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A comparison of treatment duration for Cobalt-60 and Iridium-192 sources with different activities in HDR brachytherapy using tandem-ovoid applicator

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ABSTRACT

Introduction: The long-half-life Cobalt-60 source with high dose rate (HDR) brachytherapy is an appropriate alternative to Iridium-192 (HDR) source in the treatment of GYN patients in developing countries. This study aimed to compare HDR cervical cancer treatment duration using Cobalt-60 and Iridium-192 sources for the Tandem-ovoid applicators.

Material and Methods: In the present study, BEBIG Cobalt-60 source model Co0.A86 and Iridium-192 source model mHDR-v2r were utilized. The treatment time required for both radionuclides was calculated using the TG-43 formalism. To calculate the treatment time for the Iridium source, the absorbed dose was used in the TG-43 formalism and treatment data. Then the dwell times were determined after repeating the calculations with Cobalt-60. Finally, the comparison was made for the treatment duration for the two sources.

Results: According to our findings, the treatment time for the cobalt source with the activity of 2.131 Ci is somehow the same as that of the iridium source with the activity of 5.690 Ci. If the maximum treatment duration is supposed to be 16 minutes in a treatment session, the effective time window for Iridium-192 is about 160 days. This is, however, the effective time window is 2000 days for Cobalt-60.

Conclusion: According to the findings, the use of Cobalt-60 instead of Iridium-192 is economically beneficial for equipment selection in newly constructed departments. Changes in the activities of Cobalt-60 in comparison with Iridium-192 requires editing the total treatment time of the treatment planning system for patients. Such editing may raise errors and reduce accuracy.

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Introduction

Brachytherapy has been introduced as an effective treatment for cervix, prostate, breast, endometrium, skin, esophagus, head and neck, and bronchus cancers and other types of cancer. This treatment modality has been extensively utilized in managing cervical cancer patients. Dramatic changes have been made in treatment planning systems (TPSs) and brachytherapy sources owing to extensively introducing high-dose-rate (HDR) after loading system. However, HDR brachytherapy systems have brought advantages different from the traditional low dose rate (LDR) brachytherapy treatments, including the potential for late toxicity caused by the large dose per fraction [1,2]. Accordingly, several studies have been performed to investigate the effects of the sources [3,4] and TPSs [5–8] on dose distribution in the LDR and HDR brachytherapy.

Moreover, the dosimetric data for the brachytherapy sources utilized as input information in TPSs were calculated for spherical water phantoms with various diameters [9]. The dosimetric features can be defined by appropriate experimental or theoretical modeling techniques [10,11], the most promising and the most popular of which is TG-43 since it utilizes the quantities determined in the medium to calculate dose rates [12–14]. So far, it has been technologically possible to produce small sources for HDR afterloading only for Iridium-192. The optimization of dose distributions for intracavitary treatments was achieved by the small size of the sources. Recently, the Cobalt-60 HDR sources have become accessible with identical geometrical dimensions similar to the miniaturized Iridium-192 sources [15,16]. This study compared the treatment duration for iridium and cobalt HDR sources in the brachytherapy treatment of cervical cancer utilizing the tandem and ovoid applicator. The treatment duration for the iridium and cobalt sources in different activities was calculated by TG-43 formalism.

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Materials and Methods

In this study, the BEBIG Cobalt-60 source model Co0.A86 and Iridium-192 source model mHDR-v2r were simulated. Geometrically, such sources are almost identical; hence, they are ideal for comparing the effects of the isotope choice. The iridium source comprised a cylindrical core with a length of 3.5 mm and a diameter of 0.6 mm. The source capsule made of AISI 316L stainless steel had an 8.03 g/cm^3 density. The total length and diameter of this source were 4.95 mm, and 0.9 mm, respectively. The connection to abraded cable enabled the source to move through the catheters and transfer tubes. In the dosimetric evaluation of this source, the cable was modeled as an AISI 314 stainless steel cylinder with a density of 4.81 g/cm^3 and a 0.7-mm diameter to account for the interlace associated with its flexibility [17].

The BEBIG Cobalt-60 brachytherapy source comprised a central cylindrical active core made of metallic Cobalt-60 with a 0.5-mm diameter and a length of 3.5 mm. A cylindrical stainless-steel capsule with a thickness of 0.15 mm and an external diameter of 1 mm covered the active core [18]. The geometric design and materials of the Iridium-192 source model mHDR-v2r and the new BEBIG Cobalt-60 source model Co0.A86 are illustrated in Figure 1.

