Technical Note

Original paper

The effect of tandem-ovoid titanium applicator on points A, B, bladder, and rectum doses in gynecological brachytherapy using ^{192}Ir

Mohammad Hosein Sadeghi, MSc[1], Sedigheh Sina, PhD[1,2], Amir Mehdizadeh, MSc[1], Reza Faghihi, PhD[1,2], Vahed Moharramzadeh, PhD[1], Ali Soleimani Meigooni, PhD[3]

[1]Department of Nuclear Engineering, School of Mechanical Engineering, Shiraz University, Shiraz, Iran, [2]Radiation Research Center, Shiraz University, Shiraz, Iran, [3]Comprehensive Cancer Center of Nevada, Las Vegas, USA

Abstract

Purpose: The dosimetry procedure by simple superposition accounts only for the self-shielding of the source and does not take into account the attenuation of photons by the applicators. The purpose of this investigation is an estimation of the effects of the tandem and ovoid applicator on dose distribution inside the phantom by MCNP5 Monte Carlo simulations.

Material and methods: In this study, the superposition method is used for obtaining the dose distribution in the phantom without using the applicator for a typical gynecological brachytherapy (superposition-1). Then, the sources are simulated inside the tandem and ovoid applicator to identify the effect of applicator attenuation (superposition-2), and the dose at points A, B, bladder, and rectum were compared with the results of superposition. The exact dwell positions, times of the source, and positions of the dosimetry points were determined in images of a patient and treatment data of an adult woman patient from a cancer center. The MCNP5 Monte Carlo (MC) code was used for simulation of the phantoms, applicators, and the sources.

Results: The results of this study showed no significant differences between the results of superposition method and the MC simulations for different dosimetry points. The difference in all important dosimetry points was found to be less than 5%.

Conclusions: According to the results, applicator attenuation has no significant effect on the calculated points dose, the superposition method, adding the dose of each source obtained by the MC simulation, can estimate the dose to points A, B, bladder, and rectum with good accuracy.

J Contemp Brachytherapy 2018; 10, 1: 91–95
DOI: https://doi.org/10.5114/jcb.2018.74314

Key words: brachytherapy, tandem ovoid applicator, Monte Carlo simulations (MCNP5).

Purpose

Brachytherapy has been used as one of the standard modes of radiation therapy for cervical cancer, shortly after the discovery of radium. Dose prescription guidelines for cervical cancer brachytherapy are presented by the ICRU report No. 38, 89 [1,2]. Brachytherapy is an essential component of the treatment of locally advanced cervical cancers. It enables the dose to the tumor to be boosted, whilst allowing relative sparing of the normal tissues [3].

There are different applicator systems and prescription methods for gynecological brachytherapy. With the development of computed tomography (CT), magnetic resonance (MR) compatible applicators, and computerized 3D treatment planning, it is now possible to obtain much more detailed information about tumor coverage and dose to critical organs [4]. Tandem ovoid applicator is one of these applicators used in high-dose-rate brachytherapy. Calculation of absorbed dose distribution in a patient before treatment is one of the main steps in treatment planning of radiation therapy. In high-dose-rate (HDR) brachytherapy, the accuracy of calculation becomes an important issue because of the higher dose rate and prescribed dose per session [5,6]. Thus, inaccuracies in dose distribution measurement may lead to higher dose to healthy tissues or lower dose to the tumor. TG-43 algorithm is used in most brachytherapy treatment planning systems. The dosimetry parameters of each brachytherapy source can be obtained experimentally using efficient dosimeters, i.e. film and thermoluminescence dosimetry [7,8]. Monte Carlo simulations can also be used for obtaining the TG-43 parameters of the source. In the last decade, the MC method has been widely used in different brachytherapy techniques as a tool for validation of dose

Address for correspondence: Sedigheh Sina, PhD, Mollasadra Street, School of Mechanical Engineering, 7154897474 Shiraz, Iran, phone: +989172228349, fax: +987116473474, ✉ e-mail: samirasina@shirazu.ac.ir

Received: 08.07.2017
Accepted: 24.02.2018
Published: 28.02.2018

calculations for different patient anatomy and phantoms [9,10,11]. In-vivo measurements to determine doses to organs-at-risk can be an essential part of brachytherapy quality assurance (QA) [12]. The dosimetry procedures by simple superposition accounts only for the source shield and do not consider the attenuation of photons by the applicators. The purpose of this investigation is an estimation of the effects the tandem ovoid applicator on the dose distribution around ^{192}Ir brachytherapy source inside the phantom by MCNP5 Monte Carlo simulations.

