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Original research article

Evaluation of hypothetical ^{153}Gd source for use in brachytherapy☆

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ABSTRACT

Aim: The purpose of this work is to evaluate the dosimetric parameters of a hypothetical ^{153}Gd source for use in brachytherapy and comparison of the dosimetric parameters with those of ^{192}Ir and ^{125}I sources.

Materials and methods: Dose rate constant, the radial dose function and the two dimensional (2D) anisotropy function data for the hypothetical ^{153}Gd source were obtained by simulation of the source using MCNPX code and then were compared with the corresponding data reported by Enger et al. A comprehensive comparison between this hypothetical source and a ^{192}Ir source with similar geometry and a ^{125}I source was performed as well.

Results: Excellent agreement was shown between the results of the two studies. Dose rate constant values for the hypothetical ^{153}Gd, ^{192}Ir, ^{125}I sources are 1.173 cGyh^{-1} U^{-1}, 1.044 cGyh^{-1} U^{-1}, 0.925 cGyh^{-1} U^{-1}, respectively. Radial dose function for the hypothetical ^{153}Gd source has an increasing trend, while ^{192}Ir has more uniform and ^{125}I has more rapidly falling off radial dose functions. 2D anisotropy functions for these three sources indicate that, except at 0.5 cm distance, ^{192}Ir and ^{125}I have more isotropic trends as compared to the ^{153}Gd source.

Conclusion: A more uniform radial dose function, and 2D anisotropy functions with more isotropy, a much higher specific activity are advantages of ^{192}Ir source over ^{153}Gd. However, a longer half-life of ^{153}Gd source compared to the other two sources, and lower energy of the source with respect to ^{192}Ir are advantages of using ^{153}Gd in brachytherapy versus ^{192}Ir source.

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1. Background

Brachytherapy is an advanced cancer treatment. In brachytherapy practice radioactive seeds or sources are placed inside or in a close vicinity of the tumor, irradiating a high radiation dose to the tumor while reducing the radiation exposure to the surrounding healthy tissues. Brachytherapy is a radiation therapy modality which is accounted as localized, precise and high-technology treatment. Photon emitting

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sources which are currently used in brachytherapy are ^{60}Co, ^{137}Cs, ^{192}Ir, ^{125}I and ^{103}Pd.[1–4] Based on the recommendation of the American Association of Physicists in Medicine (AAPM), task group No. 43 (TG-43U1[5]), dosimetric parameters of each source should be calculated before application of the source in brachytherapy. Then, these parameters can be entered to the treatment planning system using that source. Based on this report, the dosimetric parameters should be calculated by at least two independent investigators.[5] For this reason, various scientists have reported dosimetric parameters of different radioactive sources in their studies.[6–12] These fundamental parameters include: air kerma strength, dose rate constant, geometry function, radial dose function and two dimensional (2D) anisotropy function. Due to the need for use in brachytherapy practice, in last few years different scientists have introduced new hypothetical brachytherapy sources and reported their dosimetric parameters. Hypothetical sources are based on the geometry of a real source but their active materials are isotopes which are not commonly used in brachytherapy or are not available commercially. In a number of previous studies, TG-43 dosimetric parameters of new hypothetical sources were calculated, compared with commercially available sources and then introduced as brachytherapy sources.[2,13–15]

