


Review

Comparative Analysis of ^{60}Co and ^{192}Ir Sources in High Dose Rate Brachytherapy for Cervical Cancer

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Simple Summary: High-dose-rate (HDR) brachytherapy (BT) is an effective treatment for bulky, middle, and advanced cervical cancer. Both ^{192}Ir and ^{60}Co are radiation sources recommended by the ICRU. Previously, due to the large geometric size of ^{60}Co , ^{192}Ir occupied most of the market share. After continuous technical improvements, the geometry of miniaturized ^{60}Co sources has become comparable to that of ^{192}Ir sources. Another important point is that people suspect that the use of ^{60}Co sources will result in reduced efficacy, increased toxic reactions, and a series of issues. In this paper, we compared ^{60}Co and ^{192}Ir sources for HDR BT in terms of both dosimetry and clinical treatment. The results of reports published on the use of HDR BT for cervical cancer over the past few years as well as our own research show that this treatment is safe and ^{60}Co can be promoted as a good alternative to ^{192}Ir .

Abstract: High-dose-rate (HDR) brachytherapy (BT) is an essential treatment for cervical cancer, one of the most prevalent gynecological malignant tumors. In HDR BT, high radiation doses can be delivered to the tumor target with the minimum radiation doses to organs at risk. Despite the wide use of the small HDR ^{192}Ir source, as the technique has improved, the HDR ^{60}Co source, which has the same miniaturized geometry, has also been produced and put into clinical practice. Compared with ^{192}Ir (74 days), ^{60}Co has a longer half-life (5.3 years), which gives it a great economic advantage for developing nations. The aim of the study was to compare ^{60}Co and ^{192}Ir sources for HDR BT in terms of both dosimetry and clinical treatment. The results of reports published on the use of HDR BT for cervical cancer over the past few years as well as our own research show that this treatment is safe and it is feasible to use ^{60}Co as an alternative source.

Keywords: ^{60}Co ; ^{192}Ir ; cervical cancer; high-dose-rate brachytherapy

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1. Introduction

High-dose-rate (HDR) brachytherapy (BT) is a significant component of radiotherapy. The unique aspect of this treatment is that the radiation source needs to be placed inside the part to be treated. This ensures a higher radiation dose is transmitted to the center of the tumor target, while the dose given to the surrounding area decreases rapidly. This can better protect the organs at risk (OARs) [1–5]. As many patients are already in the advanced stage of cervical cancer after their first consultation and have lost the opportunity for operation, the mortality and incidence rates of cervical cancer are increasing year by year [6,7]. Depending on the specific condition of these patients, in addition to the commonly used first-line treatment, including surgery, radiotherapy, and chemotherapy, targeted therapy and tumor immunotherapy are also research hotspots in recent years. However, few second-line treatment options are available in the event of disease progression, and improvements

in overall survival or disease-free progression rate are not sufficiently pronounced [8,9]. HDR BT is widely accepted as an effective treatment method [10]. However, because of concerns, including the steep dose gradient and fluctuating dose absorption in the tumor and normal tissues, HDR BT is still facing a number of dosimetric challenges [11,12]. Consequently, obtaining the dose distribution around the brachytherapy source is crucial from a clinical standpoint.

The International Commission on Radiation Units and Measurement (ICRU) report 89 recommends ^{60}Co and ^{192}Ir as HDR BT sources [13]. In the early days, because the geometry of the ^{60}Co source was larger compared to that of the ^{192}Ir source, doctors preferred the use ^{192}Ir as the primary HDR radiation source in clinical practice. Nevertheless, ^{60}Co has a long half-life and only needs to be replaced about every 5 years. While ^{192}Ir has a half-life of 74 days, it has obvious advantages in terms of human resources, logistics, and economics. The ^{60}Co source is certainly more cost-effective for developing countries [14–18]. As the technology is being updated and developed continually, there is growing concern about the application of the miniaturized ^{60}Co source, so the physical properties and dosimetric parameters of ^{60}Co have been continuously studied. One important point is that the energy of ^{60}Co (1.25 MeV) is higher than that of ^{192}Ir (0.38 MeV), and people suspect that the use of ^{60}Co sources will result in reduced efficacy, increased toxic reactions, and a series of issues, such as determining how to carry out radiation protection.

In this study, we summarize papers on the dose distribution and clinical applications of the HDR ^{192}Ir and ^{60}Co radiation sources in brachytherapy for cervical cancer published by other medical centers in recent years. The two main devices considered for equipment are ^{192}Ir (Nucletron microSelectron HDR-version 2 (mHDR-V2)) and ^{60}Co (Eckert & Ziegler BEBIG Corporation (Co0.A86)), which are the devices used by our center. We compare our findings with other research results to analyze whether there is a significant difference in treatment between ^{192}Ir and ^{60}Co and provide a reference for clinical workers.

2. Dosimetric Parameters

Many medical HDR BT resources are currently available. All aspects of the source's design, composition, and parameters are provided by the manufacturer. The American Association of Physicists in Medicine (AAPM) Task Group 43 (TG-43) recommends that the dose distribution of brachytherapy sources is acquired by experimentation or by using Monte Carlo algorithms. Monte Carlo (MC) algorithms are considered the “gold standard” for radiation therapy dose calculation. The use of MC allows for accurate dose prediction, especially in highly complex and heterogeneous environments, such as human tissue. It is vital to determine the dose characteristics of brachytherapy sources. It is necessary to conduct a dosimetric analysis based on the TG-43 report in order to validate the input simulation results. Previously, Granero et al. obtained ^{60}Co and ^{192}Ir source dose rate distribution data for modern brachytherapy using Monte Carlo methods [15]. Several other researchers have also published their dosimetric parameters for ^{60}Co , which are consistent with published data [19–21]. For single ^{192}Ir and ^{60}Co sources, by comparing anisotropy and the radial dose function, it was found that the actual dose deposition of ^{60}Co has no obvious advantages or disadvantages compared with ^{192}Ir [22,23]. A report from AAPM and ESTRO was published in 2012. This recommends dose characteristics for sources of photon-emitting brachytherapy with an average emitted energy above 50 keV, which made it possible to establish the source coordinate system for ^{192}Ir and ^{60}Co (Figure 1).

