.75 g/cm^3 . This means that the effective depth of measurement, scaled by density, is 0.016 g/cm^2 for the XR-T GAFCHROMIC® film. HS and XR-T GafChromic film models (International Specialty Products, Wayne, NJ) have been developed as a more sensitive and more uniform alternative to the common GafChromic MD-55-2 model. HS model has been specifically designed for the measurement of absorbed dose in high-energy photon beams, while the XR model has been introduced for dose measurements in low energy photon beams. Although the XR-T model is not intended for use in high energy photon beams, we used it in our study because of its lower sensitivity yet higher dynamic range in comparison with the HS model GafChromic film, in large dose gradients and at high absorbed dose levels.

B. Radiochromic film dosimetry

To measure the film net optical density (OD) we have used the Nuclear Associates Radiochromic Densitometer, Model 37-443 that is especially suited to make spot measurements on GAFCHROMIC® dosimetry film, since it employs an optimum red LED light source and a filter to measure in a narrow band centered at about 670 nm. This corresponds very closely to the wavelength of the major peak in the spectrum of the photopolymer. The physical aperture of the densitometer is 2 mm.

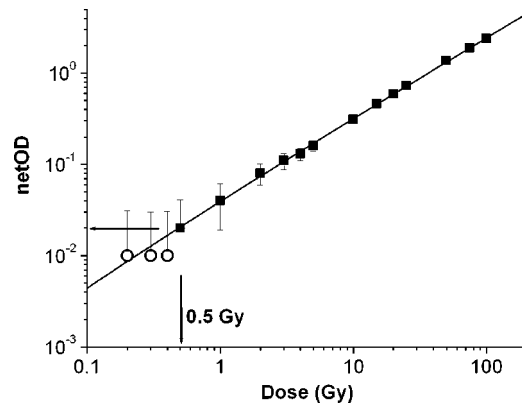


FIG. 1. Net optical density (OD) as a function of the given dose to tissue in solid water; solid points have been used for the fitting procedure, while the open symbols have been discarded because their values are smaller than the minimum read out of the personal densitometer used; the solid line through the data points represents the best fit to experimental data obtained with the third order polynomial.

The film dose response was initially calibrated for an 18 MV photon beam in accordance with recommendations described in the TG-55 document.²⁵ The netOD was measured for doses ranging from 0.1–100 Gy. Measurements were performed by irradiating 5 pieces of film ($2 \times 1 \text{ cm}^2$ in size) with 18 MV x-rays from a Varian 2300 (C/D) accelerator (Varian, Palo Alto, CA). The OD was measured in the middle of the upper half ($1 \times 1 \text{ cm}^2$) of the film to minimize the effects of variations in measured dose near the edge of the film. The bottom half part of the film was used for labeling and manual handling. Pieces of film were placed around the central axis of the beam, in the plane at the depth of dose maximum ($z_{\text{max}} = 3 \text{ cm}$) in a $30 \times 30 \text{ cm}^2$ RMI-457 solid water phantom (Gammex RMI, Middleton, WI). A $10 \times 10 \text{ cm}^2$ field size at a 100 cm source–surface distance (SSD) was used for irradiations. A sufficient amount of phantom material (20 cm), placed below film pieces, was used to provide full backscatter. The optical densities of the film pieces were measured 24 hours after irradiation. Each piece of unexposed film was measured before irradiation to obtain the background signal for subtraction from the after-exposure optical density in order to obtain the net optical density. Film was removed from its light tight envelope only during irradiation and readout to reduce the effects of the ambient light.²⁶ A control set of films, not exposed to radiation, was used to monitor any change in the film OD due to the temperature or ambient light.