Material and methods

HDR ^{192}Ir unit specifications

The MicroSelectron mHDR-v2r (MS-v2r) source (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) is simulated and used in this study. The source is composed of a cylindrical core of 3.5 mm length and 0.6 mm diameter. The source capsule is made of AISI 316L stainless steel with a density of 8.03 g/cm^3, with 4.95 mm total length, 0.9 mm diameter, and a hemispherical termination. The connection to the cable responsible for the source movement is through a truncated cone for adapting the different diameters. This cable is modeled as a cylinder with 0.7 mm diameter of AISI 314 stainless steel with a density of 4.81 g/cm^3 to account for the interlace responsible for its flexibility [13]. The source activity was 5.68 Ci in treatment time, and gamma energy that used in simulation was taken from Glasgow and Dillman [14]. The sources are presented in Figure 1.

Monte Carlo simulations

The MCNP5 Monte Carlo code was used for simulation of the phantoms, applicators, and the sources. The MCNP5 radiation transport code was used for MC calculations [15]. 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 active cores of the sources were considered as cylinders composed of ^{192}Ir with a uniform distribution of radioactive material. Table 1 shows the patient's treatment data, including dwell times and dwell positions of sources. The coordinates of the simulated sources are similar to this table.

Simulation geometry

To estimate the effects of tandem-ovoid on dose distribution, the MCNP simulations were performed with and without tandem-ovoid applicator. For dose calculations in phantom, a cubical water phantom with dimensions of 0.3 m × 0.3 m × 0.3 m was simulated. The ^{192}Ir source and the applicator set were imitated inside the phantom. To simulate the dose in absence of the applicator, for each dwell position, a Monte Carlo simulation was performed. Each time, the source was imitated in a specific dwell position, and the dose to each point in the body was obtained using tally F6 (F6 is tally order uses in MCNP5 code to calculate MeV/g – photon) and according to the following formula:

$$(1)\quad D_L(i,j,k) = F6\ (\mathrm{MeV}/(\mathrm{g}-\mathrm{photon})) \times A(\mathrm{dis/s}) \times \times \sum_m f_m\ (\mathrm{photon/dis}) \times t(\mathrm{s})$$

where $D_L(i, j, k)$ is the dose to a point with coordination of (i, j, k) located in the Lth dwell position in eV/g. *F6* is the MCNP result in MeV per gram per source particle. Σ_m fm is the number of particles emitted by the source in each disintegration, and t is the dwell time of the source in second. Finally, the dose values to different points of the phantom are obtained by the superposition method, as follows:

$$(2)\quad D(i,j,k) = \Sigma_L D_L(i,j,k)$$

In the next step, to imitate the effect of the applicator on dose distribution, the tandem-ovoid (the Titanium Fletcher-suit Delclos-style) applicator (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) was simulated. The Titanium Fletcher-suit Delclos-style applicator set is used for high-dose and pulse-dose-rate treatment of the uterus, cervix, endometrium, and vagina (Figure 2). Based on the traditional FSD design, the Titanium Fletcher-suit Delclos-style applicator is manufactured from titanium. The applicator features two colpostats, which can be used with interlocking tandems of angles