^{153}Gd is one of the hypothetical sources which were introduced by Enger et al.[14] According to the Oak Ridge National Laboratory (ORNL) study in 1960,[16] ^{153}Gd may be a favorable brachytherapy source. This radioisotope has an intermediate energy relative to other brachytherapy sources and emits photons with energies ranging between 40 and 100 keV with half-life of 242 days. In a recent study by Adams et al.[17] a novel needle, catheter and source system were presented for interstitial rotating shield brachytherapy (I-RSBT) of the prostate by ^{153}Gd sources. Their rationale for use of a shielded source and catheter system was to reduce urethra, rectum, and bladder dose. The reason for proposal of ^{153}Gd source rather than ^{125}I and ^{192}Ir sources was that the ^{125}I source has a rapid dose fall-off in tissue and the shielding thickness for ^{192}Ir would be large and, therefore, it could not be fitted inside catheters normally used in prostate brachytherapy. Treatment plans for I-RSBT and conventional brachytherapy treatments of a prostate cancer patient were obtained by Monte Carlo calculations. The platinum shield used could reduce the dose rate on the shielded side at 1.0 cm to 6.4% relative to the dose rate on the other (unshielded) side. This method also reduces the dose to the urethra, rectum and bladder. The treatment time for delivery of 20 Gy dose in I-RSBT with ten 62 GBq ^{153}Gd sources was 154 min. When it is aimed to have a reasonable dosage and treatment time, multisource approach is necessary. In the study by Enger et al.[14] the dosimetric parameters of a hypothetical source based on this radioisotope were calculated and reported in the form of plots. However, the results were not expressed numerically. Furthermore, the dosimetric parameters of the hypothetical ^{153}Gd source were not compared with commercially available sources such as ^{192}Ir. Aim is to determine the dosimetric characteristics for the hypothetical ^{153}Gd source. The results will then be compared with those reported by Enger et al. and with the dosimetric parameters of ^{192}Ir and ^{125}I brachytherapy sources.

2. Materials and methods

2.1. *Geometry of hypothetical ^{153}Gd source*

The source design for the hypothetical ^{153}Gd source is similar to that of VariSource^{TM} ^{192}Ir source (Varian Medical Systems, Palo Alto, CA).[18] This design was chosen because it was proposed in the previous study on the hypothetical ^{153}Gd source[14] and to have an appropriate comparison of the results of the two studies; it was preferred to have the same geometries. There is only one difference that the active core in the ^{153}Gd hypothetical source was defined as a pure ^{153}Gd radionuclide. The design and dimensions of this source are illustrated in Fig. 1. The active core of the source is in the form of a pure ^{153}Gd cylinder (density $\rho = 7.9\,\mathrm{g\,cm^{-3}}$) with an active length of 1.0 cm and diameter of 0.84 mm. The active core was defined in a stainless steel capsule with 11.3 mm length (including the end weld). The inner diameter of the encapsulation is 0.84 mm and its outer radius is 1.0 mm. The stainless steel encapsulation is composed of Fe (67.92%), Cr (19%), Ni (10%), Mn (2%), Si (1%) and C (0.08%) with density of 8.0 g cm^{-3}. The length and diameter of the simulated source's guide are 5.0 mm and 0.5 mm, respectively. The energy spectrum of photons emitted by ^{153}Gd radionuclide is tabulated in Table 1.[19]

2.2. *TG-43 dosimetric parameters*

Dosimetric parameters of a brachytherapy source can be determined using experimental or Monte Carlo simulation methods following the TG-43 report.[5,20] Based on this formalism, dose distribution around a brachytherapy source is determined using the following formula:

$$\dot{D}(r,\theta) = S_K \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta) \tag{1}$$

where S_K, Λ, $G(r, \theta)$, $g(r)$ and $F(r, \theta)$ are air kerma strength, dose rate constant, geometry function, radial dose function and 2D anisotropy function, respectively. These parameters are calculated from the following formulas:

$$S_K = \dot{K}_\delta(d) d^2 \tag{2}$$

$$\Lambda = \frac{\dot{D}(1\,\mathrm{cm}, \pi/2)}{S_K} \tag{3}$$

By using a line-source approximation, for $\theta = 0°$, the geometry function is calculated from the following equation:

$$G(r,\theta) = \left(r^2 - \frac{L^2}{4}\right)^{-1} \tag{4}$$

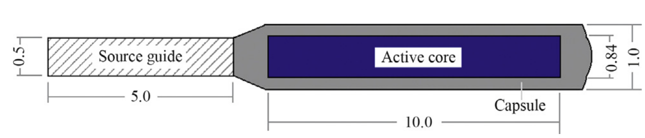

Fig. 1 – A schematic diagram showing the geometry of the hypothetical ^{153}Gd brachytherapy source (all dimensions are in millimeter).

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