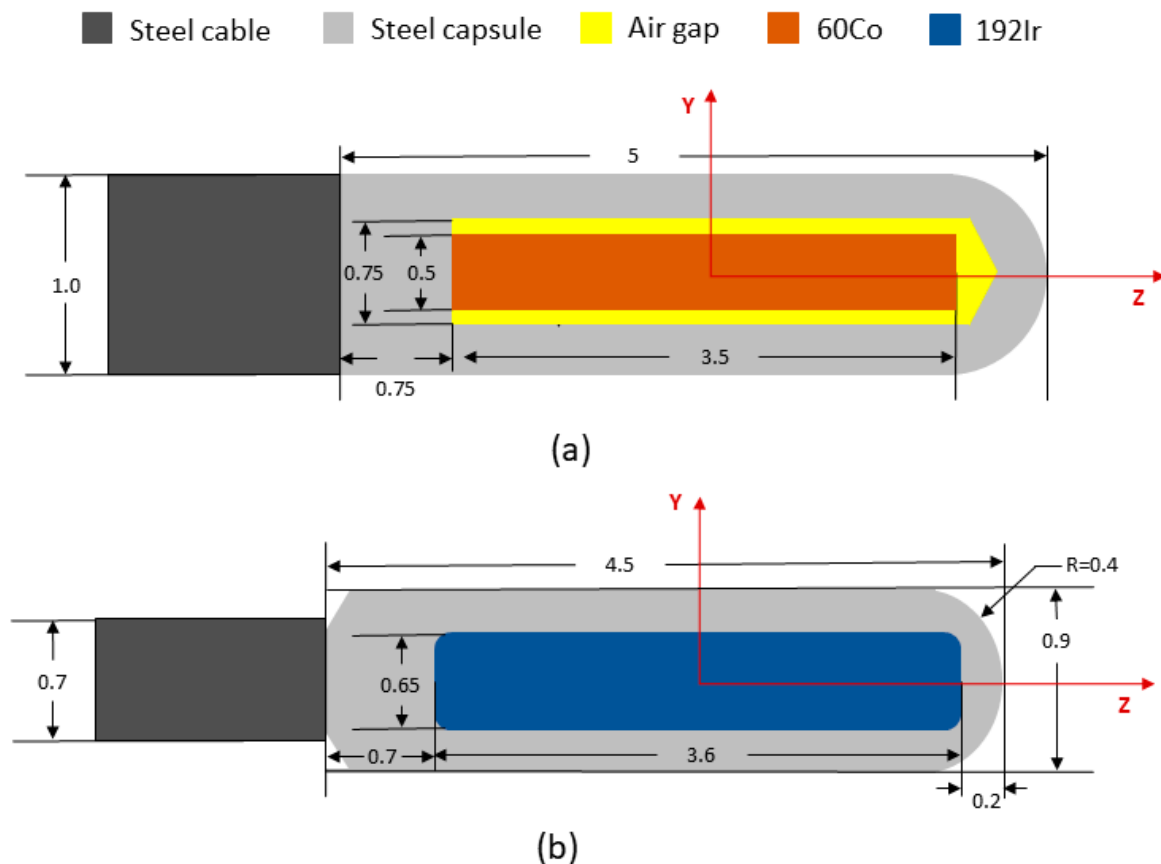


Figure 1. Reference coordinate system and schematic diagram of the model for ^{60}Co and ^{192}Ir . Dimensions are in millimeters. (a) E&Z Bebig HDR ^{60}Co model Co0.A86 source; (b) Nucletron HDR ^{192}Ir model mHDR-v2r.

We normalized the recommended dose rate parameters for both sources at the dose reference point (1 cm) and reduced them to the coordinate system (Figure 2). The figures produced show that ^{60}Co and ^{192}Ir have similar dose distribution trends with ^{60}Co producing higher dose rates at a distance from the source of less than 1 cm and ^{192}Ir producing higher dose rates at a distance from the source of more than 1 cm. This indicates that the dose gradient of ^{60}Co is greater than that of ^{192}Ir , as also confirmed by Safigholi et al. [24]. The ^{60}Co source has a faster dose rate decrease and may provide better protection to surrounding OARs. For the majority of points more than 10 mm away from the source center, even if the source step is changed, Farhood et al. concluded that the dose distributions of both sources are stable and, therefore, can be substituted for each other [25]. Dayyani et al. found slightly larger hot spots within the clinical target volume (CTV) when using the ^{60}Co source, possibly due to the steeper dose gradient of ^{60}Co . The dose values for ^{60}Co were higher than those of ^{192}Ir in this area but lower outside when the same dose was delivered to the CTV perimeter (4 cm from the source) [26]. This matched the features of the dataset. Meanwhile, we used the Oncentra treatment planning system (TPS) to place a single source in the plans of ^{192}Ir and ^{60}Co , respectively, and normalized the isodose line at the dose reference point ($\theta = 90^\circ$, $y = 1$ cm). As shown in Figure 3, within a distance of less than 25 mm from the source, it is apparent that there is little difference in the dose distribution of the two sources.

