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

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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.

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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 interface 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 the 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:

$$D(i,j,k) = F6(\text{MeV/}(g\text{- photon})) \times \frac{A(\text{dis/s}) \times \sum m_{\text{particles}} \text{(photon/dis) \times t(s)}}{S_{\text{m}} f_{\text{m}} t}$$

where $D(i,j,k)$ is the dose to a point with coordination of $(i, j, k)$ located in the $L$-th dwell position in eV/g. $F6$ is the MCNP result in MeV per gram per source particle. $S_{\text{m}} f_{\text{m}}$ 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:

$$D(i,j,k) = \sum D(i,j,k)$$

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]
The effect of tandem-ovoid titanium applicator

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) |
|----------------|---------------|----------------|------------------|
| 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         | 0.0633           | 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          | 0.0451           | -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          | 20.0 |
|                | 2             | 0.0199         | 0.0353           | -0.0106          | 12.4 |
|                | 3             | 0.0196         | 0.0323           | -0.0067          | 19.9 |
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 Delcos-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.

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