Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

A Monte Carlo study on dose distribution evaluation of Flexisource ^{192}Ir brachytherapy source

Majid Alizadeh[a], *Mahdi Ghorbani*[b], *Abbas Haghparast*[a,*], *Naser Zare*[c], *Toktam Ahmadi Moghaddas*[d]

[a] *Medical Physics and Medical Engineering Department, Faculty of Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran*
[b] *Medical Physics Department, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran*
[c] *Brachytherapy Department, Atiyeh Hospital, Tehran, Iran*
[d] *Department of Basic Medical Sciences, Neyshabur University of Medical Sciences, Neyshabur, Iran*

ARTICLE INFO

Article history:
Received 26 April 2014
Received in revised form
28 November 2014
Accepted 28 January 2015

Keywords:
Monte Carlo
Flexiplan treatment planning system
Flexisource
HDR brachytherapy
^{192}Ir source

ABSTRACT

Aim: The aim of this study is to evaluate the dose distribution of the Flexisource ^{192}Ir source.
Background: Dosimetric evaluation of brachytherapy sources is recommended by task group number 43 (TG. 43) of American Association of Physicists in Medicine (AAPM).
Materials and methods: MCNPX code was used to simulate Flexisource ^{192}Ir source. Dose rate constant and radial dose function were obtained for water and soft tissue phantoms and compared with previous data on this source. Furthermore, dose rate along the transverse axis was obtained by simulation of the Flexisource and a point source and the obtained data were compared with those from Flexiplan treatment planning system (TPS).
Results: The values of dose rate constant obtained for water and soft tissue phantoms were equal to 1.108 and 1.106, respectively. The values of the radial dose function are listed in the form of tabulated data. The values of dose rate (cGy/s) obtained are shown in the form of tabulated data and figures. The maximum difference between TPS and Monte Carlo (MC) dose rate values was 11% in a water phantom at 6.0 cm from the source.
Conclusion: Based on dosimetric parameter comparisons with values previously published, the accuracy of our simulation of Flexisource ^{192}Ir was verified. The results of dose rate constant and radial dose function in water and soft tissue phantoms were the same for Flexisource and point sources. For Flexisource ^{192}Ir source, the results of TPS calculations in a water phantom were in agreement with the simulations within the calculation uncertainties. Furthermore, the results from the TPS calculation for Flexisource and MC calculation for a point source were practically equal within the calculation uncertainties.

* *Corresponding author at*: Medical Physics and Medical Engineering Department, Faculty of Medicine, Kermanshah University of Medical Sciences, Kermanshah 67146-73159, Iran. Tel.: +98 831 4274627; fax: +98 831 4274623.
E-mail address: abbas.haghparast@gmail.com (A. Haghparast).

http://dx.doi.org/10.1016/j.rpor.2015.01.006
1507-1367/

1. Background

Brachytherapy, treatment at short distance, is a radiotherapy modality in which sealed radioactive sources of radiation are placed at short distances from the tumor. It is performed using intracavitary, interstitial or surface application techniques. With this treatment method, a high radiation dose is delivered to the tumor volume with rapid dose fall-off in the surrounding normal tissues.[1] Brachytherapy is characterized by the time duration of the irradiation and it is divided into two types: permanent implant and temporary implant. In the latter one, ^{137}Cs and ^{192}Ir are two radionuclides which are commonly used as sources. When considering the dose rate, three classifications have been established: low dose rate (0.4–2 Gy/h), medium dose rate (2–12 Gy/h) and high dose rate (>12 Gy/h) treatments.[2]