Figure 1 represents the net optical density of radiochromic films plotted against the given dose to tissue in solid water at z_{max} in the dose range from 0.1 to 100 Gy. The doses were delivered based on the calibrated linac output, measured in accordance with the TG-51 protocol.²⁷ The output, measured before and after irradiation, did not vary by more than 0.2% for the beam quality used in this study. Percentage errors in measurements are shown on the graph and represent the stan-

dard deviations over a set of 5 pieces of film exposed at the same time. The graph is plotted on a log–log scale for a better overview of the full dynamic range of the dosimeter. Solid line through the data points represents the best-fit curve obtained by minimizing the χ^2 to the experimentally measured points. We found that the best fit is obtained with a third order polynomial in log–log scale. The fitting points (solid points) have been predetermined in advance in the following way: measurements that correspond to the netOD less than 0.02 (minimum readout of the optical reader is 0.01) have been discarded (open symbols). The figure suggests that the minimum detectable dose by using this type of film and densitometer is 0.5 Gy.

For the prescription dose to the planning target volume of 54 Gy, the expected values for the surface dose have been estimated to be in the range from 1 to 20 Gy. In order to obtain reliable film ODs, we have decided to deliver twice the prescribed dose ($2 \times 54 \text{ Gy} = 108 \text{ Gy}$) for each treatment plan.

C. Dose calculations

Treatment plans for two techniques have been simulated for a RANDO phantom using a 3D TPS (CadPlan, Varian). CT slices have been obtained on the RANDO phantom, using a CT-simulator (Picker, PQ-5000), in a supine position with a slice thickness and separation of 0.5 cm from the L5 vertebral body down to the upper thigh. Virtual simulations have been performed for two techniques using the AcQsim planning software. Once the virtual simulation was completed, the CT scan data and plan parameters were exported to the TPS for dose calculation. Plans were developed in a usual way, e.g., with the stipulation that the 95% isodose volume covers the PTV set up by the physician. The treatment plans were delivered on a Varian Clinac 2300 (C/D) linear accelerator, using an 18 MV photon beam. In order to improve the statistical variance, both techniques have been delivered 3 times.

D. Experimental set-up

A graphical description and comparison of the beam arrangements for the two plans are given in Fig. 2. The RTOG technique we used for comparison consists of three plans.

- (i) Plan 1, with the prescription dose of 30.4 Gy at the isocenter; the plan consists of the AP-PA beam arrangement aiming at the tumor as well as the nodes.
- (ii) Plan 2, with the prescription dose of 13.6 Gy at the isocenter; the plan consists of the AP-PA beam arrangement aiming at the tumor as well as nodes with smaller field sizes than in Plan 1.
- (iii) Plan 3, with the prescription dose of 10.0 Gy at the isocenter; the plan consists of the standard 4-field box technique.

The conformal technique consists of two plans.⁸

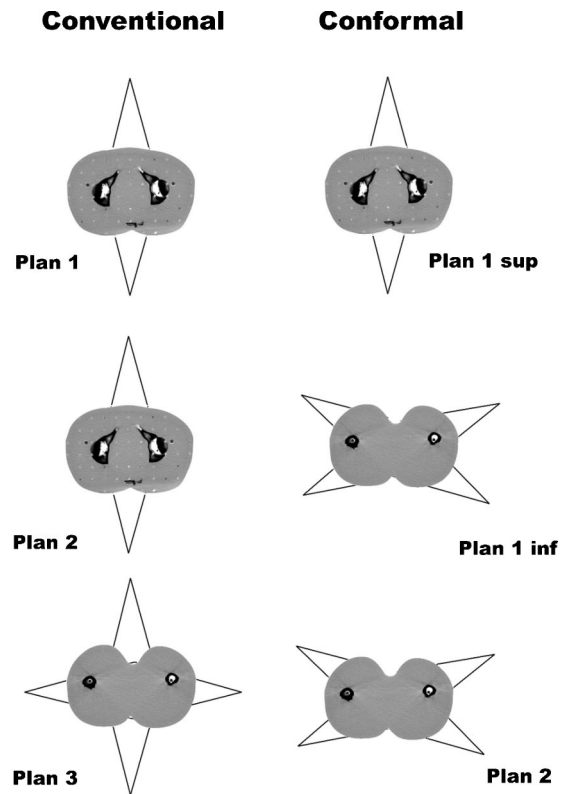


FIG. 2. A comparison of beam arrangements for the conventional RTOG technique and the conformal technique for the anal canal cancer treatments.

