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Original article

# Application of Monte Carlo calculations for validation of a treatment planning system in high dose rate brachytherapy

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ABSTRACT

*Aim:* The accuracy of treatment planning systems is of vital importance in treatment outcomes in brachytherapy. In the current study the accuracy of dose calculations of a high dose rate (HDR) brachytherapy treatment planning system (TPS) was validated using the Monte Carlo method.

*Materials and methods:* Three $^{60}$Co sources of the GZP6 afterloading brachytherapy system were modelled using MCNP4C Monte Carlo (MC) code. The dose distribution around all the sources was calculated by MC and a dedicated treatment planning system. The results of both methods were compared.

*Results:* There was good agreement (<2%) between TPS and MC calculated dose distributions except at a point near the sources (<1 cm) and beyond the tip of the sources.

*Conclusions:* Our study confirmed the accuracy of TPS calculated dose distributions for clinical use in HDR brachytherapy.



## 1. Background

Calculation of absorbed dose distribution in a patient before treatment is one of the main steps in radiation therapy treatment planning. In high dose rate (HDR) brachytherapy, the accuracy of calculation becomes a stringent issue because of the higher dose rate and prescribed dose per session.[1–3] Thus, inaccuracies in dose distributions may lead to a higher dose to limiting normal tissue or lower target dose. The algorithms implemented in conventional treatment planning systems are based on analytical methods such as Sievert integration or newly developed methods such as convolution and Monte Carlo (MC) methods.[4–6] Experimental methods including film and thermoluminescence dosimetry in solid phantoms have been traditionally used to validate the accuracy of TPS before clinical use of a TPS in brachytherapy.[7–9] In the last decade, the MC method has been widely used in different brachytherapy techniques as a tool for validation of dose calculations in patient anatomy and phantoms.[9–14] In a recent study on the application of MC code for brachytherapy calculations, the Brachydose MC code was assessed and its calculated dosimetry parameters were compared with values calculated by other authors using PTRAN code and to measured values. Overall, calculations made with Brachydose showed good agreement with PTRAN results.[15] The study of Poon et al. on the dosimetric properties of a novel intracavitary mould applicator for $^{192}$Ir high dose rate (HDR) using the MC and experimental

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method showed a good agreement between the experimental and the GEANT4 calculations.[12] In previous studies, in-air dose rate measurements and calculation of radial dose function of sources were carried out as part of acceptance testing of a new brachytherapy unit.[10,16]

## 2. Aim

In an MC study, we modelled three sources of a new HDR $^{60}$Co brachytherapy unit and compared the radial dose functions of MC calculations with a dedicated TPS.[10] The results exhibited a good agreement between MC and TPS calculated radial dose functions. In the current study, to have more information on the accuracy of TPS isodose calculations, the isodoses of three sources were calculated by MCNP4C MC code and compared with TPS calculations.

## 3. Materials and methods

### 3.1. *HDR $^{60}$Co unit specifications*

This study was performed on three HDR $^{60}$Co sources of a GZP6 afterloading unit (Nuclear Power Institute of China). This unit uses six linear braid type sources including one stepping and five non-stepping sources for intracavitary treatment such as malignancies of the cervix, rectum, oesophagus and nasopharynx. The sources consist of $^{60}$Co active cylinders (length = 3.5 cm, diameter = 1.5 mm) sealed by titanium capsules and inactive steel balls (diameter = 1.5 mm) which are covered by a steel spring. The position of active elements is constant in the source braid and is not changed for different treatments. The simulated sources are seen in Fig. 1. The GZP6 treatment planning system uses the Sievert integral to provide the 3D dose distribution around brachytherapy sources. The classical Sievert integral is generalized to 3D radioactivity distributions, incorporating photon attenuation and scattering by the surrounding medium. In the previous study a detailed explanation of the Sievert integral was provided.[10,16]