The physical source parameters associated with the clinical use of the Cobalt-60 and Iridium-192 HDR sources were compiled. In this study, the dwell time, the dwell position of the Iridium-192 source, the activity of 5.69 Ci, and the dose to point A and point B were obtained from the treatment data of an adult woman patient in a cancer center (Tables 1 and 2). The collected data show the treatment of a patient with the iridium source. The TG-43 formalism is used to calculate the dose rate based on Equation (1).

$$\dot{D}\,(r,\theta) \;=\; S_k\,\Lambda\,\frac{G_L\,(r.\theta)}{G_L\,(r_0\,.\theta_0)}\,g_L\,(r)F(r,\theta) \qquad (1)$$

where, Λ is dose rate constant (cGy / U h; 1.112 ± 0.005 for Iridium-192 , and 1.084 ± 0.005 for Cobalt-60), S_k is Air kerma strength (mGy m2/h; 23.207 for Iridium-192 and 24.149 for Cobalt-60) , F(r,ɵ) is anisotropy function, g(r) is radial dose function, and G (r,ɵ) is geometry factor calculated by Equation (2):

$$G_L(r,\theta)=\begin{cases}\dfrac{\beta}{Lr\,\sin\theta} & \text{if}\quad \theta = \theta^\circ\\[2mm] \left(r^2-\dfrac{L^2}{4}\right)^{-1} & \text{If}\ \theta \neq \theta^\circ\end{cases} \qquad (2)$$

In this equation, L is the length of the source, r is the distance from middle of the source to the calculation point, P(r,ɵ). β is the angle, in radians, subtended by the tips of the hypothetical line source with respect to the calculation point, P(r,ɵ) [19–21]. F(r,ɵ) and g(r) are set based on previous studies [20, 21]. Figure 2 presents the coordinate system for brachytherapy dosimetry calculations to convert Cartesian (x,y,z) coordinates to (r,ɵ) coordinates in TG-43 formalism [19].

First, we compared the absorbed dose calculated by the TG-43 formalism regarding the treatment data to validate the formalism accuracy. The TG-43 formalism and the absorbed dose in the treatment data were used to calculate the treatment duration for the iridium source.

Table 1. Source dwell positions and dwell times obtained from TPS treatment data of an adult patient undergoing cervix brachytherapy using Iridium-192

Position	x(mm)	y(mm)	z(mm)	Time(sec)
Tandem	0.48	8.84	1.89	15.6
	0.48	8.42	1.6	31.2
	0.48	8.01	1.32	22.4
	0.49	7.59	1.04	20.1
	0.49	7.18	0.77	24.7
	0.49	6.74	0.52	34.4
	0.49	6.3	0.28	47.8
	0.5	5.87	0.04	57.2
	0.5	5.41	-0.17	55.3
	0.5	4.96	-0.38	45.7
	0.5	4.5	-0.58	37.5
	0.5	4.04	-0.78	0.7
Ovoid Right	-1.49	3.85	-1.58	20.6
	-1.49	3.58	-1.16	3.1
	-1.49	3.28	-0.77	22.1
Ovoid Left	2.03	3.83	-1.46	20
	1.99	3.53	-1.06	12.4
	1.96	3.23	-0.67	19.9

Table 2. Points A and B absorbed doses obtained from the TPS for a typical treatment of an adult woman patient

Point	x(mm)	y(mm)	z(mm)	Abs. Dose (cGy)
B Right	-45.9	55.6	-1.9	130.69
B Left	53.4	56.1	3.9	137.91
A Right	-15	58.4	0.9	591.76
A Left	24.7	58.4	1.4	598.11

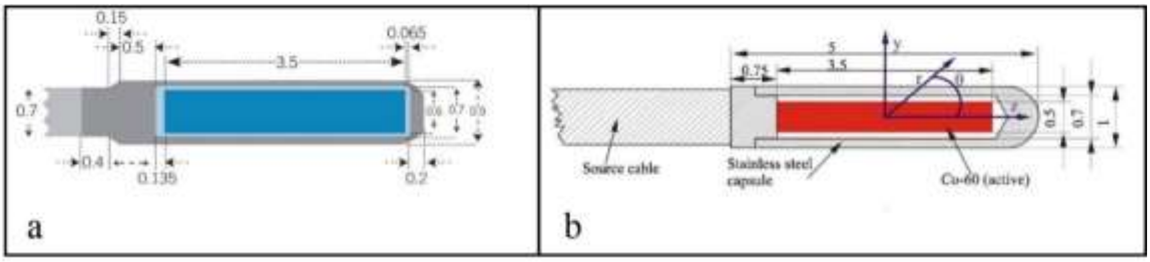

Figure 1. Sources geometries. Dimensions are in mm. (a) Iridium-192 source model mHDR-v2r and (b) BEBIG Cobalt-60 source model Co0.A86 [20,21]