^{192}Ir radionuclide has been used since 1958 as a brachytherapy source. At that time ^{192}Ir wires were used with the Paris dose calculation system, which was established by Pierquin et al.[3] ^{192}Ir has become a popular radionuclide and it is used as a substitute for ^{226}Ra.[4] At present, ^{192}Ir is commonly used in most radiotherapy centers as a source in clinical brachytherapy.[5] There are several studies on dose distribution evaluation for ^{192}Ir Flexisource source model, determined by MC simulations. Granero et al.[6] obtained the dose distribution for a ^{192}Ir Flexisource source by the MC method using GEANT4 code. They calculated dose rate per air kerma strength, anisotropy function and radial dose function at various points. In their study, it was recommended to use the obtained data for this source to verify the TPS calculations. Ballester et al.[7] calculated dosimetric parameters of ^{192}Ir wires with the use of Sievert integral, Task Group No. 43 (TG-43) formalism and Monte Carlo (MC) techniques. They then obtained the absorbed dose values of the ^{192}Ir wires with 1.0–5.0 cm sizes by utilizing GEANT4 Monte Carlo code. In another study, Bozkurt et al.[8] compared the values of dose rate per air kerma strength at distances of 0.1–10.0 cm for the ^{192}Ir wires with sizes of 1.0–5.0 cm. The study was performed using the MCNP Monte Carlo code and the obtained results were shown to be in agreement with the data from the XiO CMS commercial treatment planning system (TPS). In a comparative study between MC and TPS calculations, Zhang et al.[9] characterized dosimetric parameters for ^{125}I and ^{137}Cs sources in a collaborative ocular melanoma study (COMS) in eye plaque brachytherapy and their results showed that there was a complete adaptation between the MC and TPS data. Granero et al.[10] compared dosimetric parameters of a BEBIG ^{192}Ir source through calculation by utilizing the GEANT4 Monte Carlo (MC) code with the literature for other high dose rate (HDR) sources. They showed that the use of the obtained datasets for this source is justified. ^{192}Ir is the most frequently used source in HDR brachytherapy, especially in the treatment of prostate cancer. While there are various studies on dosimetric evaluation of ^{192}Ir sources, to the best of our knowledge, there is no study on dosimetric evaluation of the calculations of the Flexitron brachytherapy unit which contains Flexisource ^{192}Ir sources.

2. Aim

The aim of this study is to evaluate in-phantom dose rate distribution from various aspects for a Flexisource HDR ^{192}Ir source using MC simulation of the source.

3. Materials and methods

3.1. Geometry of Flexisource ^{192}Ir source

The geometry of Flexisource HDR ^{192}Ir source is illustrated in Fig. 1. This source is composed of an active iridium cylinder (density: 22.42 g/cm^3) with active length of 3.5 mm and diameter of 0.6 mm. The active part is covered by a stainless-steel capsule (composition by weight: Fe: 67.92%, Cr: 19.00%, Ni: 10.00%, Mn: 2.00%, Si: 1.00% and C: 0.08%, density: 8.00 g/cm^3). The outer diameter of the source is 0.85 mm and the total length of the source is 4.6 mm. The cable of the source is made of 304 stainless-steel in the form of a cylinder with 5 mm length and 0.5 mm diameter.[6] The radiation characteristics of the Flexisource ^{192}Ir source used in this study are listed in Table 1.[6]

3.2. Calculation of TG-43 dosimetric parameters by MC simulations

Report of Task Group No. 43 was published in 1995 by the American Association of Physicists in Medicine (AAPM) and was updated later in 2004.[11] Based on the updated version of this formalism (TG-43U1), dose rate is obtained from the below formula:

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

$$\Lambda = \frac{\dot{D}(r_0,\theta_0)}{S_K} \quad (2)$$

$$G(r,\theta) = \begin{cases} \dfrac{\beta}{Lr\sin\theta} & \text{if } \theta \neq 0 \\ \left(r^2 - \dfrac{L^2}{4}\right)^{-1} & \text{if } \theta = 0 \end{cases} \quad (3)$$

where r is the distance from source's center; r_0 is the reference distance which is 1.0 cm usually; θ is the polar angle between the longitudinal axis and the line connecting the calculation point and the source's center; θ_0 is the reference angle which is usually 90°; S_K is the air kerma strength; Λ is dose rate constant; $G_L(r,\theta)$ is geometry function; $g(r)$ is radial dose function; $F(r,\theta)$ is anisotropy function; β is the angle subtended by two hypothetical lines at the calculation point connected to the two ends of the active length; and L is the effective length.[11] The geometry and characteristics of the Flexisource ^{192}Ir source were simulated in a water phantom and a soft tissue phantom, separately. The chemical composition of the soft tissue phantom had nine components which were adopted from the report No. 44 of the International Commission on Radiation Units and Measurements (ICRU). Based on this report, the soft tissue has the following elements and