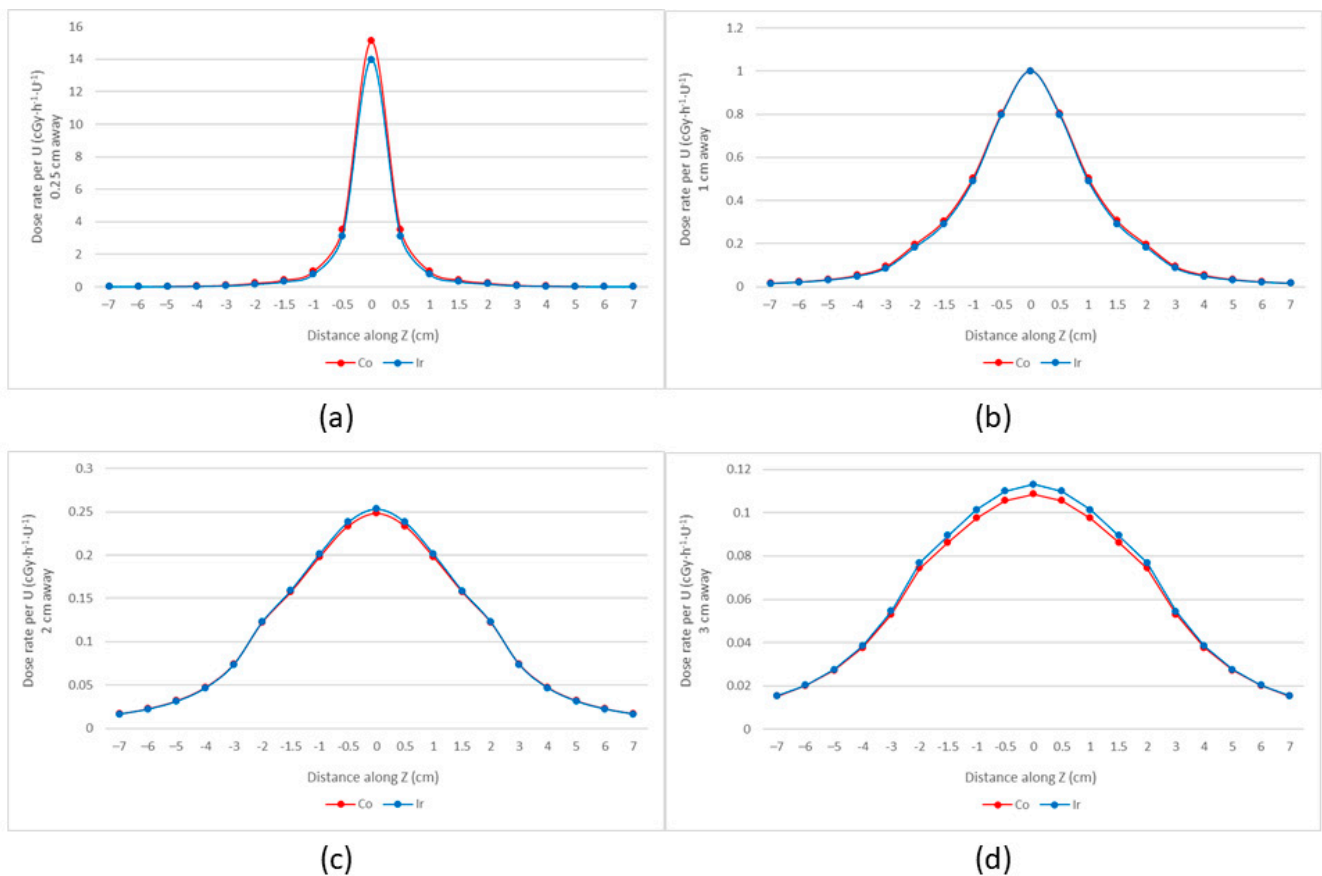


Figure 2. Dose rates of ^{192}Ir (mHDR-V2) and ^{60}Co (Co0.A86) (normalized at $y = 1$ cm). (a) $y = 0.25$ cm; (b) $y = 1$ cm; (c) $y = 2$ cm; (d) $y = 3$ cm. The ^{60}Co source produced higher dose rates at a distance from the source of less than 1 cm, while the ^{192}Ir source produced higher dose rates at a distance from the source of more than 1 cm.

At most corresponding points, the dose distributions of the two sources are comparable given the same step length within a certain distance from the source. However, in addition to the size and distance from the radiation source, tissue absorption and scattering also affect the dose distribution surrounding the radiation source. The dose distribution of a radioactive source generally follows the inverse square law close to the source. But at higher distances, both absorption and scattering processes affect the dose distribution. Absorption by human tissue results in a reduction in the actual dose, while scattering increases the dose. In most places within 10 cm from the source's center, the reference value provided by the data set is consistent with the actual dose distribution of the two sources. The dose inhomogeneity of the ^{60}Co source is greater than that of the ^{192}Ir source at 15 cm from the source [25]. The difference between ^{60}Co and the published datasets in the area above 20 cm can be as high as 43.16% [19]. The ^{192}Ir source has a slightly higher dose value. This is due to the fact that the TG-43U1 form's dosimetry calculation assumes that the patient is made out of water with a uniform density and ignores the heterogeneity of tissues in different parts of the human body. For example, the dose distribution of the radiation source is slightly different between bone, adipose tissue, and tumor tissue. Therefore, in the actual application process, the researchers' detection of a radiation source will not have the same dosimetric characteristics as the data set. In this case, treating the patient according to the value calculated by TPS may lead to the tumor receiving an insufficient dose. Having too high or too low of a dose may lead to tumor recurrence or other side effects, thereby reducing the treatment efficacy [27,28].

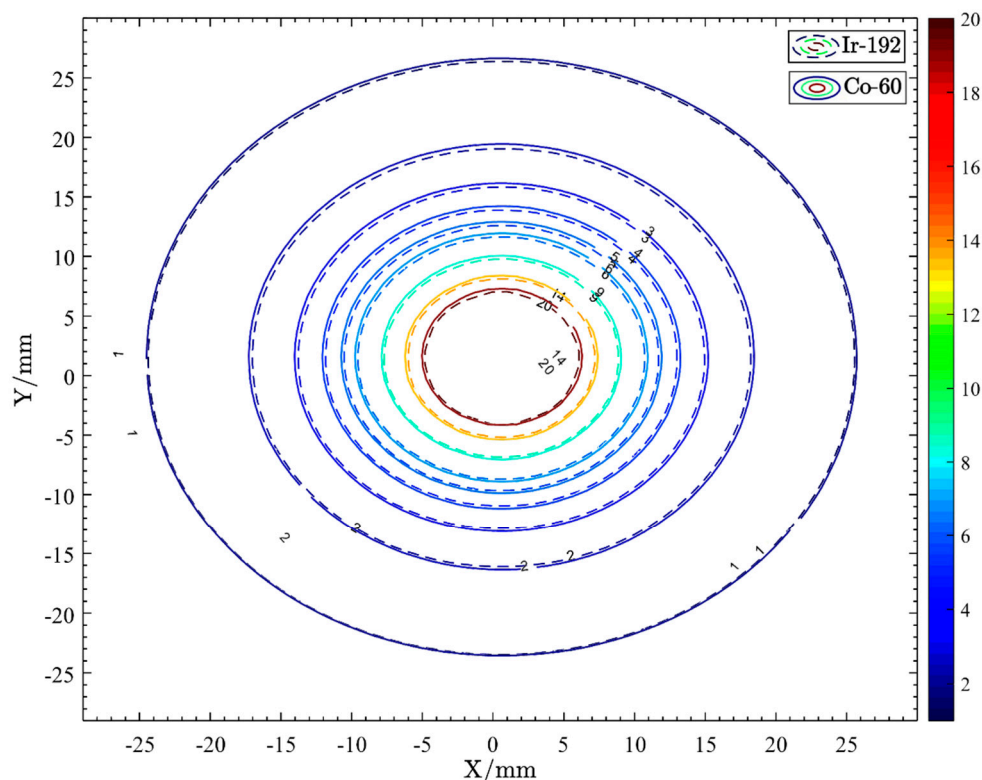


Figure 3. Isodose line of single points of ^{192}Ir and ^{60}Co .

3. Two-Dimensional Brachytherapy

For a long period of time, treatment of cervical cancer had to rely on X-ray-guided two-dimensional (2D) HDR BT. The ICRU 38 report specified the prescription reference point and the bladder and rectal reference points as the method of dose assessment. The current traditional 2D HDR BT method uses point A as the dose reference point (point A, i.e., 2 cm vertically upward of the vaginal vault, intersects with the uterus 2 cm left and right outside the central axis, anatomically equivalent to the intersection of the uterine artery and ureter). Point B is located at the point extending horizontally outward 3 cm from point A. According to the Manchester system of the source distribution, each position should be determined with the same dwell time to obtain the classical pear-shaped distribution curve. Dose control for tumors or OARs is not accurate, because target areas and OARs are not outlined. However, the report specifies dose reference points for the bladder and rectum with an aim of minimizing the exposure dose to OARs.