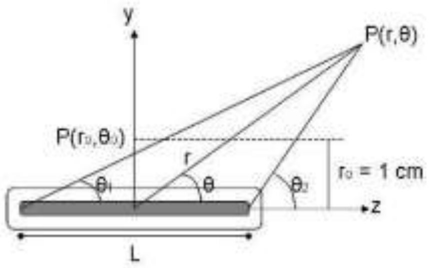

Figure 2. Coordinate system for brachytherapy dosimetry calculations [19].

Then there were calculations for different activities. If the maximum treatment duration is supposed to be 16 minutes in a treatment session, each complete treatment for a patient traditionally lasts five sessions (about one month). According to the half-lives of the Iridium-192 and Cobalt-60 sources, two different time windows (the time interval between source calibration date (written in the source certificate) and treatment time) were considered: 280 days for Iridium-192 and 3000 days for Cobalt-60. The activities at each time were calculated using Equation (3).

$$A = A_0 e^{-\frac{0.693}{T^1/_2} * t} \quad (3)$$

Where, A is activity at the time selected from the time window, A_0 is activity after the first source loading, $T\frac{1}{2}$ is the half-life, and t is the time selected from the time window.

The equivalent activity of the Cobalt-60 source was obtained by giving the same dose as the Iridium-192 to points A_L. The dose to point A_L was used to calculate the treatment time in this study. Then the treatment durations of the two sources with different activities were compared.

Equation (4) was used to calculate the treatment duration using the brachytherapy source:

$$S_k = A\,\Gamma_{AKR} \quad (4)$$

where, S_k is air kerma strength, A is activity, and Γ_{AKR} is air kerma rate constant.

$$D = A\,t\,X \quad (5)$$

In this regard,

$$(\Gamma_{AKR}\,\Lambda\,\frac{G_L(r.\theta)}{G_L(r_0.\theta_0)}\,g_L(r)F(r,\theta)) = X \quad (6)$$

where, D is absorbed dose, A is activity, t is total treatment time, and X is a constant set based on the TG-43 formalism. In the patient's treatment, 12 dwell positions in the tandem and six dwell positions in the ovoid were used. Hence, Equation (5) can be written as:

$$D = A\,(t_1 X_1 + t_2 X_2 + \cdots + t_{18} X_{18}) \quad (7)$$

Results

According to the dwell times and dwell positions of the sources used for the patient's treatment, as shown in Table 1, the dose of the iridium sources and the total absorbed dose to points A_L were calculated using the TG-43 formalism and compared with the absorbed doses obtained from the treatment data.

Table 3. Dose to point A_L for patients using TG-43 parameters of Iridium-192 source

		Iridium source							Sk (U)		
point A Left		r (cm)	ɵ	F(r,ɵ)	g (r)	Λ (cGy/U h)	Γ (cGy cm² /h Ci)	A (Ci)	Time (hr)	Dose (cGy)	A_L
	position										
tandem	1	4.0020	139	0.9580	1.0110	1.1120	4082	5.6900	0.0043	6.8270	
	2	3.5700	136	0.9620	1.0090	1.1120	4082	5.6900	0.0087	17.2170	
	3	3.1720	133	0.9670	1.0070	1.1120	4082	5.6900	0.0062	15.7110	
	4	2.7920	129	0.9730	1.0060	1.1120	4082	5.6900	0.0056	18.2920	
	5	2.4720	123	0.9870	1.0050	1.1120	4082	5.6900	0.0069	29.0310	
	6	2.2080	114	0.9950	1.0040	1.1120	4082	5.6900	0.0096	51.0080	
	7	2.0380	103	0.9990	1.0030	1.1120	4082	5.6900	0.0133	83.3730	
	8	1.9730	91	1.0000	1.0030	1.1120	4082	5.6900	0.0159	106.4650	
	9	2.0400	78	0.9970	1.0030	1.1120	4082	5.6900	0.0154	96.0170	
	10	2.2190	67	0.9900	1.0040	1.1120	4082	5.6900	0.0127	66.7030	
	11	2.4890	57	0.9810	1.0050	1.1120	4082	5.6900	0.0104	43.2240	
	12	2.8230	50	0.9730	1.0060	1.1120	4082	5.6900	0.0002	0.6230	
	right										
ovoid	2	4.7540	65	0.9910	1.0040	1.1120	4082	5.6900	0.0057	6.5660	
	3	4.7410	62	0.9880	1.0040	1.1120	4082	5.6900	0.0009	0.9900	
	4	4.8020	58	0.9850	1.0040	1.1120	4082	5.6900	0.0061	6.8620	
	left										
ovoid	2	2.6070	40	0.9510	1.0060	1.1120	4082	5.6900	0.0056	20.4360	
	3	2.6470	29	0.9170	1.0060	1.1120	4082	5.6900	0.0034	11.8570	
	4	2.7800	20	0.8620	1.0060	1.1120	4082	5.6900	0.0055	16.2230	
									Total treatment time 0.1360	Total dose 597.4250	

