FILM TECHNIQUES IN RADIOTHERAPY

FOR

TREATMENT VERIFICATION, DETERMINATION OF PATIENT EXIT DOSE,

AND

DETECTION OF LOCALIZATION ERROR *

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Abstract

In patient radiation therapy, it is important to know that the diseased area is included in the treatment field and that normal anatomy is properly shielded or excluded. Since 1969, a film technique developed for imaging of the complete patient radiation exposure has been applied for treatment verification and for the detection and evaluation of localization errors that may occur during treatment. The technique basically consists of placing a film under the patient during the entire radiation exposure. This film should have proper sensitivity and contrast in the exit dose exposure range encountered in radiotherapy. In this communication, we describe (1) how various exit doses fit the characteristic curve of the film; (2) examples of films exposed to various exit doses; and (3) the technique for using the film to determine the spatial distribution of the absorbed exit dose; and (4) types of errors commonly detected.

Results are presented illustrating that, as the frequency of use of this film technique is increased, localization error is reduced significantly.

INTRODUCTION

In the radiation treatment of patients, inability to irradiate the entire diseased area consistently and accurately may result in local failure, that is, incomplete control of disease. Reports have indicated that, among patients treated by radiation, local failure accounts for 1/3 of all deaths (1). There is experimental and empirical clinical evidence that 10 to 15 percent reductions in dose can result in failure to control a tumor (2,3). Dose reductions of this magnitude can occur if the radiotherapist has not included all of the tumor in the treatment volume from the first day of treatment, if the patient moves during treatment, or if the technician sets up the patient incorrectly. What the radiotherapist needs, then, is a tool such as film to 1) monitor the accuracy of treatment setup and 2) to estimate reductions in the tumor dose that may occur as the result of physician, patient, or technician error.

At the University of Chicago we have been interested in using a film which can be placed beneath the patient before radiation treatment and removed afterwards. Ideally, this film should have a speed and sensitivity that are appropriate to record radiation exit dose from a patient during an entire treatment, so that an image of the anatomy actually irradiated is obtained. The image quality should be such that the radiotherapist can determine whether the anatomy of interest has been included in the treatment volume. Also, the film should be capable of being developed in an automatic film processor to eliminate the chore of wet development. In this paper,

we discuss our experience with the development of such a film and with its clinical application to the problem of localization error as a potential cause of local treatment failure in radiation therapy.

In 1969, we initially used a film called Kodak Fine Grain Positive (4). Although its sensitivity was adequate for recording most of the patient exit doses in our department, due to the thinness of its base the film had to be hand-processed or taped to a leader for automatic processing. This restriction limited the use of the film technique. On the basis of a pilot study (5), however, we were able to document that errors in treatment occurred frequently enough to justify the commercial production of a film which was on a thicker base for treatment verification, and which was directly transportable through the automatic processors. Such a film is presently available and is called Kodak RP/V Therapy Verification Film (6).

EXIT DOSES AND CHARACTERISTIC CURVE OF FILM

Table I shows a list of patients treated on our 2MeV Van de Graaff generator during one day. All patients receive 1/2 the exposure from each side AP and PA each day. The distribution of exit doses to which the film is exposed are in the right-hand column. These doses range from 24 to 154 rads, with the majority between 40 and 80 rads.

Figure 1 shows the characteristic curve of RP/V film exposed to the beam of the Van de Graaff generator. Film density and contrast are satisfactory for the exit doses used in our department; the 40-80

rad range falls in the mid-density range on the straight-line portion of the curve.

Figure 2 shows an RP/V film of a pelvis treated on the cobalt-60 therapy unit, with an exit dose of 28 rads. Although this exit dose is low, the detail obtained, such as the clear outline of the pelvic brim relative to the radiation field, is still adequate.

An RP/V film of a patient being treated for Hodgkin's disease on the Van de Graaff is shown in Figure 3. The exit dose in this case was 60 rads. The majority of films are exposed to exit doses in this range. The anatomical detail in the lung area and spine adjacent to the blocks shielding parts of the lungs and spine is excellent.

Figure 4 shows a RP/V film of a patient whose brain was irradiated with the cobalt-60 beam, with an exit dose of 120 rads. Detail is still adequate, even though the film density is high. For exit doses higher than 140 rads, a bright light can be used to visualize detail.

An additional advantage of RP/V film is that it comes in a ready-pack form. This feature is extremely important because it eliminates cassette loading and unloading.

DETERMINATION OF EXIT DOSE

When the radiotherapist treats a patient, he generally assumes that the midline dose is uniform across the treatment field. If one looks at the therapy verification film however, one observes that the photographic density varies appreciably across the treatment field. In consequence, the absorbed exit dose may also vary appreciably over this field. An investigation was undertaken to develop a method whereby

the absorbed exit dose could be determined from the therapy verification film (7).

