Dependence of teletherapy timer error on treatment parameters in External Beam Radiotherapy (EBRT) using the Theratron Equinox 100 Cobalt 60 machine

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ABSTRACT

The objective of the study is to evaluate the dependence of the timer error as function of teletherapy treatment parameters of field size (FS) and depth (d) for source-to-surface distance (SSD) setup and compare withmethod used for others. Teletherapy timer error measurements were performed in a full scatter, large water phantom using a 0.6cc ionization chamber on a cobalt-60 unit at SSD of 100cm at varyingfield sizes and treatment depths, with gantry and collimator angles fixed at 0°. From the measurements, the timer error for the field size variations of 5×5cm^2, 10×10 cm^2, 15×15 cm^2, 20×20 cm^2, 30×30 cm^2, 35×35 cm^2 were found to be 0.654 s, 0.648 s, 0.622 s, 0.633 s, 0.639 s and 0.643 s respectively for a constant depth of 5cm.The timer error for treatment depths of 5cm, 7cm, 10cm, 15cm and 20cm were found to be 0.648 s, 0.585 s, 0.612 s, 0.665 s and 0.6215 s for a constant field size of 10×10 cm^2. Comparing the two set-up techniques shows that the field size variation and depth variation had almost similar timer value to the order of10^{-1}. However, the treatment depth variations showed the lowest value as compared to treatment depths. The treatment depth of 15 cm recorded the highest timer error of 0.665s and the treatment depth of 7cm showed the lowest value of the timer error of 0.585s. The timer error observedfor this experimental work with the variations in field size was found to vary in the range of 26.47% to 30.13% with the last teletherapy timer error value of 0.89s. The timer error for the varying treatment depthswas found to vary in the range of 25.27% to 34.31% with the last teletherapy timer error value of 0.89s. Therefore the results shows that timer error depends on both field size and treatment depth and must be taken into account by the creation of a lookup table similar to tissue maximum ratio (TMR) and tissue phantom ratio (TPR) tables to account for these variations during treatment planning and manual dose calculations.

Keywords: *timer error, treatment depth, field sizes.*

I. INTRODUCTION

Radiotherapy is the medical use of ionizing radiation in the treatment of cancer. There are other ways of treating cancer but radiotherapy is known to be used to manage “two-thirds” of cancer patients worldwide [1]. Radiotherapy is also known to be used alone in the treatment or used as complimentary with other treatment types such assurgery, chemotherapy or immunotherapy. When it is used before surgery the purpose is to shrink the tumor before removal, if used after surgery its goal is to destroy residual tumor after surgery [1,2].

Teletherapy, a branch of radiotherapy, which uses external source of radiation, begun soon after Wilhelm Röntgen’s discovery of X-ray in 1895. In the early years of this discovery, the production of X-rays was more focused on the treatment of skin lesions because of the beams physical and biological parameters [4, 5]. In this present era clinical radiation treatment is known to use linear accelerators or a cyclotron to generate the external beam photon [6]. External beam photon normally uses Cobalt-60 in the production of photons with an average energy of 1.25MeV for the treatment of cancers. Teletherapy is used in the treatment of various types of tumors including cancers of the head and neck, breast, lung, colon and prostate. The treatment is known to beadministered in various fractions from two fractions per treatment to more than fifty fractions for specific prescribed dose [7, 8].

From 1987, the International Atomic Energy Agency (IAEA) put out various reports relating to standards in dosimetry and radiotherapy. In two international codes of practice of the absorbed dose to water with Cobalt-60 beam (IAEA TRS 277 of 1987 [9] and IAEA TRS 277 of 1997 [10]), timer error is omitted regardless of its relevance in radiotherapy. Recently, the international codes of practice for the determination of absorbed in a cobalt-60 beam, TRS 398 [11] has included the usefulness of timer error evaluation which is established in a worksheet. This worksheet in TRS 398 provides an equation from which dosimetry reading corrected for timer error would be determined. Out of the four well documented timer errormethods, namely two-exposure method, single/double exposure method, single/multiple exposure method and graphical method [12, 13], TRS 398's Code of Practice [11] uses the third method to derive the correction. Recent reviews show that more timer error evaluation will be publishedwith time.