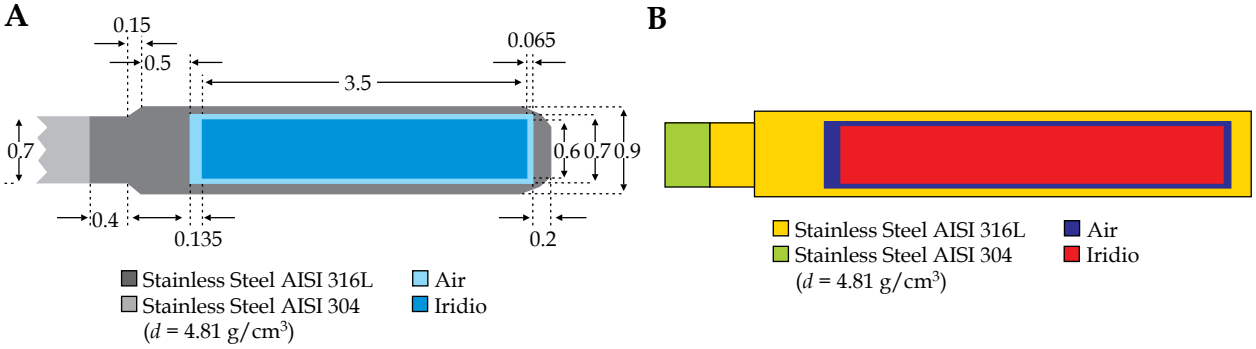

Fig. 1. Schematic diagram of **A)** MicroSelectron mHDR-v2r (MS-v2r) source; **B)** MicroSelectron mHDR-v2r (MS-v2r) source simulated with MCNP5 code, dimensions are in millimeters [13]

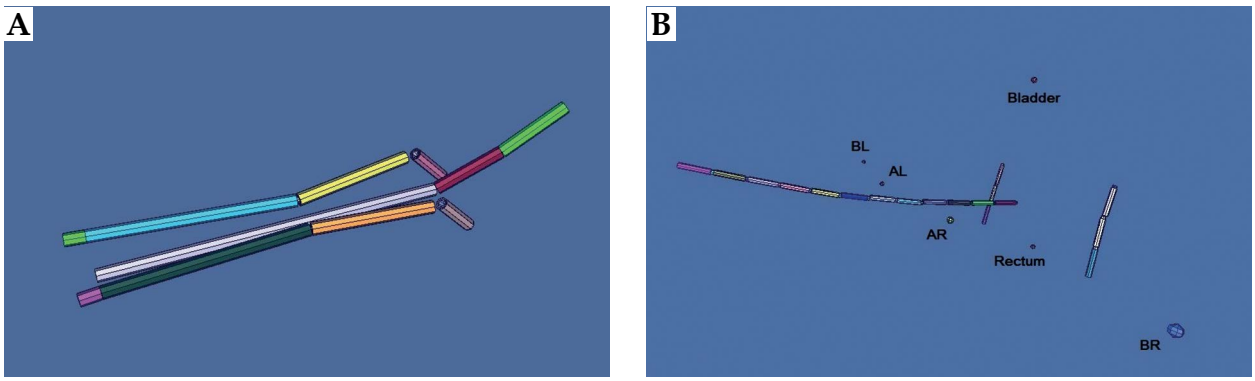

Fig. 2. A) The Titanium Fletcher-Suit Delclos-style applicator (T&O) simulated using MCNP5 code. **B)** The positions of simulated active sources in different dwell positions (3 dwell positions in each ovoid, and 12 in tandem), and the positions of points A, B, rectum, and bladder

15°, 30°, and, 45°. The tandem's intrauterine section is only 3 mm diameter and accessible tandem lengths are 20 mm, 40 mm, 60 mm, and 80 mm. Ovoid diameters are 20 mm, 25 mm, and 30 mm. The tandem angle was 30°, and the tandem length and diameter and ovoid diameter were 80 mm, 3 mm, and 20 mm, respectively, based on treatment data. The sources were simulated inside the applicator, according to the previous step. Each source was simulated separately, and the dose value were obtained according to equations 1 and 2. Experimental data are data from typical treatment of an adult woman. In this treatment, dwell positions and dwell times has been used for treatment of a patient (Table 1).

Results

The experimental data of a patient contains values of absorbed dose to points A and B, and rectum and bladder points were compared with the simulated values of dose in presence as well as in absence of the T&O applicators. Table 2 shows the calculated absorbed dose for each point in experimental and superposition method, with and without T&O applicator set. The data in the first row shows the experimental data from a typical treatment of a patient, the second row shows superposition data determined by MCNP5 simulation without simulation of tandem ovoid applicator, and the last row presents data

Table 1. The treatment data used for a patient, obtained from the treatment data of an adult woman patient

Position	Source number	Dwell position			Dwell time (sec)
		X (m)	Y (m)	Z (m)	
Tandem	1	0.0048	0.0884	0.0189	15.6
	2	0.0048	0.0842	0.016	31.2
	3	0.0048	0.0801	0.0132	22.4
	4	0.0049	0.0759	0.0104	20.1
	5	0.0049	0.0718	0.0077	24.7
	6	0.0049	0.0674	0.0052	34.4
	7	0.0049	0.063	0.0028	47.8
	8	0.005	0.0587	0.0004	57.2
	9	0.005	0.0541	–0.0017	55.3
	10	0.005	0.0496	–0.0038	45.7
	11	0.005	0.045	–0.0058	37.5
	12	0.005	0.0404	–0.0078	0.7
Ovoid right	1	–0.0149	0.0385	–0.0158	20.6
	2	–0.0149	0.0358	–0.0116	3.1
	3	–0.0149	0.0328	–0.0077	22.1
Ovoid left	1	0.0203	0.0383	–0.0146	20
	2	0.0199	0.0353	–0.0106	12.4
	3	0.0196	0.0323	–0.0067	19.9