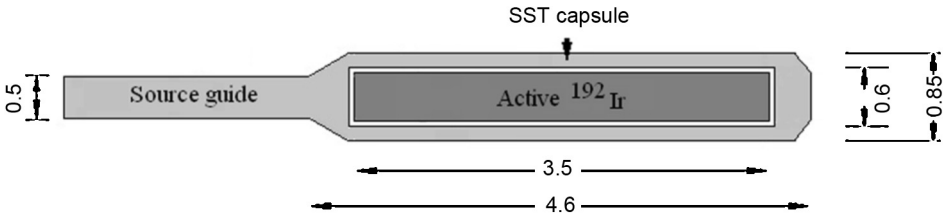

Fig. 1 – Geometry of Flexisource ^{192}Ir brachytherapy source used in this study. All dimensions are in millimeters.

Table 1 – Radiation characteristics of Flexisource ^{192}Ir source used in this study.

Half-life ($t_{1/2}$)	λ (s^{-1})	Mass for 100 MBq (μg)	Average photon energy (keV)	Reference
74 d	1.08×10^{-7}	0.29	380	2

mass fractions: H: 0.102; C: 0.143; N: 0.034; O: 0.708; Na: 0.002; P: 0.003; S: 0.003; Cl: 0.002; K: 0.003.

Monte Carlo simulation is an accepted method of dose calculation when analytical calculations are difficult or impossible.[12] Sources are available in the form of tubes, wires, needles, pellets or seeds. MCNPX (version 2.4.0) code has been used in this study for simulation of the ^{192}Ir source, phantoms, etc.[13] For air kerma strength calculation (S_K), air kerma was calculated in cells defined in the form of toruses containing air according to the method presented in the previously published article.[14] For this purpose, F6 tally (with units of MeV/g per particle) was calculated in the toruses with a 0.05 cm radius. The air toruses were arranged along the transverse axis at distances of 1.0–40.0 cm. The products of the air kerma rates and the square of radial distance from the source were averaged from 8.0 to 18.0 cm distances along the source's transverse axis. The photon and electron importance in all the cells were set at 1, except outside of the vacuum sphere with 100.0 cm radius in which it was defined as zero. Air kerma strength has units of μGy m^2 h^{-1} according to the TG-43U1 protocol. Then, the air kerma strength value was used for the calculation of dose rate constant (Λ), according to formula (2). Dose rate constant (Λ) was calculated in water and soft tissue phantoms. For this purpose, a torus with 0.05 cm width at the distance of 1.0 cm was defined in the phantom and the absorbed dose was calculated in this torus. A torus shaped cell was chosen to conform to the cylindrical symmetry of the source. In calculation of the radial dose function ($g(r)$), toruses with 0.05 cm width at distances 0.5–7.0 cm were defined. Radial dose function was calculated in water and soft tissue phantoms. The photon and electron importance in all of the cells were equal to 1, except outside the water or soft tissue phantoms which were spheres with 50.0 cm radius. In those spaces the particles' importance was defined as zero. Line-source approximation was used and a geometry function was obtained from formula (3). In this calculation the effective length of the source was 3.5 mm. For the calculation of the dose rate constant and radial dose function, the *F4 tally (in units of MeV/cm^2 per particle) was used. *F4 tally scores energy fluence, thus the absorbed dose, was obtained by multiplication of the energy fluence and the mass energy absorption coefficient (μ_{en}/ρ). Since the mass energy absorption coefficient depends on energy, the photon energy was divided into energy bins and the energy fluence in each bin was multiplied by the corresponding mass energy absorption coefficient. Then, the absorbed dose was obtained from summation of the dose components in the energy bins. The simulations were performed for 2.5×10^7 photons and the maximum MC statistical error in tallies in the calculation of dose rate constant and radial dose function was 0.41%. A point source was also simulated, in the form of a point in a stainless-steel sphere with radius of 0.125 mm which mimics the stainless-steel capsule of the Flexisource ^{192}Ir source in the transverse direction. The method of calculation of the air kerma strength, dose rate constant and radial dose function for this point source was the same as that aforementioned for the Flexisource ^{192}Ir source. The simulations were performed for 7.5×10^7 photons and the maximum MC error in the tally cells was 0.24%.

