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Monte Carlo calculation of shielded colpostat effect on rectum received dose in high dose rate brachytherapy with Cobalt-60 sources

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► ***Original article***

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ABSTRACT

Background: In the current study the effect of shielded colpostat on rectum received dose was calculated in cervical brachytherapy using Monte Carlo (MC) method. ***Materials and Methods***: Two ^{60}Co sources of GZP6 brachytherapy unit used for intracavitary treatments were simulated using MCNPX Monte Carlo code. Also the two types of colpostats including shielded and unshielded were simulated inside a water phantom. The radial dose function, depth doses and dose distribution around sources were calculated with spatial dose resolution of 2×2×2 mm. The effect of tungsten shields on rectum dose was studied. Moreover, the accuracy of treatment planning system (TPS) was verified comparing to MC results. ***Results***: Our results showed that shielded colpostats reduce the rectum dose up to 7% according to the MC calculations. Also, it was found less than 3% difference between TPS and MC results in percentage depth dose and radial doses for unshielded case. ***Conclusion***: It can be concluded that the application of shielded colpostats provide a relatively mild protection (7% reduction in dose) for the rectum in intracavitary brachytherapy due to the higher energy of ^{60}Co photons. However, application of shielded colpostats in treatment planning system is desirable for more accurate treatments.

Keywords: *Intracavitary brachytherapy, shielded colpostat, rectum dose, high dose rate brachytherpy, cobalt-60.*

INTRODUCTION

In cervical brachytherapy, two organs including rectum and bladder are considered as organs at risk and have critical importance for treatment planning purposes[1]. Then, it is necessary that these organs to be shielded against radiation as much as possible. Because, late rectal and bladder complications had been the major late complications in patients treated with a combination of external beam radiotherapy (EBRT) and high-dose-rate intracavitary irradiation for cervical cancer[2]. On the other hand, some of treatment planning systems (TPS) calculate dose distribution around the sources dose by summing the dose contributions from the individual sources, while the impact of ovoid structures such as the shields are ignored. So, to address this problem, many studies have been performed on the effect of shielded colpostats or ovoids on rectum dose in intracavitary brachytherapy with different radioactive sources [3-5]. The results show that the shielding effect varies significantly among different sources such as ^{192}Ir, ^{137}Cs and ^{60}Co and is strongly dependent on the colpostat and its shielding shape as well as thickness.

In a study, the dose perturbation around shielded ovoid in high-dose-rate brachytherapy with ^{192}Ir sources was analyzed by film dosimetry and Monte Carlo (MC) method. The

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results showed that the dose reduction in the anterior part of the shielded ovoid affects maximally the dose to the bladder where a reduction up to 20% was noted. While, the reduction of dose in the posterior part of the ovoid, which was designed to shield the rectum was as high as 23% [6].

Moreover, the study by Steggerda *et al.* showed that for the rectum, the dose reduction ranged from 0 to 11.1%, whereas the reduction for the bladder ranged from 0 to 11.9% [7].

The purpose of the current study was to investigate the dosimetric effect of two colpostats used by GZP6 brachytherapy unit for cervical cancer treatment. Although, the shielded colpostats are used in cervical cancer treatments routinely, there is no calculation option in treatment planning system of GZP6 unit to account for dose perturbation effect of shielded colpostats. Several studies have been performed on different dosimetric aspects of GZP6 brachytherapy system [8-10]. To the best of our knowledge, there is no published document about the shielded colpostat of this unit and their dosimetric effect in literature.

MATERIALA AND METHODS

HDR ^{60}Co sources

The GZP6 brachytherapy system was manufactured by the Nuclear Power Institute of China (NPIC). It is a HDR afterloading unit having six ^{60}Co source braids designed for treatment of rectum, cervix, nasopharynx and esophagus cancers. This unit uses six sources involving one stepping and five non-stepping sources for intracavitary treatment. The sources were consisted of ^{60}Co active cylinders (length=3.5 mm, diameter=1.5 mm) sealed by titanium capsules and inactive steel balls (diameter=1.5 mm) which were covered by a steel spring. In this unit channels 3 and 4 are used for treatment of cervical cancer. Schematic representation of the sources 3 and 4 which are used in this study is shown in figure 1A. Also, the position of the tungsten shield with thickness of 5 mm for rectum shielding is shown in figure 1B.