Table 4. Points A and B absorbed doses and percentage difference between absorbed doses of treatment data (table 2) and TG-43 formalism for iridium sources

	Absorbed dose (cGy)			
	Point A Left	Point A Right	Point B Left	Point B Right
Treatment data	598.11	591.76	137.91	130.69
TG-43 formalism	597.42	587.98	137.57	130.09
percentage difference	0.12%	0.64%	0.25%	0.46%

Table 5. Dose to point A_L for patients using TG-43 parameters of Cobalt-60 source. The equivalent activity for Cobalt-60, to give the same dose to point A_L of the patient as 5.69 Ci Iridium-192, is 2.131 Ci.

point A Left		r (cm)	ө	F(r,ө)	g (r)	Λ (cGy/U h)	Γ (cGy cm^2 /h Ci)	Dwell Time (hr)	Dose A_L (cGy)
	position								
tandem	1	4.0020	139	0.9960	0.9519	1.0840	11330	0.0043	6.8270
	2	3.5704	136	0.9960	0.9588	1.0840	11330	0.0087	17.2170
	3	3.1720	133	0.9970	0.9652	1.0840	11330	0.0062	15.7110
	4	2.7916	129	0.9983	0.9713	1.0840	11330	0.0056	18.2920
	5	2.4724	123	0.9986	0.9764	1.0840	11330	0.0069	29.0310
	6	2.2079	114	0.9995	0.9806	1.0840	11330	0.0096	51.0080
	7	2.0375	103	1.0000	0.9833	1.0840	11330	0.0133	83.3730
	8	1.9728	91	1.0000	0.9844	1.0840	11330	0.0159	106.4650
	9	2.0401	78	1.0000	0.9833	1.0840	11330	0.0154	96.0170
	10	2.2194	67	0.9995	0.9804	1.0840	11330	0.0127	66.7030
	11	2.4890	57	0.9986	0.9761	1.0840	11330	0.0104	43.2240
	12	2.8226	50	0.9980	0.9708	1.0840	11330	0.0002	0.6230
	right								
ovoid	2	4.7540	65	0.9987	0.9394	1.0840	11330	0.0057	6.5660
	3	4.7412	62	0.9984	0.9400	1.0840	11330	0.0009	0.9900
	4	4.8024	58	0.9980	0.9391	1.0840	11330	0.0061	6.8620
	left								
ovoid	2	2.6065	40	0.9950	0.9742	1.0840	11330	0.0056	20.4360
	3	2.6470	29	0.9929	0.9736	1.0840	11330	0.0034	11.8570
	4	2.7800	20	0.9850	0.9715	1.0840	11330	0.0055	16.2230
								Total treatment time 0.1360	Total dose 597.4250

Tables 3 presents the TG-43 parameters used to calculate the dose of Iridium-192 for the activity of 5.69 Ci in treating the patient. To validate the results in Table 3, the percentage difference between the results of dose calculations and the treatment data were compared. According to Table 4, the percentage difference between the calculations based on the TG-43 formalism and the treatment data was <1% for points A and B.

After validating the calculations, the equivalent activity of Cobalt-60 was calculated for the same dwell time, dwell positions, and absorbed dose as those of iridium source (Table 5). According to the tables, the activity of 2.131 Ci of Cobalt-60 is equivalent to 5.69 Ci of Iridium-192.

Tables 3 and 5 illustrate the treatment durations for the iridium and cobalt sources in different activities, calculated by Equation (7).