In the manufacture of teletherapy machines, many treatment parameters are entered as raw machine data been programmed collectively for efficient delivery of clinical treatment. During radiation treatment, there are various field sizes that are set for different orientations due to different sites or sizes of tumor within or outside the patient. These differences in diagnosis of sites causes the field size used in the treatment planning procedure (either symmetric or asymmetric) to differ with respect to the patient size. The teletherapy timer error has been known to be one of the retained errors in external beam teletherapy machines. Because teletherapy is known to be treated mostly in fractions an accumulated error in the shutter error dose calculation can actually go a long way to harm a patient stochastically. In teletherapy, not many studies have been conducted to observe the effects of field sizes and treatment depth on the transit time. Manufacturers across the world have also ignored the treatment time error's dependence on these treatment parameters due to numerous field sizes that can be prescribed out of regular and irregular treatment fields.

There is therefore the need to investigate the dependence of teletherapy timer error in external beam radiotherapy on certain relevant treatment parameters (such as the field size and depth) with the source-surface distance (SSD) technique which is what this study focuses on.

II. METHODOLOGY

A. Materials

Equipment used for this study include Theratron Equinox 100 Cobalt 60 unit with Prowess Panther treatment planning system, full water scatter phantom with reference dimensions of 70 cm×70 cm×45 cm for teletherapy experimental work (AAPM TG 106 [14]), waterproof Farmer-type ion chamber (PTW Feiburg, Germany with model number TM 30013 and serial number 005801), UNIDOS electrometer (PTW, Freiburg, Germany,serial number T10008-08112), thermometer and barometer.The ion chamber was calibrated against a source of known beam quality at the IAEA Secondary Standard Dosimetry Laboratory (SSDL) at voltage of 400 V, temperature of 20 °C, pressure of 101.325 kPa, humidity of 50%.

B. Experimental Setup

The stability of the Farmer type ionization chamber was confirmed with a long-life radioactive source for long time stability(^{90}Sr). All readings were corrected for atmospheric conditions at the chamber position.Set limit for the relative standard deviation of the check source reading, determined from repeated measurements, was 0.5 % from baseline values established for the source or chamber or electrometer assembly [11].

The water phantom was first placed on a bed with a stable support with a lifter which when adjusted brought the phantom to a height close to treatment set up. It was then filled with about 250 liters of water which filled it to a reference mark on the phantom. The digital thermometer was clung to one side of the phantom with the metallic sensitive part in the water. The barometer was also placed on a table in the treatment room. The water was then left for a few hours for the adjustment of stability of temperature and pressure conditions as shown in Fig 1. After a stable environmental condition was established, both the horizontal and vertical lasers were checked for correspondence with the phantom reference laser markings.

The ion chamber was fixed in the chamber holder of the water phantom making sure there was no movement possible when readings are taken. The sensitive section of the ionization chamber was lowered into the water phantom ensuring that the tip was at an SSD of 100 cm, which is the defined SSD of the machine at the surface of the skin. The electrometer was then connected to the ionization chamber with its cable. Treatment time of 5 minutes was then set to irradiate and warm up the ionization chamber for preparation of readings at $d_{max}$of 0.5 cm and field size of 30×30 cm^2.

Figure 1: General experimental Setup

C. Measurements at varying field sizes

The ionization chamber was then lowered into the water to a treatment depth of 5 cm from the surface of the water in the phantom. A field size of 5×5 cm^2 was set on the treatment console together at, SSD OF 100 cm. After beam parameters were set using the console the machine's remote control or navigator in the treatment room was used to move and confirm these parameters. The gantry angles and collimator angles were kept at a constant 0°. The electrometer was then set to start (STA button) before every reading taken in other to measure doses when the source was in transit. The treatment timer was set to treatment times of 0.5 min, 1.0 min, 1.5 min, 2.0 min, 2.5 min and 3.0 min for this setup. Two electrometer readings were taken for each timer setting. The thermometer readings were recorded before and after every batch (treatment timer changes) of measurements. The barometer reading was taken at the beginning and end of the whole experimental work. The set-up was repeated with a variation in the field size for field sizes of 10×10 cm^2 15×15 cm^2 20×20 cm^2, 30×30 cm^2 and 35×35 cm^2. The teletherapy timer error is equivalent to the x-intercept for each variation which can be gotten after the equation of straight line is evaluated. It is the x-axis value for which y = 0.Therefore, the timer errors were determined in this experiment using equations (1) and (2).