3.3. *Dose distribution calculations by MC simulations*

The geometry characteristics of the Flexisource ^{192}Ir HDR source were defined in the simulations. To obtain the dose distribution around the source, the type of cells, the number of photons scored, the distances and dimensions of the toruses were similar to those described in the method of calculation of TG-43 dosimetric parameters in this study. Finally, the MC outputs (MeV/g per photon) were converted to absorbed dose rates in units of cGy/s using the following formula:

$$\begin{aligned}\text{Dose rate (cGy/s)} = {} & \text{MC output (MeV/g per photon)} \\ & \times 10^6 \text{ (eV/MeV)} \times 1.602 \times 10^{-19} \text{ (J/eV)} \\ & \times 10^3 \text{ (g/kg)} \times 2.74 \text{ (Ci)} \times 3.7 \\ & \times 10^{10} \text{ (Bq/Ci)} \times 1 \text{ (dis/s per Bq)} \\ & \times \text{photon yield of } ^{192}\text{Ir (photons/dis)} \\ & \times 100 \text{ (s)}\end{aligned} \tag{4}$$

The value of photon yield of the ^{192}Ir radionuclide is equal to 2.363 photons/dis.[15] The activity of ^{192}Ir source, used in this study, was 2.74 (Ci) on the date of TPS data extraction (25 September 2013). The calibration date of this source was 19 April 2013.

Table 2 – Dose rate constant values (cGy h^{-1} U^{-1}) for Flexisource ^{192}Ir source in water and soft tissue phantoms.

	This study	Other study	Diff. (%)
Water phantom	1.108	1.109 (Ref. 3)	0.09%
Soft tissue phantom	1.106	–	–

3.4. *Dose distribution and dosimetric parameter calculations by TPS*

The software which is used in the Flexitron afterloading system is Flexiplan (version 2.5) which was designed and developed by sonoTECH (Neu-Ulm, Germany). This version of the software can calculate and display dose values and dose volume histograms (DVHs) even for film based orthogonal projection evaluations. The calculation program in this software applies a new optimization method in which the favorable dose for each single point of a group is entered and the dose distribution with a minimum squared error is obtained. The isodose curves are displayed based on dose calculations in a Cartesian (rectangular) three-dimensional matrix with evenly spaced user-specified grid intervals. This grid is a so-called dose matrix. The dimensions of this grid on a plane can be varied from 30 × 30 to 120 × 120 points, depending on the desired isodose display accuracy in the volume where the user defines that the isodoses are to be calculated and displayed in the Flexiplan treatment planning software.[16]

The Flexiplan software is commonly used in a number of countries including Iran, India, Iraq, etc. It can reconstruct one or more applicators and calculate the optimal dose distribution based on the contoured volumes and prescribed dosage. Flexiplan treatment planning software is used in high-dose-rate and pulsed-dose-rate remote afterloader based brachytherapy machines for the creation of treatment plans. The afterloader was manufactured in the Netherlands.