We made 2D HDR BT plans of ^{192}Ir and ^{60}Co sources on the same patient's CT. The reference points of the rectum and bladder were defined according to ICRU 38, and the prescribed dose at point A was 6 Gy with no more than 60–70% of the dose at point A being delivered to the rectum and bladder. The dose distribution in the coronal plane of the uterine cavity is shown in Figure 4. The dose distribution of ^{60}Co in the cephalocaudal direction is more prominent, while that in the horizontal direction is slightly more adducted than ^{192}Ir , and ^{60}Co at the rectum provides a higher dose [29]. Data from Palmer et al. showed no statistically significant difference in high-risk clinical target volume (HRCTV) D90 (dose to 90% volume) and also no significant difference in bladder reference points between the two 2D HDR BT treatment plans of ^{60}Co and ^{192}Ir ; however, the rectal reference point dose was significantly higher for ^{60}Co compared with that for ^{192}Ir (+3.3% ($p < 0.01$) and +2.2% ($p = 0.03$), respectively) [29]. Park et al. made 2D HDR BT treatment plans using ^{60}Co (BEBIG) and ^{192}Ir (microselectron) and found that, compared with ^{192}Ir , the dose distribution of the ^{60}Co source was $5.6 \pm 0.23\%$ lower at point B, $0.83 \pm 1.48\%$ higher at the rectal reference point, and $1.14 \pm 0.61\%$ lower at the bladder reference point [23]. We

consider that this may be due to the inherent physical properties of the two sources, which can be continuously optimized to narrow the gap between them.

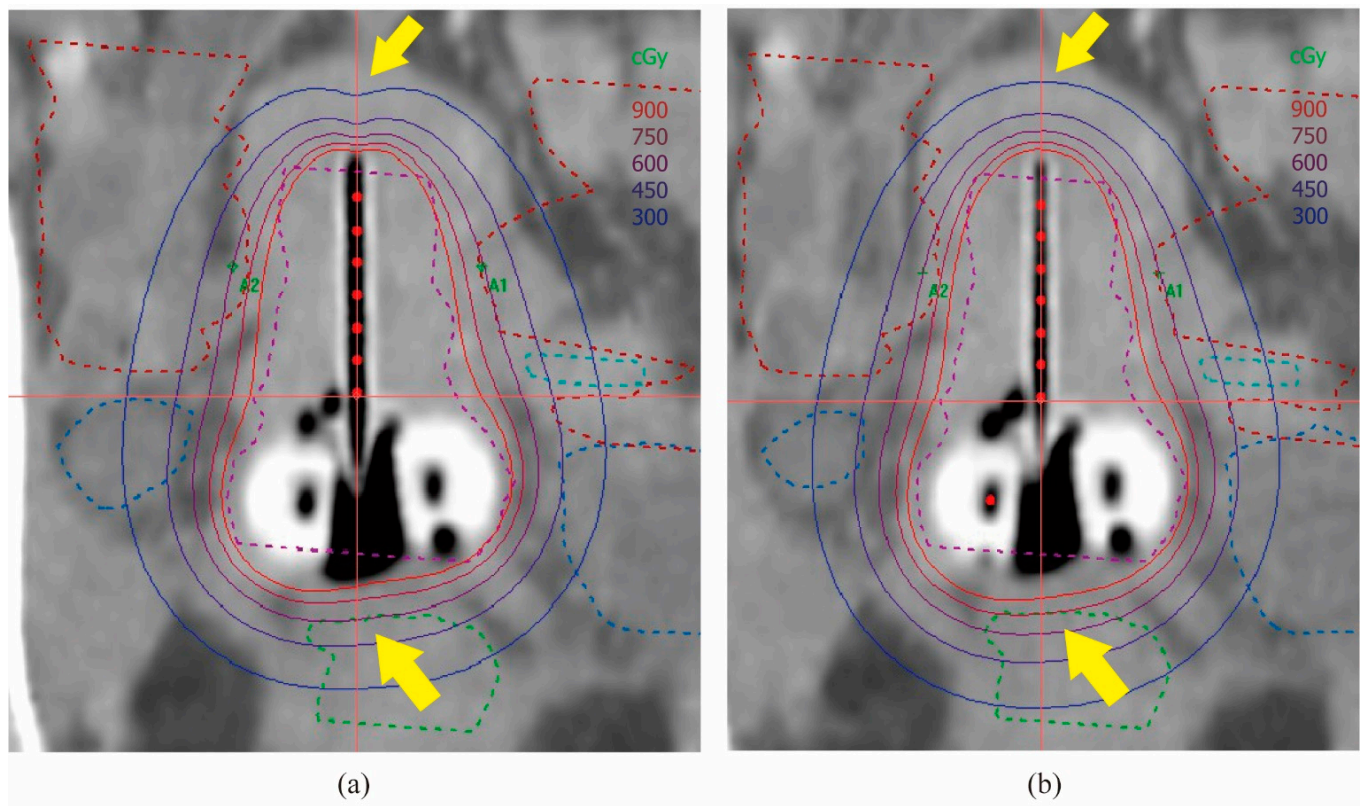


Figure 4. (2D HDR BT) Distribution of isodose lines in the transseptal canal's coronal plane. (a) 192Ir; (b) 60Co. As indicated by the arrows, 60Co was more prominently distributed in the cephalocaudal direction and provided a higher dose in the rectum.

In terms of clinical care, 174 cervical cancer patients who received brachytherapy were included in the study by Ulinskas et al. The 5-, 10-, and 15-year survival rates of the 60Co group were 35.4%, 26.9%, and 22.5%, and disease-free survival rates were 32.0%, 25.1%, and 21.4%, respectively [30]. A retrospective study by Pesee et al. of 141 cervical cancer patients treated with 60Co brachytherapy showed an overall 5-year survival rate of 63.3% and rates of 100%, 80.3%, 100%, and 54.8% for stage IB, IIB, IIIA, and IIIB cancers, respectively [31]. The incidence of grade 2 radiation proctitis was slightly higher in patients treated with HDR BT with the 850 cGy/fraction [32]. Tantivatana et al. conducted a 5-year follow-up study of patients treated with 2D HDR BT with 192Ir or 60Co sources and found no noticeable differences in the overall survival (77% vs. 81.9%), disease-free survival (73.1% vs. 74.7%), and grade 3 and 4 complications (4.7% vs. 3.4%) [33]. Rakhsha et al. studied 154 patients who received 60Co treatment for cervical cancer. The median follow-up time was 38 months. The rectal and bladder toxicity rate was 33.7%, and the 3-year DFS rates for stage I, II, III, and IVA cancer were 85.7%, 70.7%, 41%, and 16.6%, respectively [34]. In the prospective trial reported by Ntekim et al., two patients (3%) with cervical cancer treated with 60Co brachytherapy had grade 3 gastrointestinal toxicity. All other patients had \leq grade 2 toxicity, and the overall acute gastrointestinal and genitourinary toxicity levels were low and comparable to the toxicity reported for the 192Ir HDR source [35]. Tanaka et al. used the 192Ir HDR source for brachytherapy in 135 patients with cervical cancer (22 in stage I, 49 in stage II, 56 in stage III, and 8 in stage IVA) with 5-year survival rates of 90%, 78%, 53%, and 33% in stages I, II, III, and IVA, respectively [36]. Song et al. conducted a retrospective analysis of 76 patients treated with 60Co. The overall survival rates and five-year progression-free survival were found to be 69.3% and 63.7%,

respectively [37]. Thakur et al. performed a retrospective analysis of all patients treated with Ir HDR BT three times at 7 Gy in group A and twice at 9 Gy in group B. The two-year local control rates were 88.5% and 91.5%, disease-free survival rates were 85.9% and 82.6%, and overall survival rates were 95.7% and 100% in groups A and B, respectively [38]. According to Hochreiter et al., the 3-year overall survival rate, disease-free survival rate, and pelvic recurrence-free survival rate of 111 patients with endometrial cancer after ¹⁹²Ir brachytherapy were 89.6%, 90.1%, and 92.8%, respectively [39]. From the clinical trials reported so far, the use of both ¹⁹²Ir and ⁶⁰Co in HDR BT of cervical cancer patients can reduce mortality and improve survival. There are no particular advantages for ¹⁹²Ir in terms of toxic reactions and survival, and there is no discernible difference between the two radiation sources' therapeutic effects. However, there is uncertainty in the locations of the applicator, rectum, and bladder due to the presence of patient handling, bowel movements, and other factors. There is a possibility that the dose received at the actual reference point and in the rectum, bladder, and other organs may not coincide with the results calculated by TPS for 2D HDR BT [40–43]. Therefore, it is not a good predictor of patient recovery and the probability of normal tissue complications [44–47].