If the therapy verification film is to be used for determinations of the exit dose, it is necessary to obtain a proper calibration curve by which measured densities on the film can be related to the exit dose. The most important features in the use of photographic emulsions for dosimetry are proper film calibration and standardized processing techniques.

The dependence of the sensitivity of photographic emulsions on the quality of radiation has always been a problem in film dosimetry. Although film sensitivity to high-energy radiation such as ^{60}Co is quite uniform, this is generally not the case when film is exposed directly to low-energy radiation. When the ^{60}Co beam passes through a phantom or patient, the photon spectrum reaching the film may be altered to such an extent that the film sensitivity is changed (8), making the film response dependent upon field size and patient thickness. Therefore, to obtain a proper film calibration curve and to establish the validity of using the therapy verification film for determining the exit dose, we investigated the effects of field size and depth.

The film calibration for the evaluation of absorbed dose is based on measurements of exposure with an ionization chamber and on calculations of the absorbed dose in the depth. The ^{60}Co machine was used to expose films placed at specified depths in tissue-equivalent Masonite blocks which had previously been used for the determination of tissue-air-ratios (TAR) on that machine. The absorbed dose was

calculated from the equation

$$D_{Depth} = TAR \times X \cdot f \qquad (1)$$

where D_{Depth} = absorbed dose (rads) in phantom

TAR = tissue-air-ratio

X = exposure (roentgens)

f = roentgen-to-rad conversion factor.

The exposure was obtained by use of a calibrated Victoreen chamber to measure the exposure in roentgens. A correction was made for the equilibrium thickness factor (9,10).

Figure 5 illustrates the experimental setup for the calibration. For convenience and simplicity, a field size of 10 x 10 cm at a depth of 2.2 cm was selected as the standard. Masonite blocks of 7 cm thickness were added for backscatter. Equation (1) was used for calculation of absorbed doses ranging from 5 - 160 rads which were selected to define 8 points on the calibration curve. A film was inserted at the 2.2 cm depth, and the appropriate exposure was given for each of the 8 film packets. The films were processed in a well-controlled Kodak M6NA X-Omat. The same procedure was used for exposure of films at field sizes ranging from 30 cm^2 to 300 cm^2 at depths of 2 and 20 cm. A standard calibration film was always run as a control on development. Film densities were measured on a Macbeth Quantalog densitometer. Figure 6 shows a characteristic curve of net density vs log absorbed dose for the various field sizes and depths of interest, compared to the standard curve. The total variation of the absorbed dose was within 5% of the standard curve. These results indicate that the response of this film is independent of depth and

field size within the experimental conditions discussed. A single calibration curve therefore can be used to determine absorbed dose.

A similar experiment was performed with the Van de Graaff generator, which operates with a broad x-ray spectrum. Depth dose curves are used for calculation of entrance, tumor, and exit doses for patients treated on the machine. The following equation was used for the calculation of absorbed dose in the depth on the Van de Graaff:

$$D_{Depth} = X \times f \times \%DD,$$

where

D_{Depth} = exposure (roentgens)

f = roentgen-to-rad conversion factor

% DD = % depth dose.

Values for appropriate backscatter and displacement factor corrections were used (9,10).

The experimental setup and processing conditions were the same as in the previous experiment. Agreement was again obtained for the various conditions used, the total variation being ± 5% of the standard.

From the experimental results obtained on the ^{60}Co and the Van de Graaff machines, a standard film calibration curve can be obtained for determining the absorbed dose. The standard technique of a 10 x 10 cm field size at 2.2 cm depth was selected to determine the absorbed dose at exit for the patient therapy verification film.

For the sake of convenience in evaluation of patient therapy verification films, we plotted the calibration curve simply as net density vs absorbed exit dose. Figure 7 shows the curve which was used for the determination of the absorbed exit dose from a verification film of a patient being treated in the pelvic area on the cobalt-60 machine with the standard technique.

The film in its ready-pack paper envelope was maneuvered so that it was in good contact with the patient's skin over the treatment area of interest. The pelvic therapy verification film obtained is shown in Figure 8. The field size at the tumor depth was 17 x 17 cm. The measured thickness of the patient's lower abdomen was 18 cm, and that of the middle abdomen, 24 cm. From the depth dose charts, the exit doses in these areas were estimated to be 45 and 38 rads, respectively. The values correlating the measured film densities in these areas (denoted by letters A and B in Figure 8) with the absorbed exit dose from the curve in Figure 7 were 47 and 36 rads, respectively. For comparison, several TLD dosimeters were placed on the patient's skin in the lower abdominal area corresponding to the location where the film measurements were made. The average dose measured with the TLDs in this area was 48 rads.

