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Measurement of Transit Time of a Gammamed-Plus Remote Afterloading High Dose Rate Brachytherapy Source

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Accurate measurement of transit time of the HDR brachytherapy source of a remote after-loading unit is necessary to calculate the total radiation dose given to the treatment volume. Presently, most of the HDR brachytherapy treatment planning systems neglect the transit time in the computation of dose. The aim of this investigation is to use a well type ionization chamber to measure the transit time during the source movement between two dwell positions. As well type ionization chamber and a precision electrometer (manufacturer CD instruments, Bangalore) were used to measure the charge generated during the movement of the Ir-192 source of a Gammamed HDR brachytherapy unit with an interstitial needle. Effective transit time and effective speed were determined on the basis of methodology described by Sahoo [2]. Corrections were done on the basis of relative sensitivity values for varaious dwell position in the ionization chamber. In the present study the variation of effective speed with interdwell distance was minimal as compared with that of Sahoo [2]. The effective transit times were 0.129, 0.182, 0.301, 0.402, 0.701, and 0.993 seconds for 1, 2, 4, 6, 8 and 10 cm interdwell separations respectively. The effective transit times in the present study were higher than those of Sahoo [2]. Software modification accounting for the dynamic dose should be incorporated into all HDR planning systems. Such an improvement would enhance the safety and accuracy of HDR brachytherapy.

Key words: HDR brachytherapy, transit time, dynamic dose, HDR planning system, accuracy of HDR brachytherapy.

Introduction

High dose rate brachytherapy (HDR) typically uses a high activity source which afterloads to pre-programmed dwell positions within an applicator for a prescribed period of time. High dose rate afterloading technology allows for the differential weighting of dwell positions, and adds flexibility to treatment planning thereby producing customized therapy which conforms to patient anatomy. Every HDR application results in source dwell (prescribed) and transit (dynamic) radiation dose.

Accurate measurement of transit time of the HDR brachytherapy source of a remote after-loading unit is necessary to calculate the total radiation dose given to the treatment volume. Presently, most of the HDR brachytherapy treatment planning systems neglect the transit time in the computation of dose. Currently, only the stationary component of the treatment cycle is included in an isodose distribution calculated with planning software. The total dose (D_t) produced during an HDR treatment, however, is equal to the sum of the stationary (D_s) and dynamic dose (D_d) components:

$$D_t = D_s + D_d \tag{1}$$

The total dynamic dose (D_d) component delivered at an arbitrary point "P" is equal to the sum of entry ($D_p^{(1)}$), interdwell ($D_p^{(2)}$), and exit ($D_p^{(3)}$), dynamic dose contributions:

$$D_d = D_p^{(1)} + D_p^{(2)} + D_p^{(3)} \tag{2}$$

Total transit dose is inversely related to source velocity. Source velocities vary with path lengths. The total interdwell $D_p^{(2)}$ contribution represents the sum of all interdwell movements within a treatment cycle.

However, for a high activity source with small dwell times, this could introduce significant error in the calculated value of dose delivered to the treatment volume. Additionally planned stationary dwell times may not be exactly used in the remote afterloader because of any possible internal correction of the dwell time to account for the transit time of the source and the timer error that may exist. Nucletron Micro-selectron HDR unit corrects for transit time by reducing the programmed dwell time by an amount up to 0.1 s, which depends on the source speed, and the distance between two dwell positions. Measurement of interdwell position transit times and source velocity during the transit as a part of quality assurance and commissioning

program of an after-loader unit will help to assess the clinical significance of the transit dose.

Among the available procedures for the determination of transit time and speed, well type ionization chamber measurements are expected to be reasonably accurate and practical for routine clinical use. Since well ionizing chambers are being routinely used to calibrate the HDR brachytherapy source, it would be a good choice to use these for transit time measurement. The aim of this investigation is to use a well type ionization chamber to measure the transit time during the source movement between two dwell positions.

Materials and methods

An well type ionization chamber and a precision electrometer (manufacturer CD instruments, Bangalore) were used to measure the charge generated during the movement of the Ir-192 source of a Gammamed HDR brachytherapy unit with an interstitial needle. The charge was measured with the source being programmed to dwell for different amount of time at two separate locations, X_1 and X_2 along the needle. X_1 location is towards the end of the needle and X_2 is closer to the source housing. The locations of X_1 and X_2 were chosen between 1 and 15 dwell position of the source for step size of 10 mm. First the measurement of charge q_1 was carried out for the source dwelling at the X_1 location for time t_1. Then six measurement of charge q_2 were made when the source was programmed to dwell at X_1 for t_1 and then move to X_2 to dwell there for time t_2 (5, 10, 15, 20, 25 and 30 sec) . The value of the net charge, q_n, generated during source movement from X_1 to X_2, and for the source dwelling at X_2 was then calculated from