4. Three-Dimensional Intracavity Brachytherapy

With the extensive development of brachytherapy for cervical cancer, people are gradually paying attention to the limitations of traditional 2D HDR BT based on X-rays for cervical cancer: The individualized distribution of tumors is not taken into account, and the location, size, and degree of invasion of surrounding tissues cannot be accurately displayed. The dose distribution of the whole treatment plan cannot be adjusted and optimized. Thus, the clinical local control rate, toxicity response, and survival rate cannot be improved [48–51]. Recent years have seen remarkable advances in intensity-modulated radiation technology (IMRT), and image-guided three-dimensional (3D) HDR BT has been applied and promoted. Image-guided 3D BT is also based on individualized anatomical structures. By continuously optimizing the brachytherapy planning system, an optimal treatment plan can be determined, which can significantly improve the accuracy of the CTV and OARs dose assessment and provide adequate dose coverage for CTV without excessive doses of OARs. Therefore, 3D HDR BT technology has clear advantages over 2D technology for clinical treatment [52–57].

We used CT images of the same patient to produce 3D HDR BT plans for both ¹⁹²Ir and ⁶⁰Co sources. The sagittal dose distribution is shown (Figure 5). Compared with ¹⁹²Ir, the dose distribution of ⁶⁰Co is more prominent in the cephalocaudal direction, which is a similar result to that obtained by Shukla [58] and Palmer [29]. There are slight variations in the dose distribution due to the physical properties of these isotopes, which vary naturally. With treatment plan optimization techniques, the differences in the CTV dose can be reduced so that they are essentially the same in terms of actual clinical treatment outcomes. At a prescribed dose of 6 Gy of CTV D90, the difference in dose between ⁶⁰Co and ¹⁹²Ir at D1cc and D2cc of OARs is less than 10 cGy. At the bladder and rectum, there is a small increase in the dose of ⁶⁰Co compared to ¹⁹²Ir. This part of the difference can be agreed upon for actual clinical treatment through continuous optimization of the physical plan without affecting the final treatment [59].

Sinnatamby et al. analyzed brachytherapy treatment plans for 27 patients and found minimal differences in the dose distribution when using ⁶⁰Co or ¹⁹²Ir as the radiation source [60]. In the study by Gujar et al. on ⁶⁰Co, the mean HRCTV D90 was 21.4 ± 0.69 Gy in all patients, and the mean D2cc was 15.9 ± 0.58 Gy, 11.5 ± 0.91 Gy, and 4.1 ± 1.52 Gy in the bladder, rectum and sigmoid colon, respectively [61]. Tormo Ferrero et al. analyzed 3D HDR BT plans with ¹⁹²Ir and ⁶⁰Co sources and compared the dose differences, showing that, other from the dose percentage difference at point "1" (5 mm tissue depth from the top of the vaginal cylinder), there were no statistically significant changes in dose percentages for the rectum, bladder, and sigmoid D2cc or for point 0 (top surface of the vaginal cylinder) [62]. Richter J et al. reported that ⁶⁰Co and ¹⁹²Ir sources of the same

shape and structure showed almost identical dose distributions, with ^{60}Co doses in the rectum being 0.8% lower than those of ^{192}Ir sources [22]. In the study by Mobit et al., it was found that, with a 2.2 cm vaginal cylinder, the dose at 90% of the planned target volume ($V_{90\%}$) was 97% and 98% of the prescribed dose for ^{60}Co versus ^{192}Ir , 20.2% and 17.3% for $V_{150\%}$, and 3.9% and 3.5% for $V_{200\%}$, respectively. With a 2.6 cm vaginal cylinder, the DVH for ^{60}Co versus that for ^{192}Ir differed slightly. With the 3.0 cm vaginal cylinder, for ^{60}Co and ^{192}Ir , $V_{90\%}$ was 98% and 99%, $V_{150\%}$ was 11.8% and 10.7%, and $V_{200\%}$ was 3.1% and 2.7%, respectively [63]. The above results show almost no significant difference in the physical plans of the two radiation sources. Therefore, we believe that there is no major difference in the selection of ^{60}Co versus ^{192}Ir in 3D HDR BT.