Monte Carlo simulation

The Monte Carlo (MC) code MCNPX version 2.4.0 was used in this study [11]. One of the main advantages of this version is the calculation time speedup to obtain results "tallies" for a large number of repeated structures "lattices" such as voxels. Compton scattering, coherent scattering, photoelectric effect, and pair production were modeled in each simulation. For dose calculations in water, a phantom with dimensions of 30× 30 ×30 cm^3 was simulated and the sources were located in the center of water phantom. The water phantom was divided to small scoring cells with dimension of 2×2×2 mm^3 using lattice card in MCNP and the dose was calculated using *F8 tally (figure 1c). This tally scored the absorbed energy of photons and electrons passing a cell in terms of MeV. The energy cutoffs of 0.5 and 0.01 MeV were used for photon and electrons respectively. No other variance reduction methods were used in our simulations.

The simulated source braid had 2 active pellets and a number of steel balls as spacers. The steel spring and applicator were also modeled in our MC input file. Two sizes of shielded colpostats with 2 and 2.5 cm diameter were simulated in the current study.

Two photons with emission probabilities of 0.5 and energies of 1.17 and 1.33 MeV were defined in source definition card. The activity of ^{60}Co source within the active cylindrical cells was considered homogenous in our MC simulation. The absorbed dose was scored in lattice cells filled with water and the output text file of MCNP was transferred to MATLAB software (version 10). Using the m-file in MATLAB the dose distribution and also other dosimetric functions was obtained. The dose distribution calculations were performed for both unshielded and shielded colpostats. We calculated radial dose around each source in a line perpendicular to the source axis. The results for unshielded colpostats were compared with TPS results to validate our model accuracy. It should be noticed that the accuracy of TPS for unshielded colpostats had been verified in previous quality control procedures. So, the MC model was benchmarked using the TPS radial dose and dose distribution for unshielded case.

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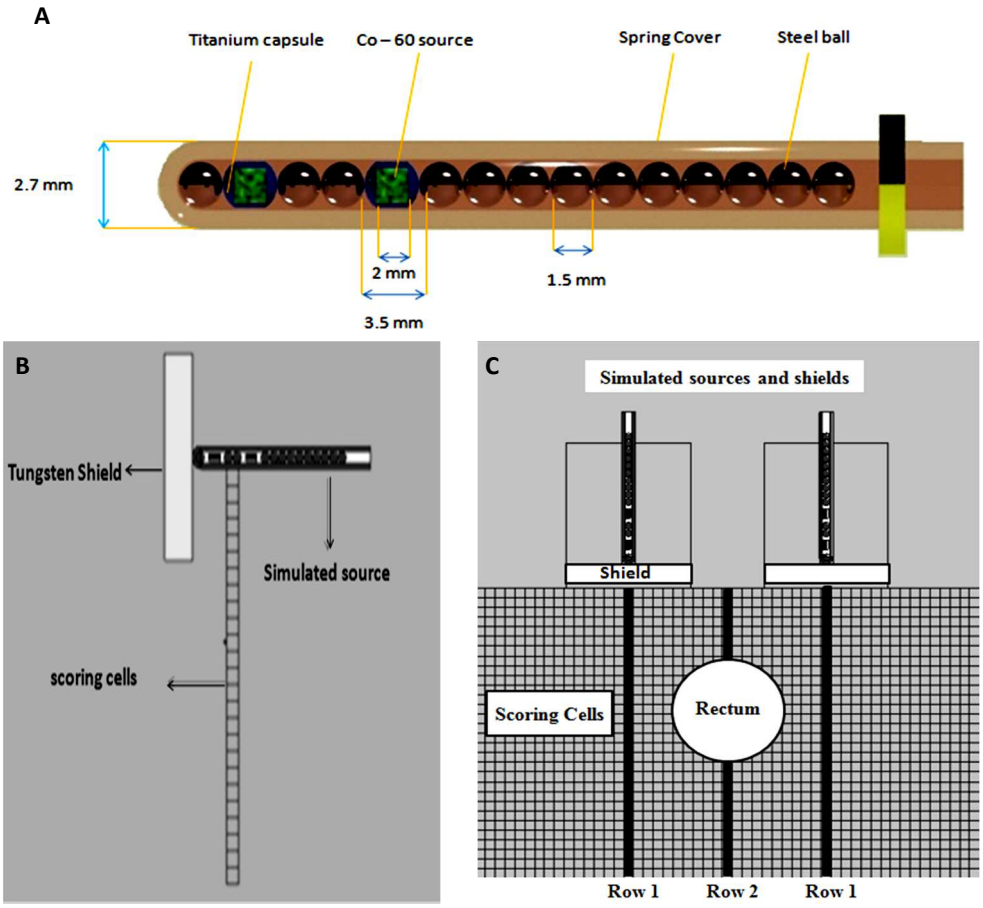


Figure 1. The graphical representation of simulated source. (A) detailed geometry and used materials in the source (B) The MCNP produced geometry including source, Tungsten shielding and the scoring cells for radial dose calculations (C) MCNP simulated geometry to calculate depth dose variations for shielded and unshielded colpostats in Rows 1 and 2.