Dose calculations in the Flexiplan TPS are TG-43 based and are performed for the case of a water phantom as the tissue-equivalent medium. In other words, this TPS considers all soft tissues as water. While the Flexiplan TPS is able to calculate dose distribution for stepping sources, all of our dose calculations with Flexiplan TPS were performed for the case of a single source positioned in water. Radial dose function for Flexisource ^{192}Ir source at 0.5–7.0 cm distances in the transverse plane was extracted from this treatment planning system. Dose rate values (in terms of Gy/100 s which is reported in this study as cGy/s) at 0.5–7.0 cm radial distances were extracted from the Flexiplan TPS of the Flexitron machine which is currently being used for brachytherapy practice in Atiyeh Hospital in Tehran, Iran.

4. Results

The results of calculation of dose rate constant for the Flexisource HDR ^{192}Ir source obtained from the simulations by the MCNPX code in water and soft tissue phantoms are listed in Table 2. Radial dose function results at 0.5–7.0 cm distances along the transverse axis of the source obtained from Monte Carlo method for the water and soft tissue phantoms; and from Flexiplan TPS a water phantom are listed in Table 3. This table also includes the percentage differences between these three data series and the other study. Dose rates (cGy/s) along the transverse axis obtained from the Flexiplan TPS, MC simulations for Flexisource and point sources are listed in Table 4. The percentage differences between the TPS calculations for Flexisource ^{192}Ir source, and MC simulations for Flexisource ^{192}Ir and point sources are also listed in this table. It should be noticed that the uncertainties reported in these tables are either combined errors calculated from uncertainties in the MC outputs and the dose rate values or were calculated from the uncertainties from MC outputs directly by multiplication of the relative uncertainty to the dose rate at each data point. The number of error values in these tables equal to zero because these values were rounded up to three decimals. Fig. 2 illustrates dose rate × r^2 (cGy m^2/s) at different radial distances from the source which was obtained from Flexiplan TPS and MC simulations of the source for the Flexisource and point sources.

Table 3 – Radial dose function values for Flexisource ^{192}Ir source in water and soft tissue phantoms obtained from Monte Carlo and Flexiplan TPS compared with the other study (Granero et al.).

r (cm)	MC (water) [A]	MC (soft tissue) [B]	Flexiplan TPS [C]	Granero et al. (Ref. 6) [D]	Diff. (%) [A] – [D]	Diff. (%) [B] – [D]	Diff. (%) [C] – [D]
0.5	1.000 ± 0.001	0.990 ± 0.001	0.99	0.997	0.30	0.74	−0.70
1.0	1.000 ± 0.002	1.000 ± 0.002	1.00	1.000	0.00	0.00	0.00
1.5	1.000 ± 0.002	1.000 ± 0.002	1.00	1.002	−0.20	−0.22	−0.20
2.0	1.010 ± 0.002	1.010 ± 0.002	1.01	1.004	0.60	−0.91	0.60
2.5	1.010 ± 0.002	1.010 ± 0.002	1.02	–	–	–	–
3.0	1.010 ± 0.002	1.010 ± 0.002	1.02	1.005	0.50	−1.48	0.50
3.5	1.010 ± 0.002	1.010 ± 0.002	1.00	–	–	–	–
4.0	1.010 ± 0.002	1.010 ± 0.002	1.02	1.003	0.70	−1.91	0.70
4.5	1.010 ± 0.003	1.010 ± 0.003	1.00	–	–	–	–
5.0	1.010 ± 0.003	1.010 ± 0.003	1.02	0.999	1.10	−1.87	1.10
5.5	1.000 ± 0.003	1.010 ± 0.004	0.97	–	–	–	–
6.0	1.000 ± 0.003	1.000 ± 0.003	1.05	0.991	0.91	−5.19	0.91
6.5	1.000 ± 0.003	1.000 ± 0.003	0.98	–	–	–	–
7.0	1.000 ± 0.003	0.990 ± 0.003	1.00	0.981	1.94	−1.54	0.92

Table 4 – Dose rate (cGy/s) along the transverse axis obtained from Flexiplan TPS and Monte Carlo for Flexisource ^{192}Ir source in water phantom.