$$q_n = q_2 - q_1 \tag{3}$$

A linear regression analysis of q_n as a function of t2 was made to express q_n as

$$q_n = I \cdot t_2 + q_0 \tag{4}$$

where I is the slope of the linear fit, which represents the charge per unit time or current, and q_0 is the intercept on the charge axis. The quantity q_0 represent the charge generated during source transit between two dwell positions, and due to any reduction in the set

stationary dwell time to account for transit time as well as any dwell time error that may exist in the unit. The combined effect of these three factors can be quantified by means of an effective transit time $t_{ef,\ tr}$ which can be calculated by using the equation,

$$t_{ef,\ tr} = q_0 / I \tag{5}$$

The measurements of q_n were made for the two source locations X_1 and X_2 separated by a distance of 1 to 10 cm. Values of transit time were determined by the above procedure for four different values of dwell time t_1 at X_1 namely 5, 10, 15 and 20 sec. These dwell times were chosen arbitrarily with the upper limit being dictated by the limitation of the electrometer.

Response of the well type ionization chamber is known to change with different source position inside the chamber. The values of current (I_n) for different locations of the source inside the ionization chamber with a step size of 10 mm were measured and the sensitivity (S_n) was then calculated from

$$S_n = I_n / I_o \tag{6}$$

where I_o is the peak current. The values of charge q_o and I obtained from the linear fit were then corrected for the sensitivity of the chamber for that location of the source. The charge generated during the transit was corrected by using the average sensitivity of the chamber for that distance of travel of the source inside the chamber.

Results

The measured charge q_n plotted as a function of actual t_2 (system corrects nominal dwell times by decay factor) is shown in Figure 1 along with fitted straight line for interdwell position separations of 1, 2, 4, 6, 8 and 10 cm. The steepness of the q_n vs t_2 fit increased with decreasing interdwell position separation from 10 cm to 1 cm. The measured sensitivity for the different location of the source inside the ionization chamber is plotted in Figure 2. Maximum sensitivity of the ionization chamber was observed at a dwell position 5 with step size of 10 mm.

The variation of source speed with interdwell position separations of 1, 2, 4, 6, 8 and 10 cm is shown in Figure 3. In the present study the variation of effective speed with interdwell distance was minimal as compared with that of Sahoo [2]. Comparison of

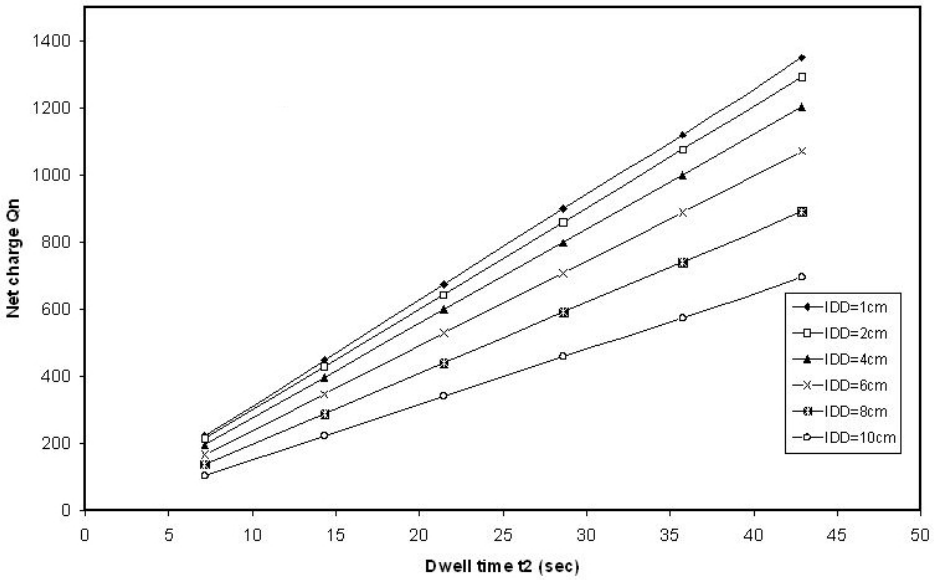

Figure 1. The measured charge q_n as a function of actual t_2 along with fitted straight line for interdwell position separations of 1,2,4,6,8 and 10 cm.

