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<원저>

Comparison of Treatment Planning on Dosimetric Differences Between ^{192}Ir Sources for High-Dose Rate Brachytherapy

- 고선량률 근접치료에서 이리듐-192 선원의 선량특성 차이에 관한 치료계획 비교 -

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— Abstract —

To evaluate whether the difference in geometrical characteristics between high-dose-rate (HDR) ^{192}Ir sources would influence the dose distributions of intracavitary brachytherapy.

Two types of microSelectron HDR ^{192}Ir sources (classic and new models) were selected in this study. Two-dimensional (2D) treatment plans for classic and new sources were generated by using PLATO treatment planning system. We compared the point A, point B, and bladder and rectum reference points based on ICRU 38 recommendation.

The radial dose function of the new source agrees with that of the classic source except difference of up to 2.6% at the nearest radial distance. The differences of anisotropy functions agree within 2% for r=1, 3, and 5 cm and $20° < \theta < 165°$. The largest discrepancies of anisotropy functions reached up to 27% for $\theta < 20°$ at r=0.25 cm and were up to 13%, 10%, and 7% at r=1, 3, and 5 cm for $\theta > 170°$, respectively. There were no significant differences in doses of point A, point B, and bladder point for the treatment plans between the new and classic sources. For the ICRU rectum point, the percent dose difference was on average 0.65% and up to 1.0%.

The dose discrepancies between two treatment plans are mainly affected due to the geometrical difference of the source and the sealed capsule.

Key words: Brachytherapy, HDR ^{192}Ir source, ICRU 38, Treatment planning system

I. INTRODUCTION

A major feature of brachytherapy is to provide the delivery of a high dose directly to the tumor, while minimizing the radiation dose to the surrounding normal tissues. Also, remote after-loading brachytherapy systems have allowed for complete radiation protection, eliminating radiation exposure to medical staff[1,2]. Iridium-192 (^{192}Ir) is the most common radionuclide

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used as current high-dose rate (HDR) brachytherapy source[3]. The average photon energy of an unencapsulated ^{192}Ir is about 380 keV, and it has a half-life of 74.2 days. In Korea, different manufacturers supplied brachytherapy units to radiation oncology departments. Most of the brachytherapy units were supplied by Nucletron (63.2%), followed by Varian (13.2%) and MDS Nordin (10.5%)[4]. There are two different source designs used with microSelectron-v1 (classic) and microSelectron-v2 (new) HDR ^{192}Ir sources by Nucletron. The microSelectron Classic after loader loaded with microSelectron-v1 HDR ^{192}Ir source has successfully used for many years. However, the microSelectron Classic after-loader by Nucletron was not commercially available any more after 2014.

The aim of this study was to compare plans obtained by using two different HDR ^{192}Ir sources (classic and new models) for intracavitary brachytherapy treatments. The dose distributions of treatment plans were evaluated using the doses at points A and B and at reference points of the rectum and bladder defined by the International Commission for Radiation Units (ICRU).

II. MATERIALS AND METHODS

1. Brachytherapy source

Two types of microSelectron HDR sources (Nucletron B.V., Veenendaal, The Netherlands) called the classic and new models were used in this study. The classic source is composed of a cylindrical ^{192}Ir active core with 3.5 mm of active length and an active diameter of 0.6 mm covered by an AISI 316L steel capsule, as shown in Fig. 1a[5]. In contrast, the active core of the new source, which is 3.6 mm in length and 0.65 mm in diameter, has rounded edges that allow the capsule thickness at the distal source tip to be reduced from 0.35 to 0.20 mm (Fig. 1b). Another change of the new source is that the capsule diameter and length are reduced to 0.9 and 4.5 mm from 1.1 and 5.0 mm, respectively[6]. By reducing the woven steel cable diameter to 0.7 mm, it allows the source to pass through smaller-diameter catheters and curved catheters with smaller radii of curvature.