- (i) Plan 1-SUP, with the prescription dose of 30 Gy at the mid-plane of the superior half-beam field; the plan consists of the AP-PA beam arrangement aiming at the nodes.
- (ii) Plan 1-INF, with the prescription dose of 27 Gy at the center of the tumor in the inferior half-beam field; the plan consists of the 4-diamond beam arrangement aiming at the tumor.
- (iii) Electron boost to the external iliac nodes in order to bring the dose to the nodes to 27 Gy using a 15 MeV electron beam; the necessary dose of 13.5 Gy to be delivered to the level of external iliac nodes was estimated from the photon beam isodose distributions.
- (iv) Plan 2, with the prescription dose of 27 Gy at the isocenter; the plan consists of the 4-diamond beam arrangement aiming at the tumor.

Beam portals have been designed in a conformal way, based on target structures outlined on the Rando phantom in accordance with our previous clinical study.⁸ In the treatment of anal canal carcinoma, CTV includes the entire anal canal and lymphatic drainage (the perirectal, obturator, inguinal, and iliac nodes) and the immediate perianal skin. This is quite a standard clinical target volume and there is very little variation from patient to patient. Occasionally, there are unusual cases with extensive perianal extension but they represent less than 5% of this patient population. Indeed, the technique described in this paper does not apply for the primary perianal skin cancer where the gross target volume can vary

significantly at the level of the contouring of the skin.

The treated area was covered with 128 pieces (each with a dimension of $1 \times 1.5 \text{ cm}^2$) of XR-T model GafChromic film every 5 cm along the circumference and 2.5 cm along the transverse direction. The net optical density has been determined for every piece of film based on the calibration protocol, described in Sec. II A. The corresponding dose values have been obtained from the function, which is inverse from the one given in Fig. 1. In order to make a surface dose histogram in the irradiated region, we constructed a matrix of 8×32 equally-spaced dose points, with spacing between the points of 2.5 cm. The dose values for the missing points (along circumferences) have been obtained by linear interpolation. Dose to the skin due to the electron boost fields was estimated from the clinical 15 MeV electron PDD data to be 12 Gy and was added to the 8 pieces of film comprised with the electron field. Film pieces encountered with the electron field were identified from the virtual simulation using the AcQsim software.

In the perineal region of the RANDO phantom, we placed a 5 mm wide and 9 cm long GafChromic film strip. In order to simulate the clinical situation in which the patient's buttocks act as a natural bolus, we have placed the pieces of bolus in the perineal region of the RANDO phantom, over the previously fixed film strip. To investigate the importance of this presence of natural bolus, we have also performed the measurements on a RANDO phantom without placing the bolus in the perineal region.

III. RESULTS AND DISCUSSION

Figure 3 represents the surface dose distributions at two transverse cuts within the irradiated area. One slice was taken in the middle of the superior part and the other in the middle of the inferior part of the irradiated region. The numbers correspond to the surface dose in Gy at the given point for the conventional technique for prescription dose of 54 Gy. On the other hand, numbers given in parentheses correspond to doses in Gy for the same points when a conformal technique is used. The actual measured doses, for a delivered dose of 108 Gy, has been scaled (divided by 2) to the prescription dose of 54 Gy. Percentage errors in measurements are calculated as maximum differences from the mean value for 3 measurements and are not larger than 3%. The surface dose in the anterior/posterior region of the treated area is 5 to 10 times higher for the RTOG conventional technique in comparison with the conformal technique. On the other hand, at the oblique beam incidence surface points, the conformal technique gives only slightly higher surface doses than the Conventional Technique. In addition, the highest surface dose observed with Conventional Technique was 34.4 Gy, whereas for the conformal technique it was 20.2 Gy.