### 3.2. *Monte Carlo simulations*

The MCNP4C radiation transport code was used for MC calculations.[17] This code allows for the development of detailed three dimensional models of brachytherapy sources and dose calculations in complex geometries and materials. The detailed simulation of photon transport includes photoelectric absorption with the creation of K- and L-shell fluorescent photons and auger electrons, coherent and incoherent scattering, and pair production. The simulations were done in photon mode and energy cut-off of 1 keV was used for low energy photons. The sources were simulated using physical measurements and information provided by the manufacturer. The active cores were considered as cylinders composed of $^{60}$Co with uniform distribution of radioactive material. Two photons with emission probabilities of 0.5 and energies of 1.17 and 1.33 MeV were defined in the source definition card. For dose calculations in water, a phantom with dimensions of 30 cm × 30 cm × 30 cm was simulated. The simulated sources were located at the centre of the simulated water phantom. The steel vaginal applicator with the diameter of 7 mm was also simulated, used with all sources. Absorbed doses in the water phantom were calculated in a matrix of scoring cells around the sources using the lattice feature of MCNP4C code. In other words, the water phantom was divided into cells with the dimension of 1 mm × 1 mm × 1 mm. Using the tally scoring feature in a lattice, the absorbed doses in the cells located in a plane vertical to the source longitudinal axis were tallied. Using MATLAB software (Ver. 7), an m-file was written and isodose distributions with distinct intervals were obtained.

The *F8 tally which scores the absorbed energy in terms of MeV was used for absorbed dose calculation in each cell. The energy deposited in each cell was scored per simulation in terms of MeV. For isodose calculation, the absorbed doses were normalized to the value of the cell located at the distance of 1 cm from the source centre. 500 million photons were run to acquire less than 1% statistical uncertainty in a scoring cell at a distance of 4 cm from the source centre.

## 4. Results and discussion

The comparison of isodose distribution is shown in Figs. 2–4. The absorbed dose in each scoring cell was normalized to the cell at the distance of 1 cm from the source centre on the transverse axis for both methods. Comparing isodose distributions for all three sources showed a close agreement between the two methods. A quantitative evaluation of isodoses revealed that there is a difference of 0.5–1 mm between isodose lines from 500% to 10%. For isodose lines of 500% in source 1 and 400% in sources 2 and 3 there was a 1 mm geometric difference, which corresponds to a 15% difference in isodose values. The reason for greater differences in the isodose lines near the sources was that a steep dose gradient exists in the near field region. For other isodose lines which are farther than about 7 mm, the geometric difference was less than 1 mm, which caused less than 2% difference in isodose values because of a smoother dose gradient. Otherwise, it was found that the discrepancy between MC and TPS calculation at points close to the source is greater for source 2 because of longer length. The TPS used point source geometry for dose calculation in water but in MC calculations the actual physical source was simulated and this caused large differences in points close to the source. But for points located farther than the normalization point (at 1 cm from the source axis) in all cases, the TPS calculations were accurate enough to be employed for different brachytherapy treatments. The results of the current study are in accordance with the research of DeMarco et al. on $^{125}$I seeds, in which a large discrepancy between calculated and measured values was observed due to the assumption of point source geometry in calculations.[18]

In spite of the observed discrepancies, we think that the TPS calculations are comparable to MC results in all cases.

In source 1, as can be seen, there are some discrepancies up to 25% beyond the applicator tip at the isodose line of 10% due the pronounced attenuation of inactive steel balls. This can be taken into account by the MC method. But the TPS cannot consider the attenuation because of its implemented algorithm.