r (cm)	Flexiplan (TPS) [A]	Flexisource source (MC) [B]	Point source (MC) [C]	Diff. (%) [A] – [B]	Diff. (%) [A] – [C]	Diff. (%) [B] – [C]
0.5	13.11	12.32 ± 0.01	14.05 ± 0.007	6.41	−6.69	14.04
1.0	3.41	3.18 ± 0.003	3.54 ± 0.002	7.23	−3.67	11.32
1.5	1.53	1.43 ± 0.002	1.58 ± 0.001	6.99	−3.16	10.48
2.0	0.87	0.81 ± 0.001	0.89 ± 0.001	7.41	−2.25	9.87
2.5	0.56	0.52 ± 0.001	0.57 ± 0.001	7.69	−1.75	9.61
3.0	0.39	0.36 ± 0.001	0.40 ± 0.000	8.33	−2.50	11.11
3.5	0.28	0.27 ± 0.001	0.29 ± 0.000	3.70	−3.45	7.40
4.0	0.22	0.20 ± 0.000	0.22 ± 0.000	10.00	0.00	10.00
4.5	0.17	0.16 ± 0.000	0.18 ± 0.000	6.25	−5.56	12.50
5.0	0.14	0.13 ± 0.000	0.14 ± 0.000	7.69	0.00	7.69
5.5	0.11	0.11 ± 0.000	0.12 ± 0.000	0.00	−8.33	9.09
6.0	0.10	0.09 ± 0.000	0.10 ± 0.000	11.00	0.00	11.11
6.5	0.08	0.08 ± 0.000	0.08 ± 0.000	0.00	0.00	0.00
7.0	0.07	0.07 ± 0.000	0.07 ± 0.000	0.00	0.00	0.00

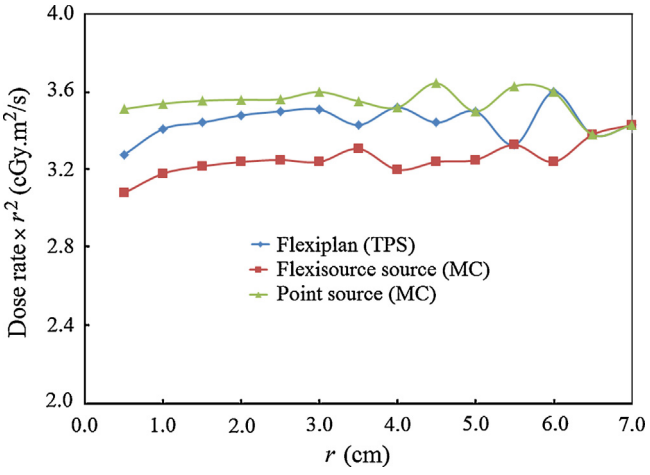

Fig. 2 – Dose rate × r^2 (cGy m^2/s) along the transverse axis versus distance in water phantom for Flexisource ^{192}Ir source and point source obtained from MC calculations and Flexiplan TPS.

5. Discussion and conclusion

In the present study Flexiplan TPS dose rate calculations were verified based on MC simulation of Flexisource HDR ^{192}Ir source. Dose rate constants for Flexisource ^{192}Ir source in a water and soft tissue phantoms are approximately equivalent. The percentage difference between the dose rate constant value from this study and the published data is small, 0.09% for a water phantom. The radial dose function results in a soft tissue and water phantom indicate that the phantom material does not have a dominant effect on accuracy of the simulations, since the maximum difference is 1.94%. The maximum difference between the radial dose functions from Monte Carlo and Flexiplan TPS is 5.19%. The dose rate constant for point source geometry shows that the soft tissue and water phantom are practically equal. The results of the comparisons between dose rates from TPS and MC for the Flexisource HDR ^{192}Ir source in a water phantom show a maximum difference of 11.00%. This value, within the uncertainties involved, indicates an agreement between these two data sets. It should be noticed that the TPS calculations are normally performed for a water medium. Furthermore, the comparison between the dose rate distributions for the Flexisource HDR ^{192}Ir source and the point source show that the use of a point source approximation instead of a complete definition of source geometry creates a relatively large error in some cases (up to 14.04%). Furthermore, the results from TPS calculation for Flexisource and MC calculation for a point source were practically equal within the calculation uncertainties. As can be considered from Fig. 2, at almost all of the data points, the point source curve is above the curves related to ^{192}Ir Flexisource and Flexiplan TPS. By taking the Flexisource MC simulations as a reference, it can be concluded that both the point source approximation and Flexiplan TPS calculations overestimate the dose rate. However, at distal points from the source, the differences of dose rate × r^2 between these methods seem to decrease.