GZP6 treatment planning system

The GZP6 brachytherapy TPS is a dedicated software with capability of dose distribution calculations around 6 braid type ^{60}Co sources for limited configurations available in brachytherapy unit. The implemented algorithm employs Sievert integral for calculation of dose distribution around brachytherapy sources. It also calculates the irradiation time for each treatment session and controls the treatment time with enabling the mechanical system for pulling out the sources from storage container and returning them to container in a given time. The accuracy of implemented algorithm has been verified in several studies and it has been reported that it provides reliable dose distribution for homogenous medium for different configuration of its sources [8, 10].

RESULTS

In figure 2 the dose distribution around two unshielded colpostats used for cervix treatment is shown. The dose calculated plane is perpendicular to the applicators axis. It should be noticed that to show both MC calculated and TPS results in the same figure the dose distribution plane has rotated 90 degree. As it is seen there is a considerable agreement between the TPS and MC results. However, in MC results the statistical noise is getting more pronounced with distance from sources, because of its statistical nature. On the other hand, the TPS of GZP6 HDR brachytherapy unit uses Sievert integral, a mathematical algorithm for dose distribution calculation around its ^{60}Co sources.

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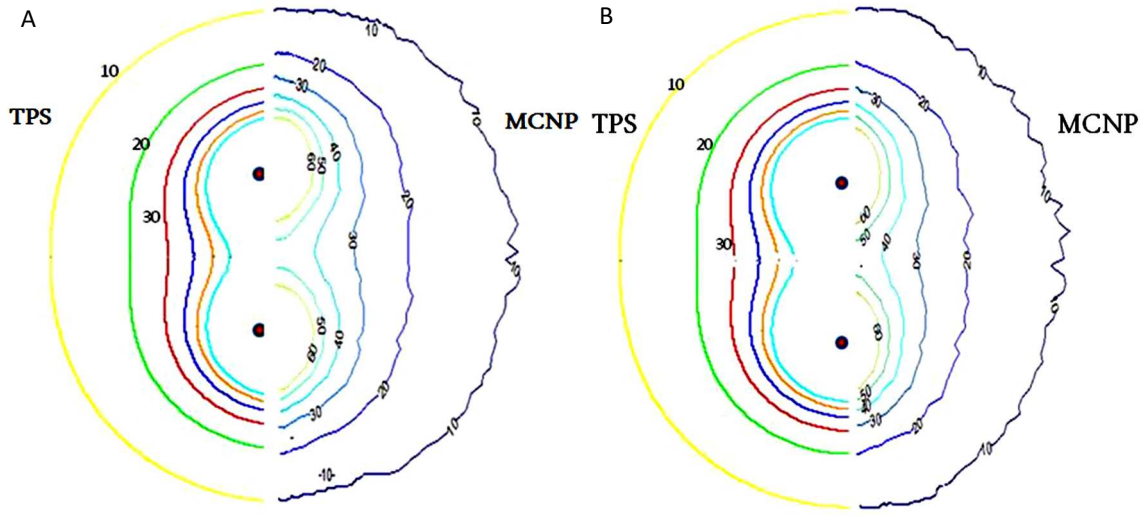


Figure 2. Isodose curves calculated by MCNP MC code and GZP6 treatment planning system for simulated source using shielded small (A) and medium colpostats (B).

So, there was no fluctuation in results and the curves are seen smooth and noiseless.

The radial dose was calculated using MC and also derived from planar dose distribution of TPS. After the normalization of all values to a dose value on colpostat surface in all calculations, the radial dose was obtained for both methods. It was found a good agreement between MC and TPS for unshielded colpostat case. Nevertheless, for radial dose at 1 cm distance from source, there was a difference of up to 3% between MC and TPS. Where, for small colpostat this difference reaches to 8% near the source. It could be related to the inaccuracies of Sievert integral in calculation of absorbed dose in the region adjacent to the sources. The larger difference in the points very close to the source is due to point source assumption of the used algorithm by TPS. This has shown in other similar studies on GZP6 unit [8,10]. Moreover, the difference between TPS and MC has been reported by other studies [6,12,13]. According to their results, this difference could be attributed to point source assumption in TPS where volume source was used by MC method.