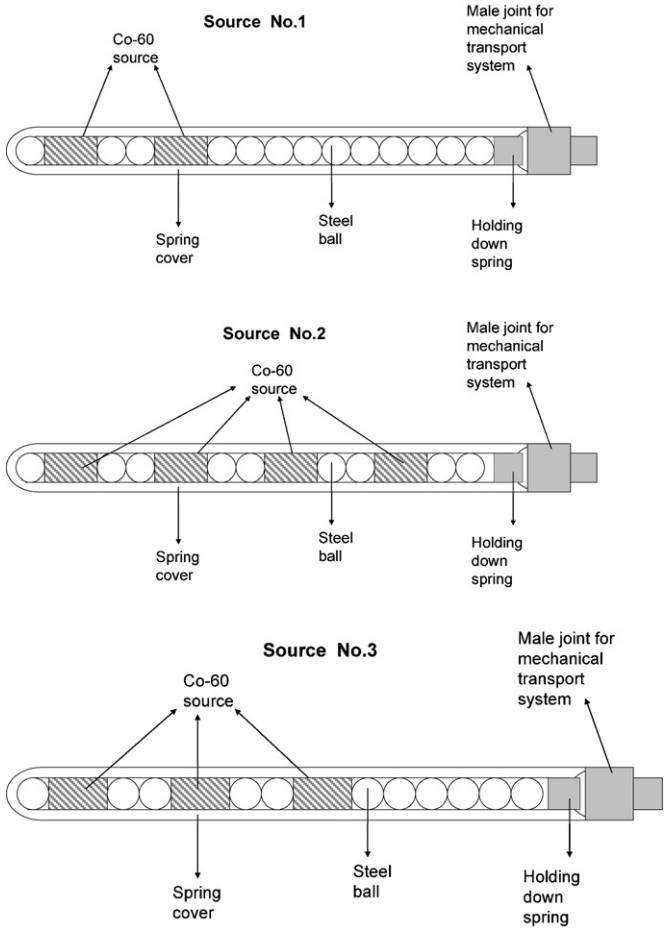


**Fig. 1 – Schematic diagrams of GZP6 $^{60}$Co braid type sources used for intracavitary treatments.**

At points beyond the tip of the applicator and far from active sources the attenuation of steel balls is enhanced, resulting in great differences between MC and TPS calculations. This problem also exists for the two other sources, but it happens in much narrower polar angles for points beyond the applica-