$$0 = mx + c \qquad (1)$$

Making x the subject

$$x = \frac{-c}{m} \qquad (2)$$

The timer errors were therefore determined from the x-intercepts of a graph of electrometer reading (nC) as a function of treatment time for varying depth and different field sizes.The average readings were corrected for environmental conditions of temperature and pressure with equation (3) obtained from TRS 398 [11]

$$k_{TP} = \frac{(273.2 + T)}{(273.2 + T_0)} \frac{P_0}{P} \qquad (3)$$

Where k_{TP} is the correction factor, T is the final temperature, T_0 is the initial temperature, P and P_0 are the final and initial pressures respectively.

D. Measurements at varying treatment depths

For the measurementsat varying depths, the field size was set at 10×10 cm^2. The ionization chamber was then lowered into the water with the mechanical gear attached to the chamber which counts 70 turns equivalent to 1 cm. 350 turns was set which corresponded to a treatment depth of 5cm from the surface of the water in the phantom. Field size of 10×10 cm^2 was set on the treatment console together with other beam parameters such as collimator angle, gantry angle and treatment cache angle. After the beam parameters were set-up using the console, the machine's remote control was used to move and confirm these parameters. The gantry angles and collimator angles were kept at 0°. The electrometer was then set to start before readingsweretaken in other to take into account doses when the source was in transit. Two electrometer readings were taken for each timer setting. The treatment timer on the console was set to treatment times of 0.5 min, 1.0 min, 1.5 min, 2.0 min, 2.5 min and 3.0 min. The thermometer and barometer readings were recorded. This set-up was repeated with a variation for the vertical mechanical counter for counts of 490 equivalent to 7 cm depth, 700 equivalent to 10 cm depth, 1050 equivalent to 15 cm depth and 1400 equivalent to 20 cm depth.

III. RESULTS AND DISCUSSION

A. Timer Error Dependence on Field Size

The timer errors obtained havebeen presented in Table 1, the values varied to a degree of 10^{-2}, which is significant in radiotherapy, because small amount of timer error can lead to over- or under-dose and go a long way to harm a patient during treatment. All the error values estimated were negative which means that the timer errors should be subtracted from the timer value estimated from the prescription before clinical treatment is carried out.

Table 1: Field size with estimated timer errors obtained for their setup

Square Field Size /cm^2	Timer error (s)
5×5	-0.654 ±0.000474
10×10	-0.648 ± 0.000665
15×15	-0.622 ± 0.000202
20×20	-0.633 ± 0.000193
30×30	-0.639 ± 0.000185
35×35	-0.643 ± 0.000368

Figure 2 shows the variations of timer error with field size, producinga polynomial function fit of the fifth order. This shows the degree of irregularity in the dependence of teletherapy timer error on field size. The source's beam is made up of a primary and scattered component. The primary beam is known not to vary with field size but the scattered beam varies with field size [15]. It wasobserved that as the field size increased from 5×5 to 15×15 the teletherapy timer error decreased from a value of 0.65s to 0.62s. The sources of scatter include the collimator, blocks and wedges in the beams path. At smallerfield sizes the beam hits the collimators before a path is created during treatment so the intensity of collimator scatter is increased.

As the field size is increased from 15×15 to 35×35, there is an increase in the timer error. This increase is produced as a result of increasing phantom scatter. The scattered beam is a product of the collimator scatter and phantom scatter given as.

$$S_{cp} = S_c \times S_p \quad (4)$$

WhereS_{cp} is total scatter correction factor,S_c is collimator scatter correction factor and S_p is phantom scatter correction factor [16].

