Technical notes

Comparison of planned and measured rectal dose in-vivo during high dose rate Cobalt-60 brachytherapy of cervical cancer

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ABSTRACT

Cobalt-60 (Co-60) is a relatively new source for the application of high-dose rate (HDR) brachytherapy. Radiation dose to the rectum is often a limiting factor in achieving the full prescribed dose to the target during brachytherapy of cervical cancer. The aim of this study was to measure radiation doses to the rectum in-vivo during HDR Co-60 brachytherapy. A total of eleven HDR brachytherapy treatments of cervical cancer were recruited in this study. A series of diodes incorporated in a rectal probe was inserted into the patient’s rectum during each brachytherapy procedure. Real-time measured rectal doses were compared to calculated doses by the treatment planning system (TPS). The differences between calculated and measured dose ranged from 8.5% to 41.2%. This corresponds to absolute dose differences ranging from 0.3 Gy to 1.5 Gy. A linear relationship was observed between calculated and measured doses with linear regression R2 value of 0.88, indicating close association between the measured and calculated doses. In general, absorbed doses for the rectum as calculated by TPS were observed to be higher than the doses measured using the diode probe. In-vivo dosimetry is an important quality assurance method for HDR brachytherapy of cervical cancer. It provides information that can contribute to the reduction of errors and discrepancies in dose delivery. Our study has shown that in-vivo dosimetry is feasible and can be performed to estimate the dose to the rectum during HDR brachytherapy using Co-60.

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Introduction

In the recent years, Cobalt-60 (Co-60) has gained in popularity as an alternative to Iridium-192 (Ir-192) for an HDR brachytherapy source. The feasibility of producing miniaturized size of Co-60 enables it to be used as an HDR brachytherapy source. Co-60 has a half-life of 5.25 years and therefore can be used for about 5 years before replacement, making it more cost-effective compared to Ir-192 which has a substantially shorter half-life of 74 days. Due to this advantage, Co-60 has gained in popularity as an HDR brachytherapy source [1]. The anisotropy, radial dose function and qualitative isodose distributions generated using Co-60 source have been reported to be comparable to that of Ir-192 [2]. Other dosimetric parameters and properties of Co-60 as a brachytherapy source have also been reported elsewhere [3,4].

The main challenge in delivering the prescribed radiation dose to the target during cervical cancer brachytherapy is the risk of radiation toxicity to surrounding normal organs at risk, particularly the rectum. Despite the use of optimization algorithms that can maximize dose uniformity to the target, dose to the rectum can be unacceptably high in some clinical situations [5–7].

The use of Co-60 as source for HDR brachytherapy poses a question on whether the rectum will receive higher radiation dose due to the relatively higher average gamma energy of 1.25 MeV, as compared to 0.38 MeV emitted by Ir-192. Park et al. compared reference point doses; Co-60 and Ir-192 for HDR brachytherapy and reported that rectal doses were 0.8% higher than Ir-192 [8]. Palmer et al. reported that plans generated using Co-60 delivered up to 10% greater dose within the rectum along the extension of the applicator axes and lower doses to regions more distant from the...
applicators compared to plans generated using Ir-192 [9]. For this reason, radiation doses to the rectum should be closely monitored especially when using Co-60 for HDR brachytherapy. The reporting of doses received by the rectum during HDR brachytherapy is important to assess the possibilities of toxicity.

An important method of acquiring doses during brachytherapy is through the implementation of real-time in-vivo dosimetry. This is the only method for assessing doses to organs at risk (OAR) during actual treatment, and is particularly important in brachytherapy due to the uncertainties related to the treatment planning which does not account for inhomogeneity as well as potential organ or applicator movement in between imaging and treatment. In-vivo dosimetry during brachytherapy can potentially avoid treatment errors and is also useful for dose reporting [10].

The present study aims to measure the rectal dose during HDR brachytherapy of cervical cancer for actual patient treatments using Co-60. In-vivo dose measurements were performed on a series of eleven HDR brachytherapy treatments using commercial semiconductor diode probe. The differences between measured rectal doses and doses computed by a treatment planning system (TPS) were evaluated.

**Methods and materials**

**Equipment**

A Bebig MultiSource® HDR brachytherapy treatment unit model 1322-0012 (Eckert & Ziegler, Germany) was used in this clinical study. This treatment unit was controlled and monitored using the MultiSource® operating system located in the control console. The radiation source used was Bebig Co-60 model Co0.A86 stepping source. The source strength (reference air kerma strength) was provided on the manufacturer’s source certificate. When commissioning the system, the source strength was checked by using a calibrated well-type ionization chamber and electrometer. This chamber was delivered with a certificate having calibration factors for Co-60 provided by a secondary standard dosimetry laboratory. This verification showed discrepancy of less than 3% compared with source certificate. Annual verification of source strength, to verify the purity of the Co-60 isotope, using this calibrated well-type ionization chamber shows discrepancies of less than 3% compared to the decay calculation from the TPS, which was input by the manufacturer.