^{192}Ir HDR sources are being used in afterloading systems. To verify and obtain dose distributions from TPS calculations, MC techniques are commonly used. In clinical practice, there are cases in which the sources are used in a stepping manner for irradiation of a target volume. In this method, a source is placed inside tubes in a number of locations, and the source is moved inside each tube at various steps, dwelling at each of them for a period of time. One way to simulate these stepping cases is to write separated MC input files, each of them including one step geometry details, and then to calculate the overall dose distribution as summation of the outputs of the all input files. However, this manner seems to be difficult due to the need for writing and running of a large number of input files. Another option is to simulate all the steps in a single input file and allocate time weighting to each source position. In this manner there may be some overlapping steps in which two source positions overlap each other. Therefore, simulation the source in its full geometrical form in each step may be difficult because they overlap each other in some cases. Definition of the source as a point source can be an option to overcome this problem. The point source model for stepping sources can be used for the calculation of dose distribution in the target

volume and also for the assessment of dose enhancement in the presence of a high atomic material (such as gadolinium, gold nanoparticles) in brachytherapy. Using the point source model, can prevent the sources from overlapping, but it should be noted that it involves uncertainties in dose calculations. In the present study, to verify the dose rate used in the Flexiplan TPS, water was considered as a phantom medium and TG-43 parameters in the water phantom were utilized. Normally, in treatment planning process with TPSs, computed tomography images are used for dose calculation in various tissues while their electron densities are considered in the calculations. However, the atomic compositions of various soft tissues are not involved in the calculations. Ghorbani et al. investigated the effect of tissue composition on dose distribution for various photon emitting sources.[17] The results of their study showed that for ^{192}Ir source no considerable difference was observed in various soft tissue phantoms. However, in the presence of bone as an inhomogeneity, it is predicted that changes in dose distributions will be observed. Evaluation of the accuracy of dose distribution calculation by Flexiplan TPS in the presence of inhomogeneities via Monte Carlo simulations or experimental dose measurements can be a subject of further study on the Flexiplan TPS.

In a study by Fazli et al.,[18] dose distribution from MC simulations, Flexiplan TPS calculations and normoxic gel dosimetry were compared for a non-homogeneous nasopharynx phantom. The phantom was irradiated by ^{192}Ir Flexitron afterloader. Their results showed a difference of up to 6.1% between MC simulations and three-dimensional TPS data. In another study, Yazdi et al.[19] compared the percentage isodose curves and cumulative DVHs obtained from an MC simulation with Flexiplan TPS calculations for Flexisource ^{192}Ir source in the presence of rib and lung heterogeneities. Their study showed that by taking into account the ribs and entering the data of breast, lungs and ribs, the Flexiplan TPS calculations include an average overestimation of 8% in the lung dose. It was reported that the TPS accuracy is limited to the regions near the implants and there is a concern for boundaries and heterogeneity regions from a dosimetric point of view.

Conflict of interest

None declared.

Financial disclosure

Kermanshah University of Medical Sciences (KUMS) has financially supported the work.

Acknowledgments

The authors would like to thank Kermanshah University of Medical Sciences (KUMS) for funding this work. The results of this study were extracted from a thesis covered by KUMS via a grant with number of 92108. We also would like to thank the personnel of brachytherapy department of Atiyeh Hospital, for their kind help in providing the treatment planning system data.