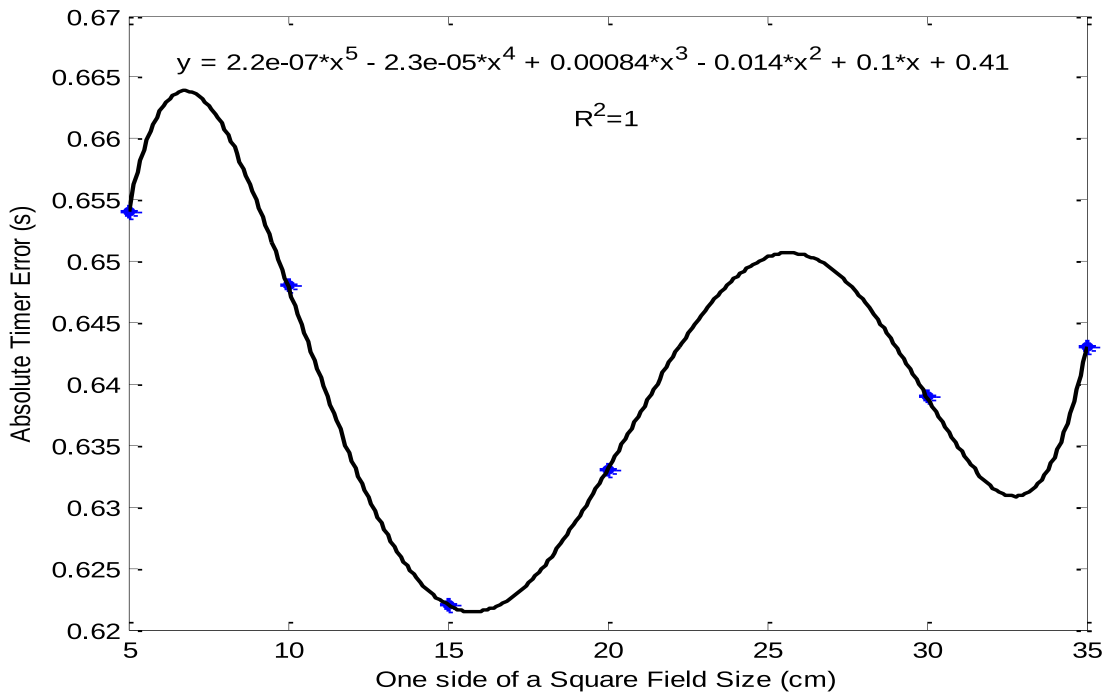

Figure 2: A graph showing the dependence of timer error on field size

As the field size increased above 15×15 cm^2, the effect of the phantom scatter factor outweighs the collimator scatter factor. This phantom scatter factor increases with increasing field size. The values calculated for timer error can be varied during every treatment calculation by the conversion of irregular field sizes to equivalent square field sizes. Corresponding timer errors of the equivalent field sizes aresubtracted during the calculations. This enhances treatment output factor's efficiency during treatment.

B. Timer Error Dependence on Treatment Depth

The timer errors obtained as presented in Table 2, varied to a degree of 10^{-1} which is more noteworthy in radiotherapy and can affect the perceived effects of treatment prescription since there is an unknown additional dose during delivery. All the teletherapy timer (shutter) error values obtained were negative which means that the timer errors should be subtracted from the timer value estimated from the prescription before clinical treatment is carried out.

Table 2: Treatment depth with timer errors obtained for their setup

Treatment depth (cm)	Timer error (s)
5	-0.648 ± 0.000648
7	-0.584 ± 2.83E-07
10	-0.612 ± 0.001203
15	-0.665 ± 0.001725
20	-0.621 ± 0.001248

The absolute values of the timer error were also plotted against the variation in treatment depth as shown in Figure 3. Apolynomial function of the fourth orderwas fitted to the curve. This elaborates the degree of irregularity in the dependence of teletherapy timer error for varying treatment depth. As the treatment depth changed from 5 cm to 7 cm, there was a decrease in the absolute value of timer error. This is as a result of electron contamination which normally occurs as a result of electrons produced from the interaction of the Cobalt-60 photons with a high Z material (usually the collimator) and air (through ionization and production of secondary electrons). The ionization chamber at shallow depths measure both photons and electrons because electrons are not attenuated at shallow depths. After this decrease, the teletherapy timer error increased from a depth of 7 cm through depths of 10 cm to 15 cm which was the highest value of timer error obtained as 0.67 seconds.