The treatment duration of different activities and different time windows for Iridium-192 and Cobalt-60 are illustrated in Figure 3 and Tables 6 and 7. The treatment durations were calculated for 280 days and 3000 days after the first source loading for Iridium-192, and Cobalt-60 sources, respectively, assuming that the Bebig Cobalt-60 source was loaded with an activity of 2.2 Ci, and Iridium-192 was loaded with an activity of 13 Ci [22]. As expected, Cobalt-60 can be used for a longer duration because of its longer half-life.

Accordingly, if the maximum acceptable treatment duration is supposed to be 16 minutes, the effective time window (the maximum time interval between source calibration date (written in the source certificate) and treatment time when the sources have to be replaced with new ones) for the patient treatment with Iridium-192 and Cobalt-60 are 160 days and 2000 days, respectively.

Discussion

This study indicated the better performance of cobalt source in HDR brachytherapy compared to the Iridium source due to the longer half-life of the former (i.e., 1925 days for Cobalt-60 vs. 73.82 days for Iridium-192). The outlook of decreased costs would be of great interest in financial considerations owing to fewer source exchanges. However, one of the points to be considered is the energy of sources. Both Cobalt-60 and Iridium-192 sources are high-energy photon-emitting brachytherapy sources, which include different energy spectra with the mean photon energy values of 0.355 MeV and 1.253 MeV for Iridium-192 and Cobalt-60 sources, respectively. These differences affect the radiation protection aspects of the treatments. The more energy the photon requires, the thicker the shielding material for the treatment and treatment rooms are. Accordingly, much heavier source housing is required by a treatment unit with the Cobalt-60 source. There is an immense potential for Cobalt-60 as an alternative to Iridium-192 for recently made departments for which the required equipment is still being selected. Typically, the decay of the Iridium-192 source is 1% of the whole activity per day; however, it is 1% per month for the Cobalt-60 source because of the difference in half-lives of the sources. Accordingly, we have to edit treatment planning for a patient every session because of the variations in the Iridium-192 source activities. The treatment planning editing can cause errors and reduce accuracy. If the total treatment time for a patient is five sessions (about one month) according to use one Cobalt-60 source instead of 12 Iridium-192 sources, the problems about editing the treatment planning solved. Note that the doses taken by the patient in treatment with both sources are the same because they are high dose rates.

From an economic perspective, remarkable financial saving is obtained from Cobalt-60 source replacements per five years in comparison to Iridium-192 replacements per four months. Palmer et al. [23] indicated that the irradiation time per patient for the five-year usage of the Cobalt-60 source is 25% higher on average than that for the Iridium-192 sources. Nevertheless, by including ancillary activities and patient set-up time in the total patient treatment time, which are of course independent of source type, a 10% decrease is found in increasing the percentage of total patient-time for Cobalt-60 compared to Iridium-192.

In this study, the difference in absorbed doses calculated by the TG-43 formalism and the treatment data was <1%. System-guided tips ±5% difference is predictable and negligible in all treatments used in brachytherapy; hence, the observed difference (<1%) is nonsignificant [24,25]. According to the findings, the effective time window for Iridium-192 is 160 days, and then the source has to be replaced with a new one. For the Cobalt-60 source, the effective time window is 2000 days. This implies that using one Cobalt-60 source is equal to about 12 Iridium-192 sources.

Conclusion

Many radionuclides have been used as the brachytherapy sources; however, only a few ones are now common. The brachytherapy sources are characterized by their half-lives, specific activities, and energy spectrum [26].

Above 150 radiotherapy centers are currently operating worldwide, which use the Cobalt-60 sources in modern high dose-rate (HDR) brachytherapy treatment units. In such novel systems, the miniaturized Cobalt-60 sources are used instead of the traditional Iridium-192 sources. They are now more popular because of longer source replacement intervals, lower operating costs, and the decreased movement frequency of radioactive sources across countries, compared to Iridium-192 [27].

If the source has a long half-life, the decay of the source during the treatment period may not be considered explicitly in calculating the dose. Both the Cobalt-60 and Iridium-192 isotopes have been widely used in brachytherapy. Now, a large number of HDR afterloading units armed with the Cobalt-60 or Iridium-192 sources exist. Recently, the Cobalt-60 sources have become available with identical geometrical dimensions similar to the miniaturized Iridium-192 sources. These two radionuclides represent various physical characteristics; however, Cobalt-60 has exhibited economic and logistical advantages [15].

According to the results of this study, the use of Cobalt-60 instead of Iridium-192 is economically beneficial for the brachytherapy departments. However, the changes in the treatment time should be considered, and the effective time window of the two sources should be considered carefully.

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