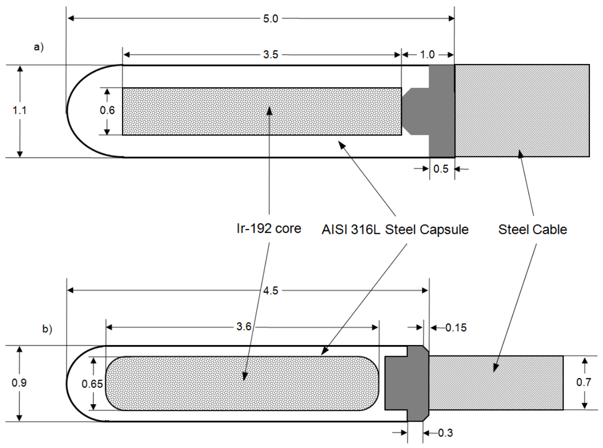


Fig. 1 Schematic design and dimensions of different microSelectron HDR ^{192}Ir sources: (a) classic model; (b) new model. Dimensions are given in mm

2. Dose distributions around HDR ^{192}Ir sources

A total of 27 patients who had been treated with brachytherapy for cervical cancer were included in this study. During intracavitary brachytherapy, Fletcher Williamson applicator (Nucletron B.V., Veenendaal, The Netherlands) was used in all patients. The dose distributions around the classic and new HDR ^{192}Ir sources were calculated by PLATO version 14.2 (NucletronB.V., Veenendaal, The Netherlands).

The dose calculation algorithm of the PLATO planning system is based on the recommendations of

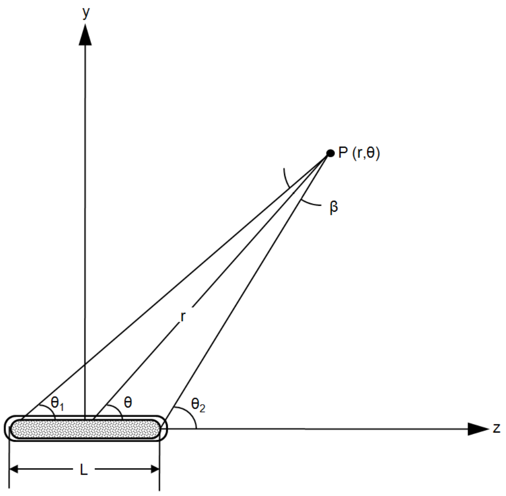


Fig. 2 Illustration of geometry assumed in the dose calculation formalism endorsed by AAPM TG-43

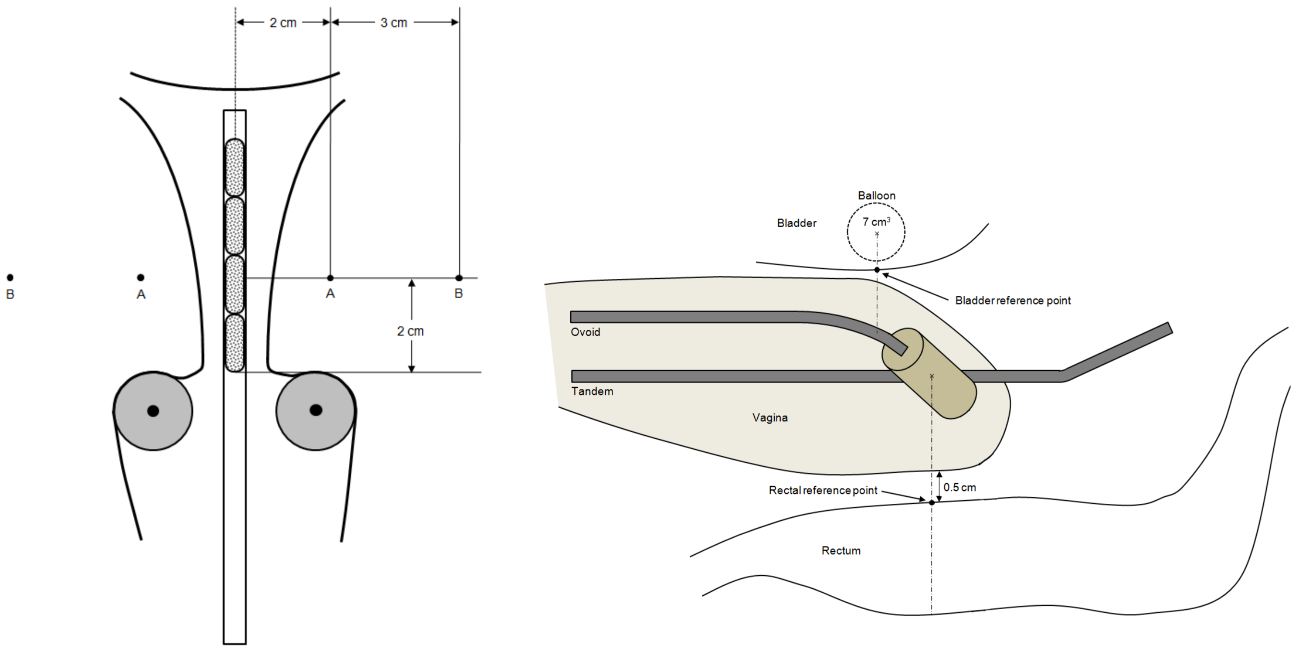
the American Association of Physicists in Medicine (AAPM) Task Group No. 43 Report (TG–43)[7]. Fig. 2 gives the reference for the coordinate system defined by AAPM TG–43.