Table 2. Absorbed dose for points A, B, bladder, and rectum

	Absorbed dose					
	Point A left	Point A right	Point B left	Point B right	Rectum	Bladder
Experimental data	598.11	591.76	137.91	130.69	460.39	355.26
Superposition-1 (without applicators)	584.92	573.41	134.36	128.42	466.32	353.22
Superposition-2 (with T&O applicator)	580.25	569.81	131.65	124.64	457.8	345.02

Table 3. The percentage difference between point dose calculation methods

	Point A left	Point A right	Point B left	Point B right	Rectum	Bladder
Experimental and superposition-1	2.205%	3.1%	2.574%	1.736%	1.271%	0.574%
Experimental and superposition-2	2.986%	3.709%	4.539%	4.629%	0.562%	2.882%
Superposition-1 and superposition-2	0.798%	0.627%	2.016%	2.943%	1.827%	2.321%

that were determined by MCNP5 simulation, considering tandem ovoid applicator.

According to the results obtained for the dose to the point A left (A_L), the percentage difference between experimental results and superposition-1 method, between superposition-1 and superposition-2 methods, and between experimental and superposition-2 methods are shown in Table 3 (range from 0.627% to 4.629%). The average value of all the percentages listed is 2.655%. The greatest difference is between experimental data and superposition-2 (with T&O applicator) but the difference in all important dosimetry points was found to be less than 5%.

Discussion

The number of cancer patients treated by brachytherapy have been increasing. With this treatment, high-dose can be delivered locally to the tumor, while the dose falls off rapidly in surrounding normal tissues. Because of the continuing improvement in the treatment planning system, dosimetry plays an important role in brachytherapy [16]. Brachytherapy has been a standard component of therapy for cancer for over 100 years. Although the Manchester system of prescribing to point A has been widely used in treatments with tandem and ovoids, several authors have questioned the accuracy of this planning method in terms of target coverage and dose to critical nearby structures [4,17,18]. In particular, the method described in ICRU report No. 38 emphasize dose distributions based on the visualization of the applicator and bony landmarks rather than coverage of the tumor and critical structures [4]. Several studies have shown ICRU prescription points to be underestimations of bladder and rectal maximum doses. The accuracy of using MCNP5 code for calculating the dose of organ at risk for gynecological brachytherapy was shown by Gifford *et al*. in 2005 [19]. In this study, the organ at risk dose was calculated by MCNP5 code. The MC calculations compared with experimental data has good accuracy for dose calculation, and there are no significant differences between the results of superposition method and other methods for different dosimetry points. The difference in doses between superposition-1 and superposition-2 is due to the absence of T&O applicator. Dose reduction in superposition-2 and superposition-1 is caused by the attenuation effect of the applicator presence. We tried to simulate the same conditions as experimental method in MC simulations. The difference in all important dosimetry points was found to be less than 5%. This difference is insignificant; based on ± 5% difference is predictable and negligible in all treatments used in brachytherapy according to system-guided tips [20,21,22].

Conclusions

The results of this study showed that applicator attenuation has no significant effect on the calculated points dose. The superposition method, adding the dose of each source obtained by the MC simulation, can estimate the dose to points A, B, bladder, and rectum points with good accuracy. The tandem-ovoid (the Titanium Fletcher-suit Delclos-style) applicator and the MicroSelectron mHDR-v2r (MS-v2r) ^{192}Ir source were the specific applicator and source that were used in a treatment of patient. Other kinds of applicators and sources that use in brachytherapy can be investigated in a similar study.

Disclosure

Authors report no conflict of interest.