In figure 3, the absorbed dose variation with depth has been shown for two shielded colpostats, small and medium along the colpostat longitudinal axis. In these curves, both shielded and unshielded cases have been calculated by MC. The dose reduction percentage along the line crossing the rectum for small and medium colpostatats was calculated (ROW2 in figure 1c). The dose reduction percentage in every point was calculated by this formula:

$$\textit{Reduction Percentage}= \textit{[(unshielded dose)-(shielded dose)/(shielded dose)]}\times 100$$

The maximum dose reduction was found to be 15% and 14% for medium and small colpostat behind the shield respectively. At the distance of 3 cm, resembling the location of rectum, the dose reduction was 7% for both small and medium colpostats (see insets of both A and B figures).

In figure 4 the dose variations with depth in a plane vertical to shield surface and parallel to source insertion axis have been shown for both shielded and unshielded cases. The dose variation has been calculated in a line just behind the shields (ROW1 in figure 1c). Also, the dose reduction effect of shield has been depicted as insets in both figures A and B. The maximum dose reduction happened between 18-20% in the point adjacent to shield and at the rectum level it reached to 4-7% for both colpostats. Additionally, there was a slight difference between small and medium colpostat concerning the shielding effect on rectum.

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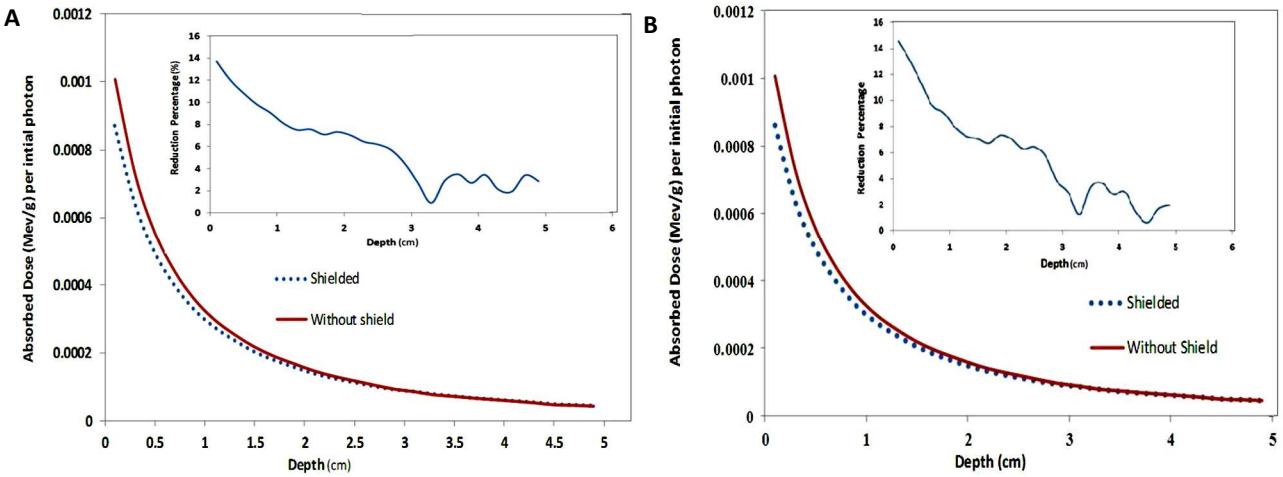


Figure 3. MC calculated depth doses for shielded and unshielded small colpostats along the source longitudinal axis crossing the rectum and depicted by ROW 2 in figure 1.