The longitudinal axis of the source is defined as the polar axis. The dose distribution is described in terms of a polar coordinate system with origin at the center of the active source. According to this formalism, the dose rate distribution around a brachytherapy source is defined by:

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

where S_K is air kerma strength of the source and in units of cGy cm^2 h^{-1}, Λ is the dose rate constant in units of cGy h^{-1} U^{-1}, $G(r,\theta)$ is the geometry factor, $g(r)$ is the radial dose function, $F(r,\theta)$ is the anisotropy function, r is the distance to the point of interest and θ is the angle with respect to the long axis of the source.

For the calculation of the dose distribution, we used the values calculated by Williamson loaded on the commercial treatment planning system for each microSelectron HDR sources. Source positions were loaded according to the standard loading pattern in accordance with the Manchester system[8,9]. Point A was defined by drawing a line connecting the superior aspects of the vaginal ovoids and measuring 2 cm superior along the tandem from the interception with this line and then 2 cm perpendicular to this in the lateral direction (Fig. 3a). Point B is located on the pelvic wall 3 cm lateral to point A. Bladder and rectum reference points were established by ICRU Report 38[10]. The bladder reference point is obtained on an anterior–posterior line drawn through the center of the balloon at the posterior surface. On the rectum reference point, an anterior–posterior line is drawn from the inferior end of the intrauterine sources (or from the middle of the intravaginal sources). The point is located on this line 5 mm behind the posterior vaginal wall (Fig. 3b). To minimize the dose to the bladder and rectum points, an optimization algorithm was used to determine the dwell weights to obtain the dose distribution shape. A dose of 5 Gy at point A was prescribed for all the patients.



(a) (b)

Fig. 3 The original definition of the Manchester System and the reference points established by ICRU 38: (a) Point A, Point B and (b) bladder and rectum points

3. Evaluation of Dose Distribution Between "classic" and "new" Sources

To investigate the effect on the dose distributions around the new source and classic sources on the actual treatment plan, evaluations were done under corresponding conditions (e.g., the same prescription dose and dwell positions). The doses to point A, point B, and the ICRU reference points in the bladder and rectum were calculated. Each of the comparisons was performed using the percent dose difference. The percent difference of a calculated dose was expressed with the following formula:

$$Diff.(\%) = \frac{(D_{new} - D_{calssic})}{D_{new}} \times 100$$

A two-sample *t*-test was used to assess the statistical significance of the differences between the plans for HDR ^{192}Ir sources. Statistical analysis was performed using the SPSS version 16 (SPSS Inc., Chicago, IL).

III. RESULTS AND DISCUSSION

Fig. 4 shows a comparison between radial dose functions of microSelectron HDR ^{192}Ir sources in dosimetric data loaded by commercial treatment planning system. The radial dose function of the new source agrees with that of the classic source, except at the nearest radial distance with differences of up to 2.6% is present. The radial dose function of the new source slightly increases with the radial distance due to the increased diameter from 0.6 mm to 0.65 mm for ^{192}Ir active core and reduced thickness from 0.25 mm to 0.125 mm for stainless s teel capsule. It is well known that the intensity of radiation depends on the thickness of material. Especially, as the capsule thickness was reduced by a factor of 1/2, the radiation intensity transmitted by material of stainless steel was increased with radial distances. For that reason, the radial dose function along the transverse axis as the distance from the center of the sources lightly increases.