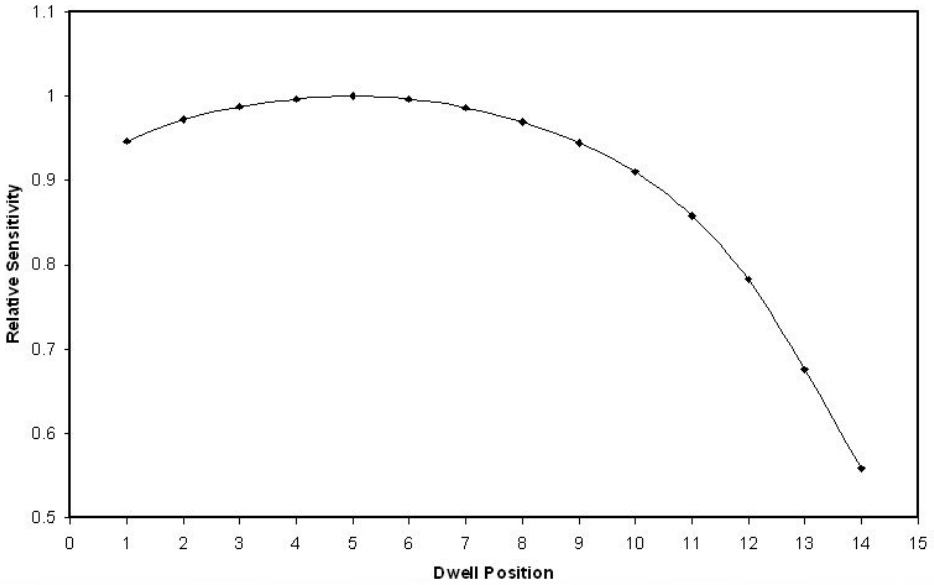

Figure 2. The measured sensitivity for the different location of the source inside the ionization chamber.

Table 1. Interdwell position transit times for the present study and from Sahoo (2001).

Distance [cm]	Effective Transit Time [sec]	
	Present study Mean (SD)	Sahoo (2001) Mean (SD)
1	0.129 (0.127)	0.04 (0.04)
2	0.182 (0.178)	0.05 (0.02)
4	0.301 (0.090)	0.19 (0.02)
6	0.402 (0.200)	0.24 (0.05)
8	0.701 (0.026)	0.40 (0.09)
10	0.993 (0.811)	0.45 (0.06)

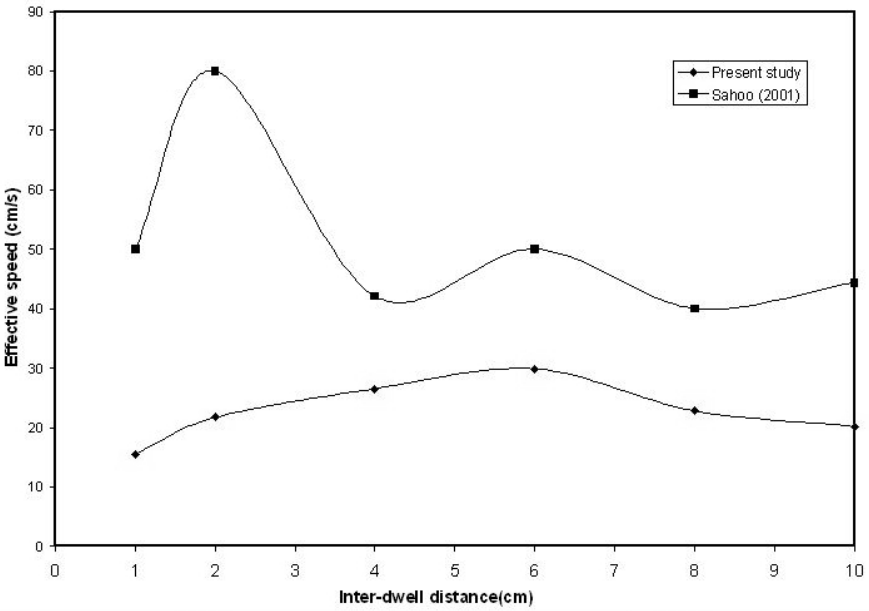

Figure 3. The variation of source speed with interdwell position separations of 1, 2, 4, 6, 8 and 10 cm.

source speeds from the present study with those of Sahoo [2] is also shown in the figure. Effective transit times have been indicated in Table 1 for the present study and for Sahoo [2]. The effective transit times in the present study were higher than those of Sahoo [2].

Discussion

High dose rate afterloading offers many advantages over conventional LDR brachytherapy. However, the linear quadratic model predicts an increased risk of late tissue effects following delivery of "tumor equivalent" HDR doses. Late tissue complications involving the small bowel, rectum, bladder, endobronchus or esophagus can be life-threatening. To reduce the risk of late tissue effects, radiobiologists recommend an increased fractionation schedule for HDR brachytherapy. Since source movement is inherent during each HDR treatment cycle, the total transit dose is linearly increased with the number of fractions.