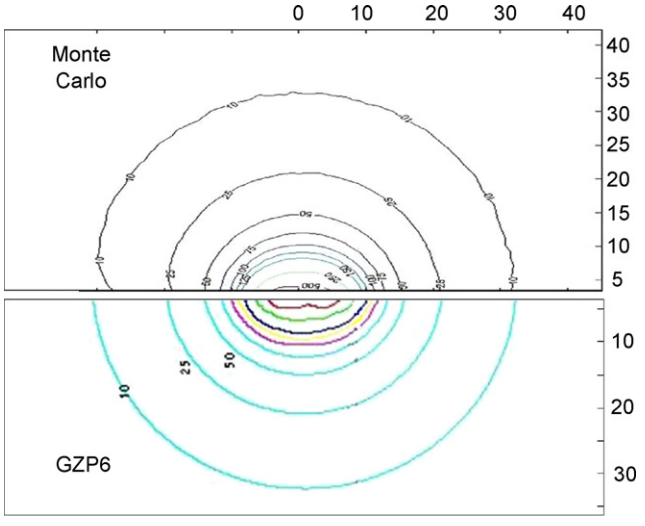


**Fig. 2 – Comparison of MC and GZP6 calculated isodose distributions for source 1.**

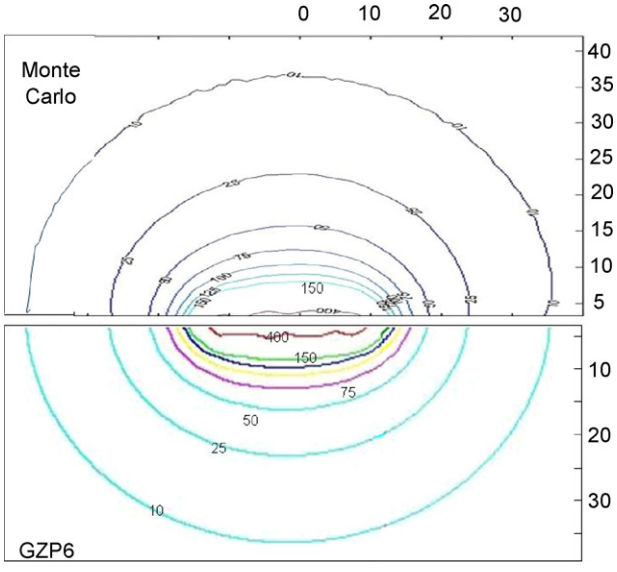


**Fig. 3 – Comparison of MC and GZP6 calculated isodose distributions for source 2.**

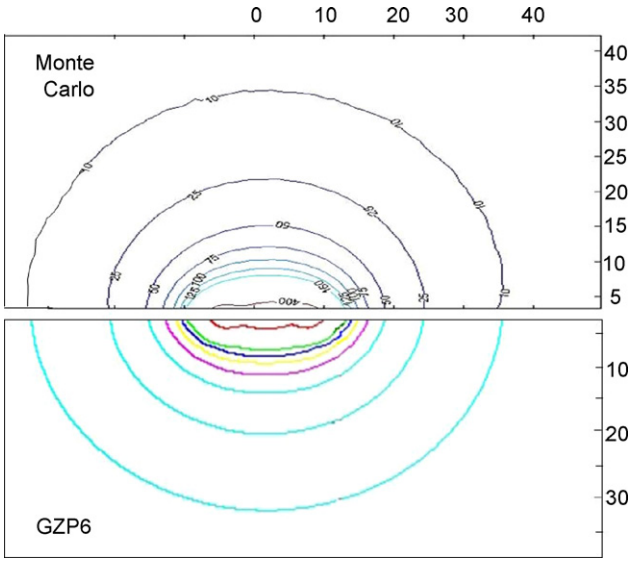


**Fig. 4 – Comparison of MC and GZP6 calculated isodose distributions for source 3.**

tor tips. There is a close agreement with the study of Fragoso et al. in which the dose distribution delivered by low dose rate Cs-137 brachytherapy sources was investigated using MC techniques and polymer gel dosimetry.[19] Their results showed differences in dose as large as 20%, beyond the applicator tip, between MC and TPS methods. The discrepancy was ascribed to the presence of stainless steel in the applicator and source set, which were not considered by the TPS calculations.

The Sievert integral method has shown acceptable accuracy in dose calculation for different type brachytherapy sources. In a study, the Sievert integral method was repeated for different brachytherapy sources.[20] The modified Sievert method calculated dose distributions for a wide range of sources with good accuracy, while the classical Sievert model failed to accurately calculate dose distributions around highly filtered sources emitting photons with average energies of 28–400 keV.

Our results are in agreement with the results of Wallace et al. In their study, the transverse radial dose distribution around the Nucletron MicroSelectron high dose rate (HDR) $^{192}$Ir brachytherapy source was studied using MCNP MC code.[3] They observed significant differences between the planning computer results and the Monte Carlo dose calculations in the near field (radius less than 1 cm). The observed discrepancy was attributed to the HDR brachytherapy planning computers, which employ algorithms based on a point source with attenuation and scatter correction methods.

## 5. Conclusion

In the current investigation we used MCNP4C code to generate two dimensional dose distributions for three braid type $^{60}$Co sources and compared them with TPS provided isodose distributions. Overall, the MC results were in good agreement with TPS calculated isodoses. However, there was a small discrepancy at points beyond the tip of sources because of the algorithm used in the TPS. Finally our results validated the TPS isodose calculations for clinical use in HDR brachytherapy.