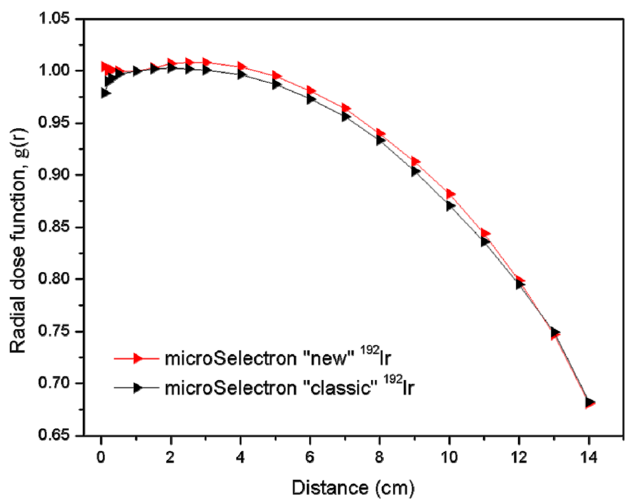
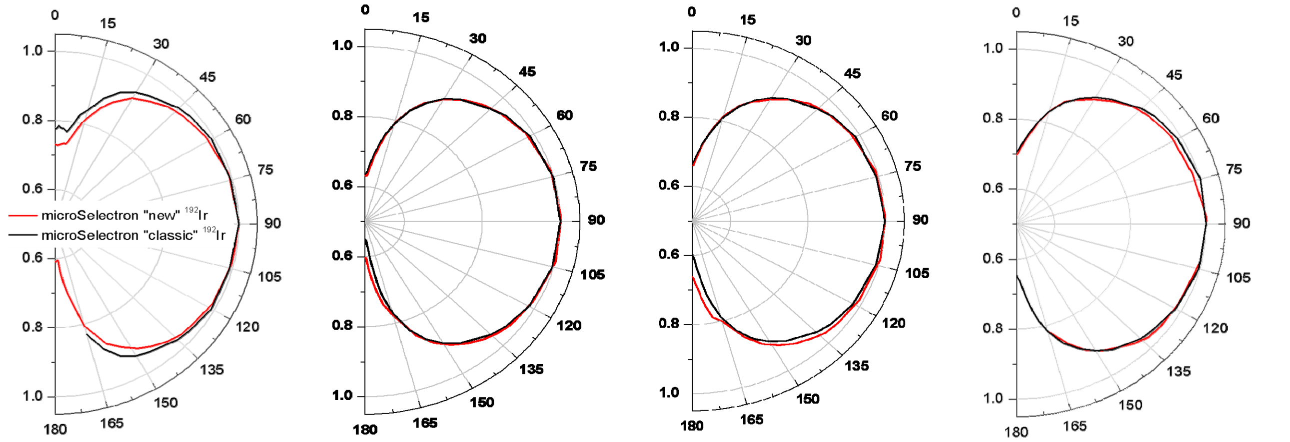


Fig. 4 Radial dose functions for two microSelectron HDR ^{192}Ir sources

Anisotropy functions at different radial distances from two brachytherapy sources are shown in Fig. 5. The differences of anisotropy functions agree within 2% for r=1, 3 and 5 cm and 20°〈θ〈165°. The largest discrepancies of anisotropy functions reached up to 27% for θ〈20° at r=0.25 cm. As the distance increases from 1 to 5 cm, the anisotropy function values agree within 5% for θ〈170°. The largest differences were up to 13%, 10%, and 7% for 1, 3 and 5 cm distances for θ〉170°, respectively.