REFERENCES

1. Khan FZ. *Physics of radiation therapy*. 4th ed. Minneapolis, MN: Lippincott Williams & Wilkins; 2003. p. 316.
2. Gerbaulet A, Pötter R, Mazeron JJ, et al. *The GEC ESTRO handbook of brachytherapy*. Leuven: The European Society for Therapeutic Radiology and Oncology, ESTRO; 2002. p. 7.
3. Pierquin B, Dutreix A, Paine CH, et al. The Paris system in interstitial radiation therapy. *Acta Radiol Oncol* 1978;**17**(1):33–48.
4. Baltas D, Sakelliou L, Zamboglou N. *The physics of modern brachytherapy for oncology*. New York: Taylor & Francis; 2007. p. 157–64.
5. Patel NP, Majumdar B, Vijiyan V, et al. In-air calibration of an HDR ^{192}Ir brachytherapy source using therapy ion chambers. *J Cancer Res Ther* 2005;**1**(4):213–20.
6. Granero D, Pérez-Calatayud J, Casal E, et al. A dosimetric study on the Ir-192 high dose rate Flexisource. *Med Phys* 2006;**33**(12):4578–82.
7. Ballester F, Hernandez C, Perez-Calatayud J, et al. Monte Carlo calculation of dose rate distributions around ^{192}Ir wires. *Med Phys* 1997;**24**(8):1221–8.
8. Bozkurt A, Acun H, Kemikler G. Dosimetric investigation of LDR brachytherapy ^{192}Ir wires by Monte Carlo and TPS calculations. *Jpn J Radiol* 2013;**31**(1):24–30.
9. Zhang H, Martin D, Chiu-Tsao ST, et al. A comprehensive dosimetric comparison between ^{131}Cs and ^{125}I brachytherapy sources for COMS eye plaque implant. *Brachytherapy* 2010;**9**(4):362–72.
10. Granero D, Perez-Calatayud J, Ballester F. Monte Carlo calculation of the TG-43 dosimetric parameters of a new BEBIG Ir-192 HDR source. *Radiother Oncol* 2005;**76**(1):79–85.
11. Rivard MJ, Coursey BM, DeWerd LA, et al. Update of AAPM Task Group No. 43 Report: a revised AAPM protocol for brachytherapy dose calculations. *Med Phys* 2004;**31**(3):633–74.
12. Andreo P. Monte Carlo techniques in medial radiation physics. *Phys Med Biol* 1991;**36**(7):861–920.
13. Waters LS. *MCNPX user's manual. Version 2.4.0. Report LA-CP-02-408*. Los Alamos National Laboratory; 2000.
14. Bahreyni Toossi MT, Ghorbani M, Mowlavi A, et al. Air kerma strength characterization of a GZP6 Cobalt-60 brachytherapy source. *Rep Pract Oncol Radiother* 2010;**15**(6):190–4.
15. Borg J, Rogers DW. Spectra and air-kerma strength for encapsulated ^{192}Ir sources. *Med Phys* 1999;**26**(11):2441–4.
16. SonoTECH. *Flexiplan user's guide and tutorial, Version 2.5. Germany*; 2009.
17. Ghorbani M, Salahshour F, Haghparast A, et al. Effect of tissue composition on dose distribution in brachytherapy with various photon emitting sources. *J Contemp Brachyther* 2014;**6**(1):54–67.
18. Fazli Z, Sadeghi M, Zahmatkesh MH, et al. Dosimetric comparison between three dimensional treatment planning system. Monte Carlo simulation and gel dosimetry in nasopharynx phantom for high dose rate brachytherapy. *J Can Res Ther* 2013;**9**(3):402–9.
19. Yazdi HS, Shamsaei M, Jaberi R, et al. The effect of rib and lung heterogeneities on the computed dose to lung in Ir-192 high-dose-rate breast brachytherapy: Monte Carlo versus a treatment planning system. *J Can Res Ther* 2012;**8**(3):394–8.