## REFERENCES


1. Hoskin PJ, Rembowska A. Dosimetry rules for brachytherapy using high dose rate remote afterloading implants. *Clin Oncol (R Coll Radiol)* 1998;**10**:226–30.
2. Huh H, Kim W, Loh JJ, Lee S, Kim CY, Lee S, et al. Rectum dose analysis employing a multi-purpose brachytherapy phantom. *Jpn J Clin Oncol* 2007;**37**:391–8.
3. Wallace S, Wong T, Fernando W. Monte Carlo dosimetry of the microselectron HDR $^{192}$Ir brachytherapy source using MCNP4A. *Australas Phys Eng Sci Med* 1998;**21**:11–7.
4. Anagnostopoulos G, Baltas D, Karaiskos P, Pantelis E, Papagiannis P, Sakelliou L. An analytical dosimetry model as a step towards accounting for inhomogeneities and bounded geometries in $^{192}$Ir brachytherapy treatment planning. *Phys Med Biol* 2003;**48**:1625–47.
5. Casal E, Ballester F, Lluch JL, Perez-Calatayud J, Lliso F. Monte Carlo calculations of dose rate distributions around the Amersham CDCS-M-type $^{137}$Cs source. *Med Phys* 2000;**27**:132–40.
6. Williamson JF. Radiation transport calculations in treatment planning. *Comput Med Imaging Graph* 1989;**13**:251–68.
7. de Almeida CE, Rodriguez M, Vianello E, Ferreira IH, Sibata C. An anthropomorphic phantom for quality assurance and training in gynaecological brachytherapy. *Radiother Oncol* 2002;**63**:75–81.
8. Sharma SD, Bianchi C, Conte L, Novario R, Bhatt BC. Radiochromic film measurement of anisotropy function for high-dose-rate Ir-192 brachytherapy source. *Phys Med Biol* 2004;**49**:4065–72.
9. Watanabe Y, Roy J, Harrington PJ, Anderson LL. Experimental and Monte Carlo dosimetry of the Henschke applicator for high dose-rate $^{192}$Ir remote afterloading. *Med Phys* 1998;**25**:736–45.
10. Mesbahi A. Radial dose functions of GZP6 intracavitary brachytherapy Co-60 sources: treatment planning system versus Monte Carlo calculations. *Iran J Radiat Res* 2008;**5**:181–6.
11. Ochoa R, Gomez F, Ferreira IH, Gutt F, de Almeida CE. Design of a phantom for the quality control of high dose rate $^{192}$Ir source used in brachytherapy. *Radiother Oncol* 2007;**82**:222–8.
12. Poon E, Reniers B, Devic S, Vuong T, Verhaegen F. Dosimetric characterization of a novel intracavitary mold applicator for $^{192}$Ir high dose rate endorectal brachytherapy treatment. *Med Phys* 2006;**33**:4515–26.
13. Sowards KT. Monte Carlo dosimetric characterization of the IsoAid ADVANTAGE $^{103}$Pd brachytherapy source. *J Appl Clin Med Phys* 2007;**8**:18–25.
14. Venselaar JL, van der Giessen PH, Dries WJ. Measurement and calculation of the dose at large distances from brachytherapy sources: Cs-137, Ir-192, and Co-60. *Med Phys* 1996;**23**:537–43.
15. Taylor RE, Yegin G, Rogers DW. Benchmarking brachydose: Voxel based EGSnrc Monte Carlo calculations of TG-43 dosimetry parameters. *Med Phys* 2007;**34**:445–57.
16. Mesbahi A, Naseri A. In-air calibration of new high dose rate Co-60 brachytherapy sources: results of measurements on a GZP6 brachytherapy afterloading unit. *Rep Pract Oncol Radiother* 2008;**13**:11–5.
17. Briesmeister JF. MCNP—a general Monte Carlo N-particle transport code, version 4C. Report LA-13709-M. Ref Type: Report. NM: Los Alamos National Laboratory; 2000.

18. DeMarco JJ, Smathers JB, Burnison CM, Ncube QK, Solberg TD. CT-based dosimetry calculations for $^{125}$I prostate implants. *Int J Radiat Oncol Biol Phys* 1999;**45**:1347–53.
19. Fragoso M, Love PA, Verhaegen F, Nalder C, Bidmead AM, Leach M, et al. The dose distribution of low dose rate Cs-137 in intracavitary brachytherapy: comparison of Monte Carlo simulation, treatment planning calculation and polymer gel measurement. *Phys Med Biol* 2004;**49**:5459–74.
20. Williamson JF. The Sievert integral revisited: evaluation and extension to $^{125}$I, $^{169}$Yb, and $^{192}$Ir brachytherapy sources. *Int J Radiat Oncol Biol Phys* 1996;**36**:1239–50.