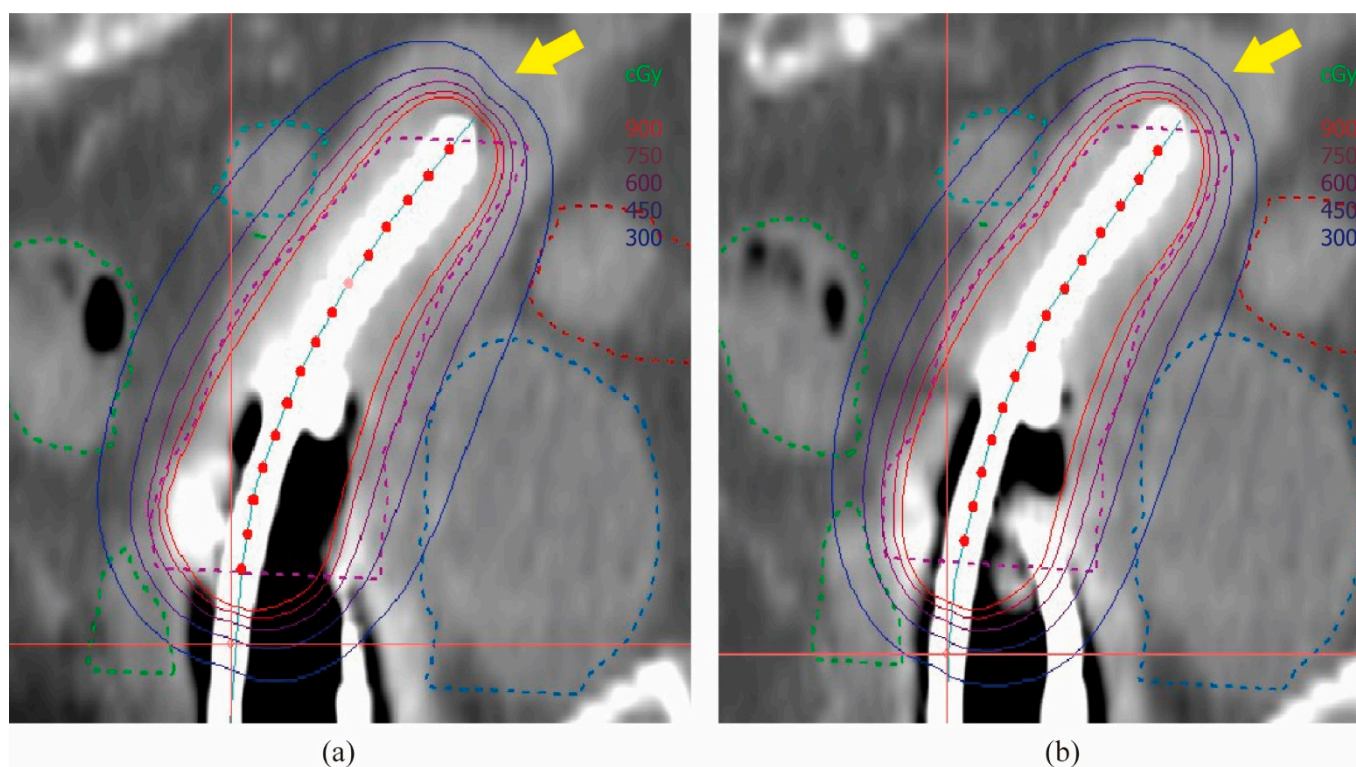


Figure 5. (3D HDR ICBT) Isodose line distribution in the sagittal plane of the transseptal canal. (a) ^{192}Ir ; (b) ^{60}Co . As indicated by the arrows, ^{60}Co was more prominently distributed in the cephalocaudal direction.

In our study, the dose-volume histogram (DVH) of the 3D HDR BT plans for ^{192}Ir and ^{60}Co are shown in Figure 6, and the curves of the two are basically coincident. For OARs, the dose of ^{60}Co is slightly lower than that of ^{192}Ir , so we speculate that the use of ^{60}Co may have a better protective effect. This is slightly different from the results of Suresh et al., who found that the average rectal dose of ^{60}Co was higher than that of ^{192}Ir , but the average dose of ^{60}Co was lower than that of ^{192}Ir for the bladder and sigmoid. They mentioned that, compared with the ^{192}Ir radioisotope, the absorption, attenuation, and scattering effects of the ^{60}Co radioisotope are correspondingly reduced due to the higher average gamma energy. When using ^{60}Co , reductions in these factors will lead to a lesser dose being received by the target tissue, yet high doses being transmitted to distant tissues (OARs) [64]. We found that, on the one hand, these differences originate from differences in the intrinsic physical properties of the ^{60}Co and ^{192}Ir sources, because ^{60}Co has a higher gamma capability, and its internal self-absorption is less than that of ^{192}Ir . On the other hand, different physicists give different weights to the dose optimization of CTV and OARs in radiotherapy plans, resulting in different dose results. In actual clinical applications, in order to ensure the prescribed dose of CTV is received and to simultaneously eliminate

the dose difference brought about by the choice of the radiation source or the subjective operation of the physicist, adjusting the step radiation source's dwell time will optimize the dose distribution, which is the advantage of brachytherapy [65].

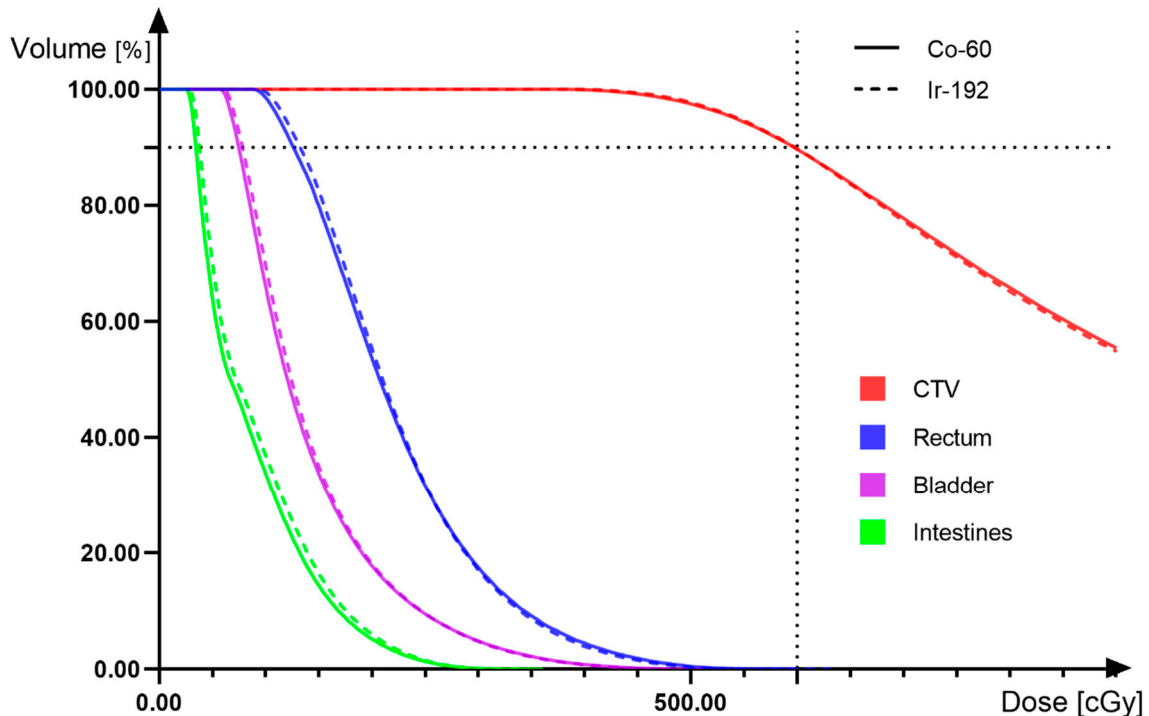


Figure 6. (3D HDR ICBT) Dose-volume histogram comparing 192Ir and 60Co.

In terms of clinical treatment, Atasever et al. performed a retrospective analysis of 50 patients with stage IA-IIIC2 cervical cancer treated with 3D HDR ICBT using 192Ir. The results were 76% complete remission, 4% partial remission, 12% presence of local recurrence, and one-year and five-year survival rates of 88% and 67.5%, respectively [66]. Wang et al. reported a retrospective analysis of 373 patients with stage IIB cervical cancer undergoing HDR ICBT using 192Ir. The disease-free survival, three-year overall survival, and local control rates were 82.2%, 87.5%, and 92.5%, respectively [67]. In a study by Kusada et al. on 192Ir HDR ICBT, the local control 2-year rates of pelvic control and progression-free survival were 85%, 83%, and 75%, respectively [68]. At present, there is a lack of clinical trials for 3D HDR ICBT in cervical cancer patients using 60Co alone, and by recording clinical outcomes such as survival, toxicity, or local recurrence, we will continue to pay close attention to progress in this regard.