It is apparent from Fig. 3 that the conformal technique distributes the skin dose in a more uniform manner than the conventional technique. Figure 4 represents a comparison of the SDHs for the two techniques, again with a clear advantage for the conformal technique. The difference in the SDH shapes for the two techniques is a direct consequence of the

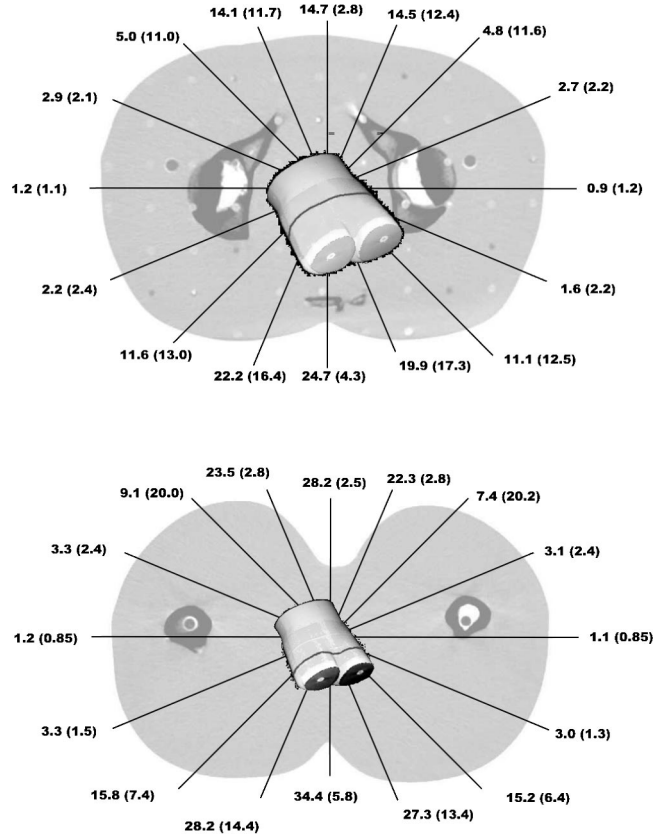


Fig. 3. Dose distributions at two levels within the irradiated area; numbers correspond to surface dose values in Gy for conventional while numbers in parentheses correspond to dose values in Gy for a conformal technique with the prescription dose of 54 Gy; the black line represents the position of the slice within the irradiated region: in the middle of superior (up) and in the middle of inferior (down) part of the skin exposed to radiation.

skin dose distribution differences observed in Fig. 3. A 20% isodose surface covers 45% of the irradiated skin when using the conventional technique, whereas the same isodose surface covers only 20% of the skin exposed to radiation with the conformal technique. Both the conventional and the con-

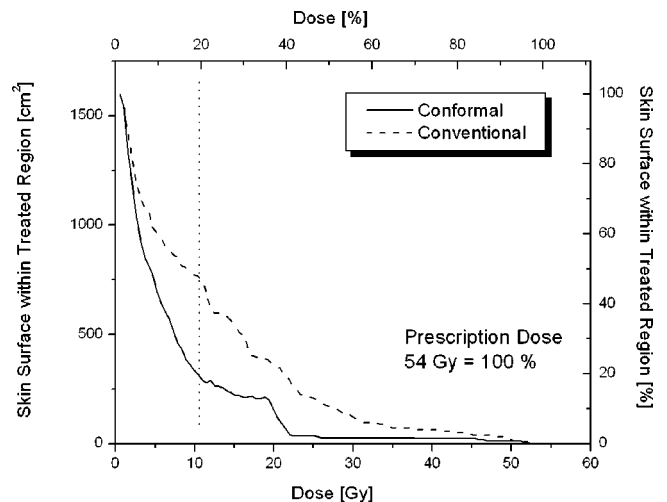


Fig. 4. The dose surface histogram for a conventional and conformal technique used for the anal canal cancer treatments.