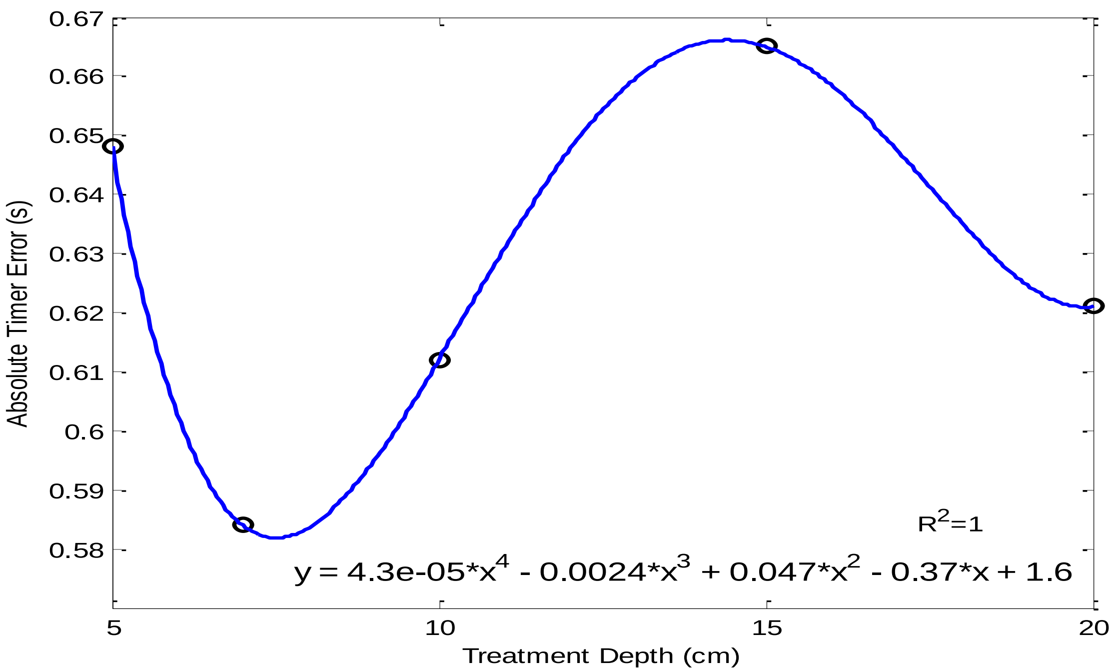

Figure 3: A graph showing the dependence of timer error on treatment depth

The increase in timer error is as a result of scattering as the ionization chamber detects radiation deeper in the water medium as shown in Figure 4. The teletherapy timer error decreased again from a value of 0.67s to 0.62s. At higher depths there is beam attenuation which can account for the decrease in timer value. Also, the lack of back scatter can cause this since the ionization chamber requires an amount of material to be present beneath it before back scatter can occur. The estimated timer errorscan be varied during every treatment calculation by varying the value for each treatment depth corresponding to teletherapy timer error that was subtracted during timer value calculation. This will also enhance treatment output factor's efficiency during treatment.

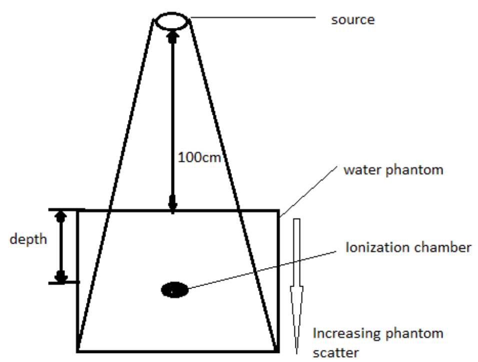

Figure 4: Diagram showing increasing phantom scatter.

C. Comparison between Timer Error Dependence for Treatment Field Size and Treatment Depth

In this work the teletherapy timer error determined for both treatment parameters considered (field size and depth), had little variations in the order of 10^{-2} and 10^{-1} respectively. Due to the linearity of the ionization chamber,the individual variations allowed a straight line to be used for determination of the correspondence with Samat et al [17]. The teletherapy timer error variations with respects to field size showed more consistent values as compared to the timer error variation with treatment depth. For a prescribed dose there are both variation in field size and depth so in other to incorporate this influence of dependence, it is advised to use an average in correlation to the respective field size and depth during calculation.

IV. CONCLUSION

The timer error dependence on field sizes showed irregular polynomial of the fifth order whereas timer error variations with treatment depths showed irregular polynomial of fourth order. Comparing the two set-up techniques of varying field size and varying depth showed almost similar timer values to the degree of 10^{-1}. However, the treatment depth variations produced the leasttimer erroras compared to field size.

Therefore, teletherapy timer error dependence on field size and treatment depth must be incorporated into the treatment planning calculations for patients undergoing radiotherapy in order to minimize errors due to inaccurate timer error estimation in dose delivery.

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