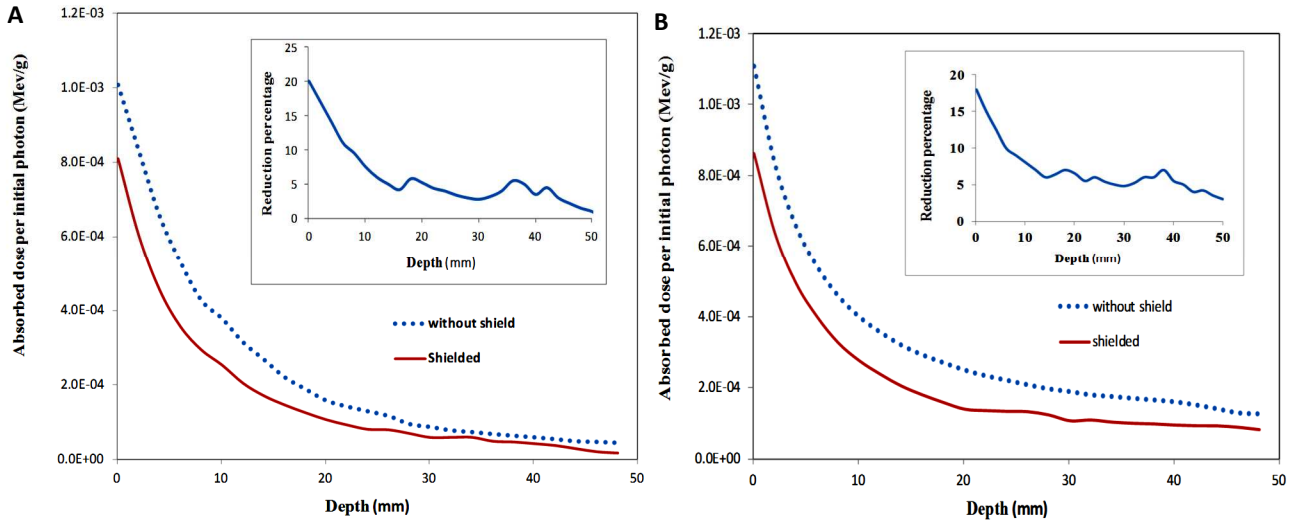


Figure 4. Comparison of absorbed dose variation with depth between shielded and unshielded cases for small and medium colpostats along the line perpendicular to tungsten shield depicted by ROW 1 in figure 1C. (A) small Colpostat. B) medium colpostat.

DISCUSSION

Our results showed that rectum dose reduction with the shielded colpostat is about two times and in some cases three times less than the dose reduction for rectum compared to the other studies with dose reduction as high as 23% for ^{192}Ir sources [6]. The main difference stems from the different radioactive sources used in our study and others. The mean energy of ^{60}Co photons is 1.25 MeV, while for ^{192}Ir it is about 0.37 MeV. Consequently, the linear attenuation coefficients of tungsten against the ^{60}Co and ^{192}Ir photon differ significantly, comparing the half value layer of 3.3 mm and 7.9 mm for ^{192}Ir and ^{60}Co respectively. So, it leads to the observed differences for the current results with ^{60}Co and other with ^{192}Ir.

Also, the shape and the orientation of the shields inside colpostat could change the pattern of photon absorption and scattering inside the phantom material and lead to different dose reduction for rectum in brachytherapy procedures [5]. A study on the effect of tungsten shielding was performed and ionization chamber measurements in a Lucite phantom

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showed that placing a tungsten rod in the applicator reduces the dose in the shielded region by up to 85% for ^{192}Ir sources [14]. Another study by Gifford *et al.* calculated the rectum shielding effect in Fletcher Suit Delclos by MC, radiochromic film and normoxic polymer gel dosimetry. Their results showed that the ovoid shields reduce the dose by as much as 50% for a ^{137}Cs source at the distance of 1.25 cm from the long axis of the ovoid[3]. Our results was not comparable with their results, because the photon energy of used source i.e, ^{137}Cs, was about 50% less than ^{60}Co source of our study.

In another study on effect of ovoid shields in a selectron-LDR cervical applicator on dose distributions in rectum and bladder large, Steggerda *et al.* concluded that overall dose reductions cannot be achieved with shielding and an average dose reduction of 5% was reported for rectum. Our result of 7% dose reduction in rectum was in good agreement with their finding. They recommended that it is safe to use an unshielded applicator when post implant CT images are used to realize optimized dose distributions [7].

To sum up, according to other studies the dose reduction effect of shielded colpostats could be very different dependent on the used sources and the geometry of colpostats. Also, the magnitude of dose reduction is strongly relies on the distance from the shield and the shielding effect decreases significantly with distance from the colpostat surface. Finally, to have more accurate estimation on rectum dose, it is necessary to take into account the shields in TPS algorithms. Otherwise, practical dose measurements as well as MC calculation would provide useful information on the extent of shielded colpostats on rectum dose in critical conditions.

CONCLUSION

A MC study was conducted in order to provide a reliable estimation on the amount of dose reduction by shielded colpostats in ^{60}Co sources of GZP6 brachytherapy unit. A MC model was built and validated and used for MC calculations. MC results showed that the maximum dose reduction value for ^{60}Co sources for two medium and small colpostats was approximately 20% just behind the tungsten shield. For both colpostats the attenuation value in rectum region (3 cm from source) was found to be about 7%.

We believe that the 7% reduction in rectum dose does not provide very significant advantage over non-shielded colpostats compared to values reported for low energy sources such as ^{192}Ir. However, its application with GZP6 brachytherapy unit is recommended to lower the rectum dose as much as possible. Also, in order to calculate the rectal dose accurately, the shields must be included in the dose calculation algorithm in treatment planning system.

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Conflicts of interest: *none to declare.*

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