The Co-60 source has an active core of 0.5 mm in diameter and a central cylindrical active core length of 3.5 mm. The active core is encapsulated by a cylindrical stainless-steel capsule with an external diameter of 1 mm.

A flexible PTW probe type 9112 (PTW, Germany) was used for rectal dose measurement. This probe is comprised of five separate semiconductor diodes surrounded by a rubber encapsulation. It has a diameter of 7 mm and each of the five diodes in the probe is spaced 15 mm apart. In this study, the diode located at the distal end of the probe is labelled as R1, with the four other consecutive diodes labelled as R2 to R5 as shown in Fig. 1. This probe was connected to a built-in PTW Multidose electrometer via a single-pin channel of the treatment unit. Measurements were displayed as absorbed dose at the MultiSource® control software.

Prior to every in-vivo rectal dose measurement, the PTW probe was calibrated with the Co-60 source and built-in electrometer. A PMMA cylindrical after loading phantom, type 9193 (PTW, Germany), also known as Krieger phantom, was used as a medium for the insertion of the rectal probe during measurements. This phantom has a diameter of 20 cm and height of 12 cm, and was mounted on a tripod to reduce backscattering. It consists of four peripheral holes at 8 cm radius from the centre.

![Figure 1](image1.png)

**Figure 1.** The positions of diodes R1 to R5 in the rectal probe as identified in the reconstructed sagittal plane of CT images.

![Figure 2](image2.png)

**Figure 2.** The setup of rectal diode probe and source applicator on the Krieger phantom during calibration.

The setup of the diode probe calibration is shown in Fig. 2. The aim of diode probe calibration was to obtain calibration factor for each individual diode R1 to R5, which will be used to calculate the absorbed dose during in-vivo dose measurement. To achieve this, probe current or charge was collected by the probe at a known preset time during Co-60 irradiation. From this measurement, calibration factor for each individual diode were determined by the
MultiSource® control software. An overall uncertainty of 7% has been associated with the use of this probe for in-vivo dosimetry [11]. Other physical characteristics for this probe for in-vivo dosimetry have also been reported elsewhere [12,13].

Clinical in-vivo dose measurement

The present study reports on a series of eleven HDR brachytherapy sessions for the treatment of locally advanced cervical cancer. Patients were first treated with external beam radiotherapy to the whole pelvis with a total prescribed dose of 45 Gy delivered in 25 fractions followed by three fractionated HDR brachytherapy treatments with a prescribed dose per fraction of 7 or 7.5 Gy to Point A [14].

During the brachytherapy procedures, a computed tomography/magnetic resonance compatible brachytherapy applicator (CT/MR Fletcher suit) set consisting of two ovoids and an intrauterine tube (tandem) was used for securing the Co-60 source during irradiation. During each insertion, the intrauterine tube was placed into the uterine cavity and the ovoids were positioned in the vagina at the level of the fornices. The rectal diode probe was then inserted into the rectum and affixed to the patient’s body with an adhesive band.

Following applicator and rectal probe insertion, axial CT images of patient were obtained using a Philips Brilliance 16 slice CT Simulator (Philips, Netherlands). The axial scans were performed with patient in supine position using a 3 mm of slice thickness. CT image data set was then transferred to the HDRplus™ TPS via DICOM network for treatment planning.

A series of axial and reconstructed orthogonal CT images were used by the physicist to generate a treatment plan by first reconstructing the applicator and subsequently defining the rectum and bladder reference points according to ICRU recommendations [14]. In addition, each diode was identified on the CT images. Appropriate source positions were determined with sufficient dwell time for each applicator tube. All treatment plans were approved by the treating oncologists and plan data was sent to MultiSource® control console for delivery of treatment. Doses as measured by all diodes of the rectal probe were recorded. The measured doses were compared to doses calculated by TPS.

Results

Figure 3 shows boxplots for the differences between calculated and measured dose for each diode (R1 to R5) in the rectal probe acquired for eleven brachytherapy applications. The absolute percentage differences between calculated and measured dose ranged from 8.5% to 41.2% for all diodes. This corresponded to dose differences ranging from 0.3 Gy to 1.5 Gy. Larger differences (as indicated by the range of the dose differences) in the calculated and measured doses were observed for readings recorded by R1 and R2 diodes due to the influence of a number of large maximum dose differences recorded by these diodes. Although the ranges in the dose differences for these diodes were relatively large, the medians were consistent with other diodes. The median percentage differences ranged from 1.4% to 5.4% which corresponded to differences of 0.1-1.4 Gy.