Absorbed exit dose measurements obtained from the film with calibration curve on patients treated for Hodgkin's disease show that the exit dose across the treatment field varies almost by a factor of 2, due to the variety of anatomical structures and differences in patient thickness within the treatment field.

The technique described has been found useful for the determination of absorbed exit dose in areas where healthy tissue has been unnecessarily irradiated, for observations of changes in exit dose as the patient gains or loses weight, detection of changes in source output, alteration of shielding blocks or incorporation of compensators for more selectively controlled dose across the treatment field, and estimation of exit dose from behind shielding blocks.

LOCALIZATION ERRORS

Figures 8, 10, and 11 show examples of treatment errors commonly detected in our department (1). During pelvic irradiation (Figure 9) the patient rotated and the treatment area was partially missed. In this case, the error was caused by the patient. In Figure 10, the larynx shield was placed improperly by the technician. In this example, the block partially shielded the diseased region. Figure 11 shows an example of diseased areas that were not included in the treatment field due to overshielding of a patient being treated for Hodgkin's disease. The arrows indicate where diseased regions along the axillary wall and spine were not irradiated. This type of error is in part the fault of the physician who designed shielding blocks which, in fact, protect areas that should be included in the treatment field.

Figure 12 shows the results of a study in which the relationship of percent localization error in the treatment of Hodgkin's disease and malignant lymphoma cases and verification films per patient are plotted against time (12). The trend of increased use of film and corresponding reduction of error illustrates the importance of the therapy verification film as a tool to detect and minimize localization errors.

CONCLUSION

The radiotherapist is undoubtedly aware that localization error is a problem inherent in patient radiotherapy. The verification film technique gives the therapist the opportunity to (1) check the treatment setup, (2) make appropriate adjustments, thereby minimizing the propogation of errors, (3) determine the exit dose distribution, and (4) detect and evaluate localization errors. In our department, we keep every verification film in the patient's record file to document how consistently and precisely diseased areas were included in the treatment field. At some time in the future such a record may be required. The film technique is a simple, but very important tool for the optimization of treatment in combination with other factors such as beam calibration, improved dosimetry, and optimal time, dose, and fractionation schemes.

Figure 1 Characteristic curve of Kodak RP/V Therapy Verification Film.

Figure 2 RP/V film of a pelvis. The exit dose is 28 rads.

Figure 3 RP/V film of a patient being treated for Hodgkin's disease. The exit dose is 60 rads.

Figure 4 RP/V film of a patient being treated for a brain tumor. The exit dose is 120 rads.

Figure 5 Illustration of experimental setup used for film calibration.

Figure 6 Characteristic curve showing independence of film response to field size and depth for ^{60}Co. The 10 x 10 cm field and 2.2 cm depth are used as a standard and are shown as solid curve.

Figure 7 Calibration curve for pelvic RP/V film shown in Figure 8.

Figure 8 Pelvic RP/V film. A and B denote film density areas where exit doses obtained from the calibration curve in Figure 7 are 47 and 36 rads, respectively.

Figure 9 RP/V film of a pelvic treatment in which the patient rotated and the proper treatment area was partially missed.

Figure 10 RP/V film showing improper placement of larynx shield.

Figure 11 RP/V film with arrows showing where diseased areas were not included in the treatment field due to overshielding.

Figure 12 Relationship of percent localization error and number of verification films per patient to time in the radiotherapy of Hodgkin's disease and malignant lymphoma. Percent localization is defined as total localization errors divided by total verification films for each interval.

TABLE I

Exit dose exposures of patients treated on the Van de Graaff generator during one day. All patients receive one-half the exposure on each side AP and PA.

	Field Type	Exit Dose (rads)
1.	Whole Abdomen	24
2.	Lower Abdomen	28
3.	Whole Abdomen	33
4.	Thoracic Spine	37
5.	Pelvis and Lumbar Spine	46
6.	Whole Abdomen	46
7.	Pelvis and Lumbar Spine	47
8.	Pelvis and Lumbar Spine	49
9.	Extended Mantle	50
10.	Pelvic	56
11.	Thoracic Spine	56
12.	Whole Thorax	57
13.	Mediastinum	59
14.	Neck	61
15.	Extended Mantle	61
16.	Pelvic	62
17.	Extended Mantle	67
18.	Mediastinum	68
19.	Pelvic	69
20.	Hip	72
21.	Lumbar Spine	74
22.	Hemithorax	106
23.	Hemithorax	112
24.	Pelvis and Lumbar Spine	116
25.	Skull	132
26.	Arms, Axilla	154

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