References

1. ICRU report 38. Dose and Volume Specification for Reporting Intracavitary Therapy in Gynaecology. International Commission on Radiation Units and Measurements, Bethesda 1985.
2. ICRU report 89. Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix. International Com-

mission on Radiation Units and Measurements, Bethesda 2013.
3. Otter S, Franklin A, Ajaz M et al. Improving the efficiency of image guided brachytherapy in cervical cancer. *J Contemp Brachytherapy* 2016; 8: 557-565.
4. Fellner C, Pötter R, Knocke TH et al. Comparison of radiography and computed tomography-based treatment planning in cervix cancer in brachytherapy with specific attention to some quality assurance aspects. *Radiother Oncol* 2001; 58: 53-62.
5. Huh H, Kim W, Loh JJ et al. Rectum dose analysis employing a multi-purpose brachytherapy phantom. *Jap J Clin Oncol* 2007; 37: 391-398.
6. Sina S, Faghihi R, Meigooni AS et al. Impact of the vaginal applicator and dummy pellets on the dosimetry parameters of Cs-137 brachytherapy source. *J Appl Clin Med Phys* 2011; 12: 3480.
7. Anagnostopoulos G, Baltas D, Karaiskos P et al. An analytical dosimetry model as a step towards accounting for inhomogeneities and bounded geometries in 192Ir brachytherapy treatment planning. *Phys Med Biol* 2003; 48: 1625-1647.
8. Casal E, Ballester F, Lluch JL et al. Monte Carlo calculations of dose rate distributions around the Amersham CDCS-M-type 137Cs source. *Med Phys* 2000; 27: 132-140.
9. Sina S, Faghihi R, Meigooni AS et al. Developing a Treatment Planning Software Based on TG-43U1 Formalism for Cs-137 LDR Brachytherapy. *Iran Red Cresc Med J* 2013; 15: 712.
10. Mesbahi A. Radial dose functions of GZP6 intracavitary brachytherapy 60 Co sources: treatment planning system versus Monte Carlo calculations. *Iran J Radiat Res* 2008; 5: 181-186.
11. Ochoa R, Gómez F, Ferreira IH et al. Design of a phantom for the quality control of high dose rate 192 Ir source used in brachytherapy. *Radiother Oncol* 2007; 82: 222-228.
12. Oyekunle EO, Obed RI, Akinlade BI et al. Comparison of doses to the rectum derived from treatment planning system with in-vivo dose values in vaginal vault brachytherapy using cylinder applicators. *J Contemp Brachytherapy* 2015; 7: 485-491.
13. Granero D, Vijande J, Ballester F et al. Dosimetry revisited for the HDR 192Ir brachytherapy source model mHDR-v2. *Med Phys* 2011; 38: 487-494.
14. Glasgow GP, Dillman LT. Specific gamma-ray constant and exposure rate constant of 192Ir. *Med Phys* 1979; 6: 49-52.
15. Briesmeister JF. MCNPTM-A general Monte Carlo N-particle transport code. Version 4C, LA-13709-M, Los Alamos National Laboratory, 2000; 2.
16. Yu PC, Chao TC, Lee CC et al. A Monte Carlo dosimetry study using Henschke applicator for cervical brachytherapy. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 2010; 619: 411-414.
17. Kapp KS, Stuecklschweiger GF, Kapp DS et al. Dosimetry of intracavitary placements for uterine and cervical carcinoma: results of orthogonal film, TLD, and CT-assisted techniques. *Radiother Oncol* 1992; 24: 137-146.
18. Schoeppel SL, Lavigne ML, Martel MK et al. Three-dimensional treatment planning of intracavitary gynecologic implants: Analysis of ten cases and implications for dose specification. *Int J Radiat Oncol Biol Phys* 1994; 28: 277-283.
19. Gifford KA, Mourtada F, Cho SH et al. Monte Carlo calculations of the dose distribution around a commercial gynecologic tandem applicator. *Radiother Oncol* 2005; 77: 210-215.
20. Tanderup K, Hellebust TP, Lang S et al. Consequences of random and systematic reconstruction uncertainties in 3D image-based brachytherapy in cervical cancer. *Radiother Oncol* 2008; 89: 156-163.
21. Hellebust TP, Kirisits C, Berger D et al. Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group: considerations and pitfalls in commissioning and applicator reconstruction in 3D image-based treatment planning of cervix cancer brachytherapy. *Radiother Oncol* 2010; 96: 153-160.
22. Kertzscher G, Andersen CE, Siebert F-A et al. Identifying afterloading PDR and HDR brachytherapy errors using real-time fiber-coupled Al 2 O 3: C dosimetry and a novel statistical error decision criterion. *Radiother Oncol* 2011; 100: 456-462.