5. 3-Dimensional Intracavity-Interstitial Brachytherapy

Since the tumor will invade normal tissues in all directions during the process of growth, especially for some large tumors, the main body of which may be far from the cervix, brachytherapy will not provide a suitable dose for irradiation if it relies on the uterine cavity tube alone, so intracavity-interstitial brachytherapy (IC-ISBT) has been further developed and promoted. External irradiation combined with simple intracavitary brachytherapy has been proven to be an incredibly efficient method for the treatment of cervical cancer in its early stages, but still has limitations when used for intermediate and advanced cervical cancer [5,69,70]. HDR IC-ISBT can place the needles along the tumor morphology and combine with the intracavitary applicator, guaranteeing that a large dose is transmitted to the center of the cervix while providing the tumor target area with highly conformal coverage. At the same time, through technical optimization, the dose given to the OARs does not exceed the upper limit, so it has a better local control rate for advanced large-volume cervical cancer [71–76]. Previously, the 60Co source was not suitable for use

with interstitial techniques due to its large size, and current technology has improved. It has been shown that there is no significant difference in dose distribution in CTV and OARs for HDR IC-ISBT treatment plans using ^{60}Co or ^{192}Ir sources [22]. With the development of HDR IC-ISBT for cervical cancer, more patients with advanced cervical cancer have been effectively controlled [53,77].

We made ^{60}Co and ^{192}Ir HDR IC-ISBT plans for the CTs of 30 patients, respectively, and in accordance with the ICRU 89 document, delineated the target volume on the CT and derived the dose data for comparison. The CTV D90 of ^{60}Co and ^{192}Ir plans were both 6Gy. The average physical dose values of OARs (bladder, rectum, intestines) $D_{2\text{CC}}$ were as follows (Table 1). The paired *t*-test results showed a statistical difference in dose between the two radiation source physics plans at the OARs, and the mean dose values for OARs of ^{60}Co HDR IC-ISBT plans were slightly lower than those for ^{192}Ir . We randomly selected two treatment plans for one patient with two different radiation sources and derived the DVH plot (Figure 7), which shows that the CTV curves largely overlap. In OARs, the dose value of ^{60}Co was lower than that of ^{192}Ir , and it is possible that ^{60}Co has a better protective effect on OARs. The cross-sectional dose distribution (Figure 8) shows that the HDR IC-ISBT plans produced using ^{60}Co and ^{192}Ir sources were also largely consistent in terms of dose distribution after optimization by the physicist. Our results are similar to those of Mourougan et al. who performed a study on the use of HDR ISBT for breast cancer treatment using ^{60}Co and ^{192}Ir . The results showed that the volume difference between ^{192}Ir and ^{60}Co contained in the reference isodose line was 2.34% ($p < 0.05$). There were 2.5% and 1.2% differences in V150% and V200%, respectively, and the results were found to be statistically significant. However, Mourougan pointed out that the physical differences shown here are not clinically significant, and the actual ^{60}Co dose distribution is essentially the same as that of ^{192}Ir [78].

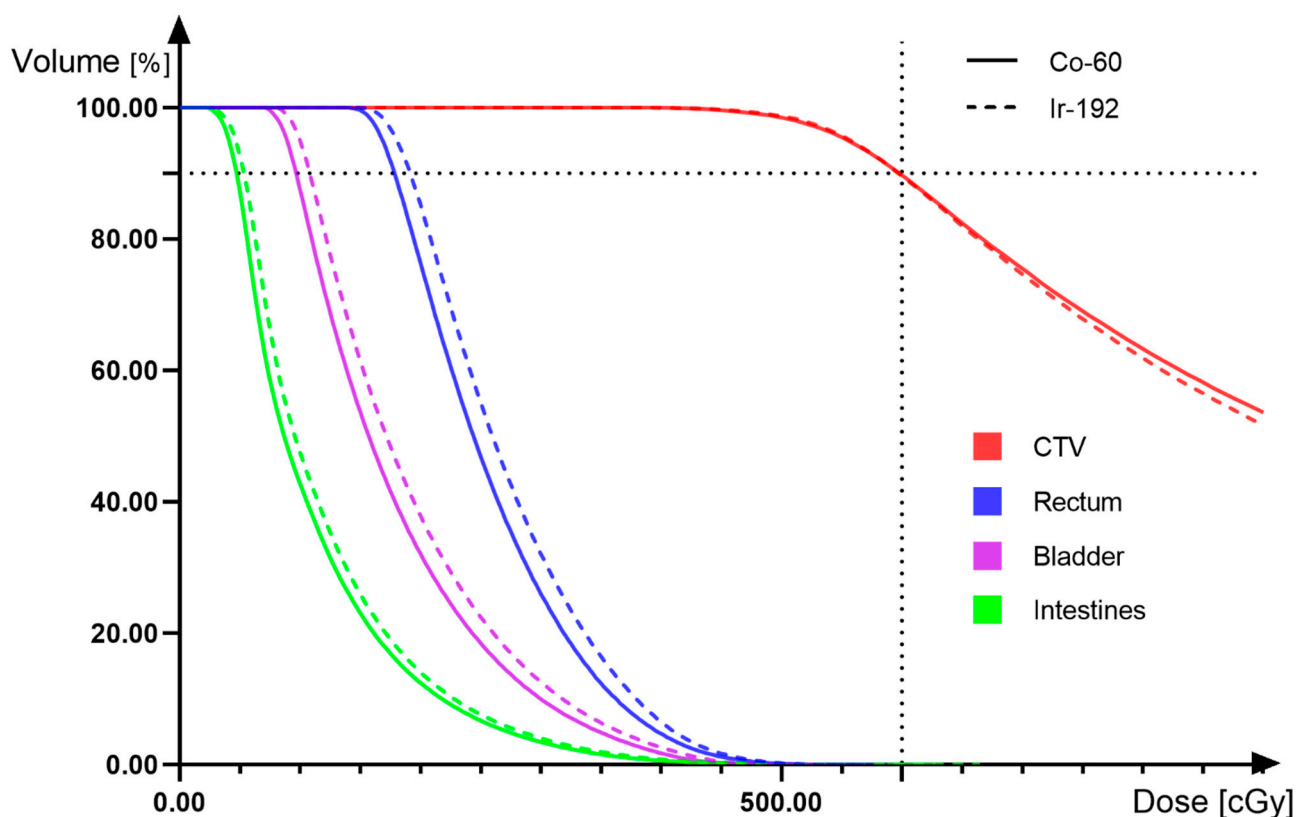
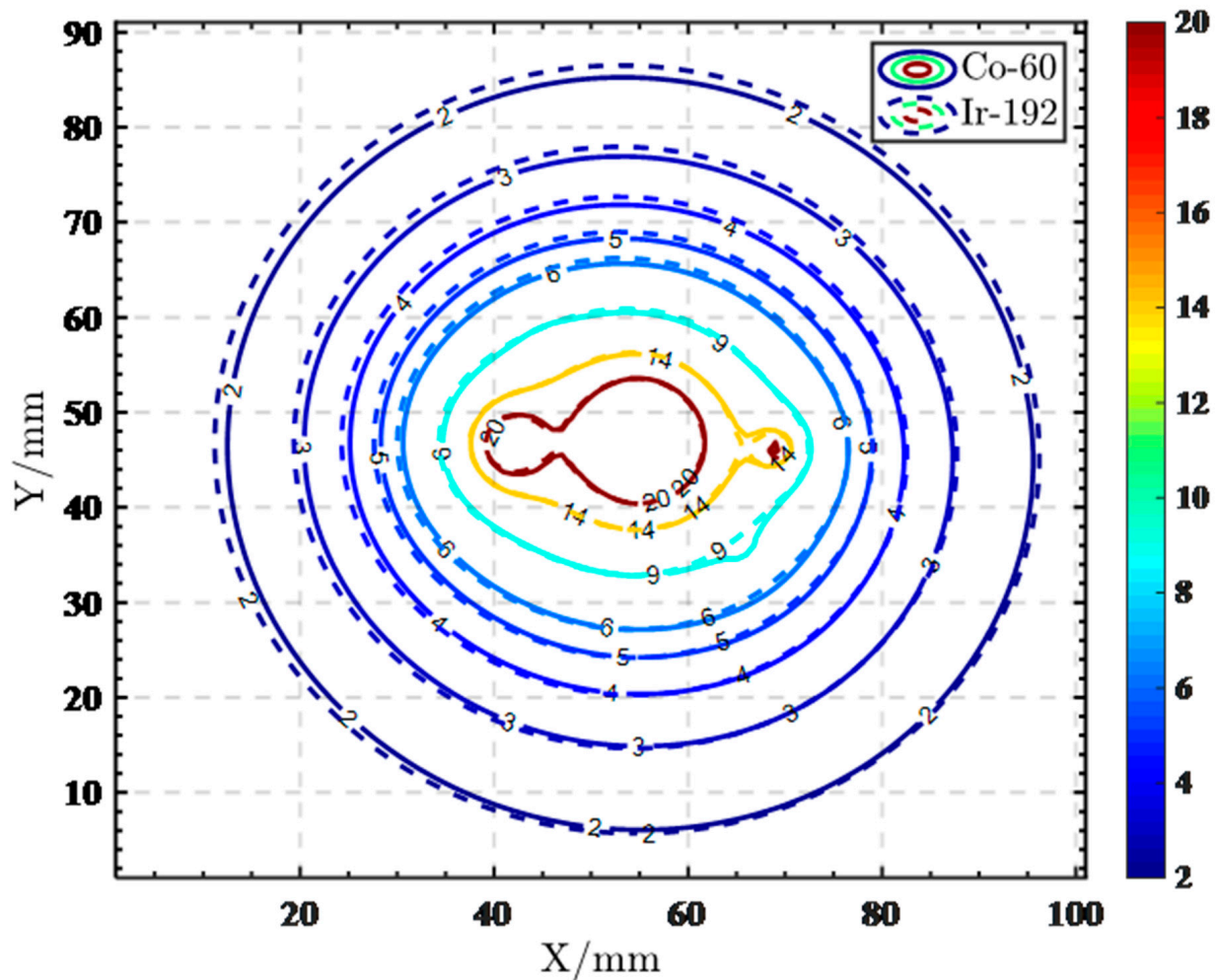