Bastin et al (1993) measured the transit dose produced by a moving high dose rate brachytherapy source and assessed its clinical significance. The doses produced from source movement during Ir-192 HDR afterloading were measured using calibrated thermoluminescent dosimeter rods. Transit doses at distances of 0.5-4.0 cm from an endobronchial applicator were measured using Lucite phantom accomadating 1×1×6 mm thermoluminescent rods. Surface transit dose measurements were made using esophageal and endobronchial catheters, a gynecologic tandem, and an interstitial needle. No difference was detected in thermoluminescent dosimeter rod responses to 4 MV and Ir-192 spectra (427 nC/Gy) in a range of dose between 2 and 300 cGy. The transit dose at 0.5 cm from an endobronchial catheter was 0.31 cGy/(Curie-fraction) and followed an inverse square fall-off with increasing distance. Surface transit doses ranged from 0.38 cGy/(Curie-fraction) for an esophageal catheter to 1.03 cGy/(Curie-fraction) for an endobronchial catheter. Source velocity is dependent on the interdwell distance and varies between 220-452 mm/sec. A numeric algorithm was developed to calculate total transit dose, and was based on a dynamic point approximation for the moving high dose rate source. This algorithm reliably predicted the empirical transit doses and demonstrated that total transit dose is dependent on source velocity, number of fractions, and source activity. Surface transit doses are dependent on applicator diameter and wall material and thickness. Total transit doses within or outside the

desired treatment volume are typically < 100 cGy, but may exceed 200 cGy when using a large number of fractions with a high activity source.

Clinical dosimetry for HDR brachytherapy with a single stepping source generally neglects the transit dose. Wong's study investigated the effects of the transit dose in the target volume of an HDR brachytherapy stepping source [3]. A video method was used to analyse the entrance, exit and the interdwell transit speed of the source for different path lengths and step sizes ranging from 2.5 mm to 995 mm. The transit speed was found to vary with the step size and path length. For the travelled distances of 2.5, 5.0, 10.0, 230 and 995 mm, the average transit speeds were 54, 72, 233, 385 and 467 mm s^{-1} respectively. The results also showed that the manufacturer has attempted to compensate for the effects of interdwell transit dose by reducing the actual dwell time of the source. A well-type chamber was used to determine the dose differences between two sets of measurements, one being the stationary dose only and the other being the sum of stationary and transit doses. Single catheters of active lengths of 20 and 40 mm, different dwell times of 0.5, 1, 2 and 5 s and different step sizes of 2.5, 5 and 10 mm were used in the measurements with the well-type chamber. Most of the measured dose differences between stationary and stationary plus interdwell source movement were within 2%. The additional dose due to the source transit can be as high as 24.9% for the case of 0.5 s dwell time, 10 mm step size and 20 mm active length. The dose difference is mainly due to the entrance and exit source movement but not the interdwell movement.

Sahoo [2] used an HDR -1000 well ionization chamber and a precision electrometer used to measure the transit time of the Ir-192 source of a Nucletron Micro-selectron HDR brachytherapy unit. The charge generated both during source dwelling at a selected position in an endobronchial catheter inserted into the chamber and during source travel to this position from another location at a distance of 0.5 to 10 cm from it was measured. A linear regression analysis of the measured charge as a function of dwell time was made. The interdwell position transit time was calculated from the ratio of the charge intercept and the slope of the straight line obtained from the regression analysis. The values of the effective transit time, which is a combination of interdwell position transit time and dwell time error of the after-loading unit, were found to be 0.03 and 0.45 s for 0.5 and 10 cm separation between two dwell position, respectively. The average time for 1 cm travel of the source between two dwell positions was found to be 0.022 s, resulting in an average speed of 45.5 cm/s.

The values of transit time given in Table 1 are specific to the after-loader unit and to the procedure used in the present investigation. These values can change for different after-loader units as shown and will depend on the procedure used to measure it. The results presented here are not intended for general use in clinical HDR brachytherapy procedures. The uncertainties or errors associated in this measurement have many components, namely, error in the charge measurement in the well chamber, timer error of the after-loader unit, the error in the incorporation of transit time by the unit, and error in the linear fit of the charge and time. The important benefit of the source speed measurement would be the ability to estimate the magnitude of the transit dose relative to the prescribed dose and then to take the corrective action if clinically necessary. With the knowledge of source speed or interdwell position transit time and the nature of internal correction mechanism of the unit to account for the source transit time, one can accurately calculate the given dose to the implant volume. Additionally, the adequacy of the internal correction for transit time can also be evaluated from the knowledge of the source speed.

The increased national use of HDR brachytherapy and increased emphasis on treatment fractionation further warrants the need for the calculation and documentation of dynamic dose for each planned HDR treatment. Dynamic doses should be included in calculated isodose distributions. Dynamic dose contributions to tissues outside the prescribed treatment volume should be documented. When significant dynamic doses are projected, catheter repositioning, reduction in fractionation number, or change to a large diameter applicator could be considered. Software modification accounting for the dynamic dose should be incorporated into all HDR planning systems. Such an improvement would enhance the safety and accuracy of HDR brachytherapy.

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