In the use of the Monte Carlo methods for the calculations of brachytherapy dosimetry parameters, most of studies have shown that collision kerma via photon track-length estimator is not accurate for distances less than 0.2 cm due to the lack of the electronic equilibrium and the ignorance of the dose contribution from the beta spectrum of ^{192}Ir[(11-14)] source. Along the central axis of the microSelectron-v2 source, the doses scored by using energy deposition are about 4% and within 1% greater than the collision kerma at distances of 0.1 cm and 0.2 cm, respectively[(15)]. Wang and Li[(12)] showed that the dosimetric differences between dose scored by using energy deposition and collision kerma based on track-length estimator at short distances (〈0.2 cm) from the source mainly depend on the source geometry and materials. For that reason, dosimetric differences between HDR ^{192}Ir



(a) (b) (c) (d)

Fig. 5 Anisotropy functions at different distances from two microSelectron HDR ^{192}Ir sources. (a) 0.25 cm, (b) 1.0 cm, (c) 3.0 cm, and (d) 5.0 cm

Table 1 The doses computed at Point A, Point B and reference points defined in the ICRU report 38 for the new and classic ^{192}Ir sources

Parameter	microSelectron HDR ^{192}Ir sources	
	"new" model	"classic" model
Prescribed dose (cGy)		
Point A (Left)	498.16±10.66	498.16±10.73
Point A (Right)	501.84±10.66	501.84±10.73
Point B (Left)	127.92±8.52	128.29±8.63
Point B (Right)	128.00±8.16	128.36±8.27
Bladder	311.71±82.86	309.85±82.95
Rectum	356.28±37.52	355.36±37.69
Ratio (%)		
Point B dose/Point A dose	25.59±1.67	25.67±1.69
Bladder dose/Point A dose	71.26±7.50	71.07±7.54
Rectum dose/Point A dose	62.34±16.57	61.97±16.59

sources at short distances for the source were showed by as much as 2.6% for the radial dose function and 27% for the anisotropy functions, respectively.

Table 1 shows the doses distributions obtained by PLATO planning system for the microSelectron HDR ^{192}Ir sources. The doses at point B were about 25−26% of the dose at point A. The average doses to the bladder and rectum points were 62.34±16.57% and 71.26±7.50% of the dose at point A for the new source and 61.97±16.59% and 71.07±7.54% of that at point A for the classic source, respectively. There were no significant differences between the plans generated by two different HDR ^{192}Ir sources.

The resulting mean dose to point A was not significantly different for the classic and new sources (Table 2). The doses to point B for the new source were generally lower than those for the classic source. On the other hand, for the doses to the bladder and rectum points, the doses from the new source were higher than those from the classic source. For the doses to point B, there was good agreement between the new and classic source. The maximum discrepancy of the percent dose difference for two brachytherapy source were 0.7% and 1.0% for bladder and rectum points, respectively. In the results of the dose distributions of the treatment plans using two

Table 2 The percent differences between doses calculated with “new” and “classic” ^{192}Ir sources using a treatment planning system

Patient #	Percent differences (%)					
	Point A		Point B		Reference points	
	Left	Right	Left	Right	Bladder	Rectum
1	-0.03	0.03	-0.35	-0.28	0.25	0.98
2	0.00	0.00	-0.08	-0.11	0.41	0.38
3	0.03	-0.02	-0.08	-0.16	0.45	0.59
4	0.04	-0.04	-0.04	-0.18	0.27	0.96
5	0.02	-0.02	-0.18	-0.21	0.19	0.64
6	0.02	-0.02	-0.11	-0.21	0.25	0.97
7	0.01	-0.01	-0.15	-0.17	0.29	0.81
8	0.03	-0.03	-0.39	-0.36	0.34	0.69
9	0.00	0.00	-0.13	-0.18	0.23	0.94
10	0.00	0.00	-0.31	-0.36	0.10	0.40
11	-0.03	0.03	-0.44	-0.43	0.22	0.95
12	0.01	-0.01	-0.25	-0.29	0.06	0.59
13	-0.02	0.02	-0.21	-0.20	0.22	0.80
14	-0.02	0.02	-0.33	-0.27	0.53	0.22
15	0.02	-0.02	-0.35	-0.27	0.21	0.56
16	0.00	0.00	-0.54	-0.54	0.18	0.86
17	0.00	0.00	-0.36	-0.33	0.66	0.26
18	0.00	0.00	-0.22	-0.16	0.70	0.28
19	0.02	0.02	-0.39	0.02	0.12	0.31
20	-0.05	-0.05	-0.33	-0.34	0.23	0.70
21	0.02	0.02	-0.28	-0.31	0.17	0.35
22	-0.05	0.05	-0.19	-0.24	0.20	0.51
23	0.03	-0.03	-0.54	-0.56	-0.01	0.84
24	0.00	0.00	-0.18	-0.06	0.42	0.78
25	0.02	-0.02	-0.46	-0.47	0.09	0.74
26	0.00	0.00	-0.25	-0.31	0.18	0.80
27	0.00	0.00	-0.45	-0.42	0.16	0.53
Average	0.00±0.02	0.00±0.02	-0.28±0.14	-0.27±0.14	0.26±0.17	0.65±0.25