Figure 4 shows a histogram of dose ratios between calculated and measured doses for all diodes. Dose ratio with values larger than zero indicates that the calculated dose is larger than the measured dose. The histograms show that 8 of 11, 7 of 11, 7 of 11 and 7 of 11 brachytherapy applications yield higher calculated doses than the measured doses at R1, R2, R3 and R4 diodes respectively. Differences in dose of more than 10% were recorded in 3 of 11 applications for each of these four diodes. On the other hand,
8 of 11 applications recorded higher measured doses than the calculated doses for R5 diode. However, none of these dose differences was larger than 10%. In general, except for the R5 diode, the histogram shows that the absorbed doses for rectum as calculated by the TPS were higher than the doses measured using the diode probe.

Discussion

In-vivo dosimetry is the only practical way to check the delivered dose during radiotherapy and brachytherapy [15]. Through in-vivo dosimetry, discrepancies in the doses delivered and the doses calculated using TPS may be determined. Various dosimeters have been used for in-vivo dosimetry as well as treatment verification during brachytherapy [16,17]. In this study, the results of TPS calculation were used as the reference. In the case where the measured dose does not correspond to the dose calculated during treatment planning, the treatment can be altered to prevent large errors. Undesirable radiation side effects may be avoided and hence in-vivo dosimetry is recommended in intracavitary brachytherapy [11]. The percentage differences between calculated and measured of rectal doses in this study were in the range of ~8.5% to 41.2% (median = 2.6%). The magnitudes in the percentage differences were considerably large but they were comparable with the results of in-vivo rectal dose measurement during HDR brachytherapy using Ir-192 reported by other authors; Waldhäusl et al. reported percentage dose differences of ~31% to 90% (mean = 11%) between calculated and measured dose during HDR brachytherapy using Ir-192 [11]. In a similar study, Eich et al. reported differences of ~50% to 40% (mean = 4 ± 19%) between calculated and measured doses using diodes [18].

In this study, relatively larger deviations in the rectal doses between treatment planning and actual measurement were recorded for diodes R1 and R2. We hypothesize that R1 and R2 were not secured rigidly to their positions, compared to other diodes which were located closer to the patients’ outer anatomy and were positioned/tapped more securely to patients. Therefore, diodes R1 and R2 were more prone to geometrical shift in between treatment planning and actual treatment delivery. A study is under way to assess the geometrical shifts of brachytherapy applicator and diode probes real-time during brachytherapy, which will be able to confirm our hypothesis.

A few factors may contribute to the differences between calculated and measured dose of the rectum during brachytherapy. The most important factor contributing to this is the possibility of geometrical shift of the diodes between simulation and delivery. A geometrical shift during treatment can be caused by movement of the patient’s internal movement of organs, diode detector or the applicators. The shift can be caused by movements of the detector between the CT scan and irradiation. It has also been reported that in-vivo dose measurement can be affected by rectal peristaltic motion or patient movement [15,11,19,20]. Diode displacement has been reported in many studies which is significant and attributed primarily to be a source of error in performing in-vivo dosimetry in brachytherapy. Waldhäusl et al. has highlighted that more than 10% difference of measured doses with TPS calculated doses for even small geometrical shifts of applicator [11]. This was supported by Allahverdi et al. which confirmed that the diode displacement was the reason for the over response of the diode [15]. Moreover, at close distance of source in high-dose gradient region, any small variation in the position of the detector would result in large difference in the dose to what has been originally planned. To overcome dose discrepancies due to geometrical shift, it is recommended for the patient to be imaged real-time using C-arm fluoroscopy to determine the position of diodes in the rectal probe on the TPS just before the treatment is delivered.

It is a standard procedure in brachytherapy to use stainless-steel applicator system during treatment. A dose attenuation of up to 2% along the transverse plane of the source was reported when the metal applicator was used during brachytherapy [21]. The TPS does not account for this factor in its algorithm for dose calculation in brachytherapy planning. Thus, this may contribute to the discrepancies between calculated and measured doses during HDR brachytherapy.

Although the values of percentage difference were considerably large, the absolute difference was reasonably small where median difference of 2.6% recorded in our study corresponded to 0.1 Gy, which is only 1.4% of the prescribed dose of 7 Gy. The results from our study also revealed that a large proportion of the differences was attributed to higher calculated doses by the TPS (rather than higher measured doses).

Conclusion

Our study has shown that in-vivo dosimetry is feasible and can be performed to estimate the dose to the rectum during HDR brachytherapy using Co-60. The uncertainties involved in performing in-vivo dosimetry are similar to that of HDR brachytherapy using Ir-192, the most important one being the possibility of geometrical shift of measuring detectors in between insertion and treatment. Despite these uncertainties, in-vivo dosimetry is beneficial to provide a higher level of confidence to the physicists and other treatment staff on the accuracy of the treatment. It is therefore recommended for treating institutions to have their own in-vivo dosimetry program of quality assurance to ensure safe HDR brachytherapy delivery.

Conflict of interest

Do not exist.

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