Figure 7. (3D HDR IC-ISBT) Dose-volume histogram comparing ^{192}Ir and ^{60}Co .

Table 1. Mean physical doses for CTV and OARs ($\bar{X} + S$).

	CTV D90/Gy	Bladder D2cc/Gy	Rectum D2cc/Gy	Intestines D2cc/Gy
Co	6	4.70 ± 0.29	4.41 ± 0.68	3.57 ± 1.12
Ir	6	4.81 ± 0.28	4.49 ± 0.68	3.66 ± 1.13
<i>p</i> value		<i>p</i> < 0.05	<i>p</i> < 0.05	<i>p</i> < 0.05

**Figure 8.** (3D HDR IC-ISBT) Cross-sectional isodose line distribution of ¹⁹²Ir and ⁶⁰Co.

In terms of clinical treatment, Mohan Kumar et al. used ⁶⁰Co for HDR IC-ISBT, and the results showed that the median EQD₂ of the 2 cm³ bladder, rectum, sigmoid, and D90 CTV_{HR} were 70 Gy (53–75 Gy), 64 Gy (51–71 Gy), 48 Gy (44–72 Gy), and 77 Gy (70–86 Gy), respectively, while the 2-year local control rate was 87.14% [79]. Tiwari et al. reported significantly better local control (90.4% vs. 76.2%) and DFS (78.8% vs. 57.1%) in patients in the IC-ISBT group compared to those in the ICBT group with no discernible difference in the mean dose for the bladder and sigmoid 2cc but a statistically lower dose for the rectum 2cc [80]. A study involving 315 patients with locally advanced cervical cancer who received HDR ISBT of ¹⁹²Ir was conducted by Fallon et al. More than half of the patients (51%) were treated with 3D HDR ICBT, and it was discovered that the overall local control (2D and 3D groups) was 87% at 10 years. The 2D and 3D results were not reported separately; however, the entire trial continues to demonstrate that HDR ISBT is a secure and efficient treatment [81]. Murakami et al. reported that, in their study, the two-year overall survival rate, local control rate, and progression-free survival rate were 81.6%, 80.2%, and 54.4%, respectively, for patients treated with ¹⁹²Ir HDR ISBT [82]. The 5-year follow-up of the

entire cohort of patients treated with ¹⁹²Ir HDR ISBT by le Guyader et al. showed local recurrence-free survival (LFS) in 85% of patients, lymph node recurrence-free survival (NFS) in 83% of patients, metastasis-free survival (MFS) in 70% of patients, progression-free survival (PFS) in 61% of patients, and an overall survival (OS) rate of 75% [83]. In comparison to the findings of previous studies, the results for the dosimetric parameters, local control, and toxicity of cervical cancer patients treated with HDR ISBT using ⁶⁰Co were found to be basically consistent with those of ¹⁹²Ir.

6. Conclusions

By retrieving the relevant domestic and foreign literature published over the past few years, we comparatively analyzed the differences in dosimetric and clinical outcomes between treatment with ⁶⁰Co and ¹⁹²Ir. The results showed that, although the initial physical properties differ, there are no clear differences in dosimetric parameters in the brachytherapy planning system after optimization. In terms of actual clinical effects, small dose differences will not cause significant differences in the toxicity, disease-free survival, local recurrence rate, or survival rate of patients. Compared with ¹⁹²Ir, ⁶⁰Co has no obvious advantages or disadvantages as an HDR brachytherapy source. It is safe and feasible to use ⁶⁰Co for treatment. In particular, ⁶⁰Co has a long half-life and is replaced about every 5 years, which will save a lot of manpower and reduce economic costs for developing countries. We recommend the use of ⁶⁰Co as a high-dose-rate brachytherapy source in clinical practice, especially in developing countries.

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