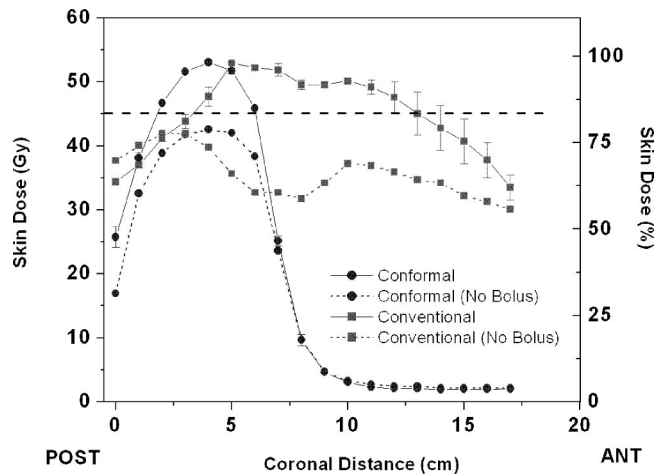


FIG. 5. The dose distribution in the perineal region as a function of the coronal distance; solid lines correspond to the measurements while the dotted lines correspond to the measurements without a bolus placed in the perineal region of the Rando phantom.

formal technique must have a prescription dose as a maximum dose, since the adjacent perineal skin is part of the PTV. Results presented in Figs. 3 and 4 confirm the clinically observed toxicities³⁻⁸ when the conventional technique is used.

Aside from the SDH curves, we were also studied in the dose distributions along the perineal region in the treatment area. Figure 5 represents the skin dose profile in the sagittal direction for the perineal region. The readings have been taken 1 cm apart and the points in Fig. 5 represent the average, while the error bars correspond to standard deviations of 3 measurements.

For each technique, we have carried out measurements with and without the bolus in the perineal region of the Rando phantom. In the clinical setup, when the patient is treated in the supine position, the buttocks are acting as a natural bolus. The solid lines in Fig. 5 represent results of the measurements with the addition of bolus on the Rando phantom body within the perineum in order to reproduce the clinical setup. This highlights the importance of not treating the patient in the prone position, especially for elderly patients where the lack of the muscular tonus might result in an under-dosing the clinically critical area.

Figure 5 also highlights the sparing of the anterior perineal skin region and the conformal dose shaping over the posterior perineum when using the conformal technique. A 45 Gy isodose line (85% of the prescription dose) encounters only 25% of the perineal region when the conformal technique is used, compared to 65% when the Conventional technique is employed. Clinical experience³⁻⁷ has shown that acute skin toxicity in the perineal region requires a mandatory treatment interruption, which has been reported as a negative factor in the local tumor control.

IV. CONCLUSIONS

GafChromic film, model XR-T, was used to compare the skin dose deposition effect of conventional and conformal

techniques, used for the anal canal cancer treatments. The film was initially calibrated in the dose range from 0.1 Gy to 100 Gy and the minimum detectable dose was estimated to be 0.5 Gy. Skin surface-dose-histograms as well as the skin dose profiles in the sagittal direction of the perineal region were reconstructed for both techniques.

Surface doses in the anterior and posterior region of the treated area are 5 to 10 times higher for the conventional RTOG technique in comparison with the conformal technique. The highest surface dose observed with the conventional technique was 34.4 Gy (64% of the prescription dose), whereas with the conformal technique it was 20.2 Gy (37% of the prescription dose). The conformal technique distributes the skin dose in a way that is more uniform than the conventional technique. A 20% isodose surface covers 45% of the irradiated skin with the conventional technique, while for the conformal technique the same isodose surface covers only 20% of the skin exposed to radiation. A 45 Gy isodose line encounters only 25% of the perineal region when the conformal technique is used, compared to 65% for the conventional technique. In addition, the conformal technique dose profile better confines the perineal skin than the conventional technique. Our results confirm clinically observed improvement in the skin dermatitis when using the conformal techniques compared to the conventional technique.

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