brachytherapy sources, there was not a significant difference between the two sources for the target coverage (point A) and the doses to point B and bladder, but the new source was highly evaluated with approximately 0.7% for the dose to the rectum. It is concluded that the rectum point is located close to the source and is mainly positioned at sharp dose gradient due to difference of the tip of the source and end cap thickness of the sealed capsule.

IV. CONCLUSIONS

Based on actual patient plans considered in this study, the dose distributions around microSelctron HDR ^{192}Ir brachytherapy sources, the new and classic model, were compared using a treatment planning system for intracavitary brachytherapy. The geometrical differences between the source leads to deviations of radial dose function and anisotropy function, especially at short radial distances less than 1 cm and high polar angle due to geometrical characteristics of the source. In comparison with treatment plans for all patients, there were not significant differences in doses of point A, point B, and bladder point between the new and classic sources. For the rectum point, the percent dose difference was on average 0.7% and up to 1.0%.

In this study, we investigated the discrepancies of dose distributions between the new and classic sources using a treatment planning system since the microSelectron classic HDR ^{192}Ir source was not commercially available after 2014. Overall, dosimetric differences of dose distributions of treatment plans for all patients were agreement within 1%. The dosimetric differences of the resulting treatment plans have with no statistical significance. Therefore, in the use of two kinds of HDR ^{192}Ir brachytherapy sources used in this study, it is considered that the dose distributions of 2D-based treatment planning have with no clinically significant differences. Nevertheless, additional evaluation of the dose distributions between the two brachytherapy sources based on 3D treatment planning and DVH (dose-volume histogram) is required as further investigation.

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•국문초록

고선량률 근접치료에서 이리듐-192 선원의 선량특성 차이에 관한 치료계획 비교

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강내 근접치료(intracavitary brachytherapy)에서 다른 고선량률 ^{192}Ir 선원의 기하학적 특성으로 인한 선량분포의 차이를 비교 및 분석하였다.

본 연구에서는 Nucletron사에서 제작된 microSelectron-v1 (classic) 선원이 2014년 이후로 판매가 종료되면서 새로운 microSelectron-v2 (new) 선원과의 선량분포 차이를 치료계획시스템을 이용하여 비교 및 분석하였다. 두 선원에서 획득된 선량분포를 비교하기 위하여 point A, point B, ICRU 방광 및 직장의 기준점을 분석인자로 사용하였다.

선원과 가까운 거리에서는 microSelectron-v2 선원의 반경선량함수(radial dose function)가 microSelectron-v1 선원 보다 최대 2.6% 높았다. 선원으로부터 거리가 1, 3, 그리고 5 cm의 비등방성함수(anisotropy function)는 $20° < \theta < 165°$에서 두 선원 간에 2% 이내에서 잘 일치하였다. 다만, 거리가 0.25 cm에서 $\theta < 20°$ 구간에서는 두 선원 간 최대 27%의 차이를 보였으며, 거리가 1, 3, 그리고 5 cm에서 $\theta > 170°$ 구간에서는 두 선원 간 각각 13%, 10%, 그리고 7% 차이를 보였다. 두 선원을 이용한 치료계획에서는 point A, point B, 방광에 들어가는 선량의 차이는 없었으며, ICRU에서 권고하는 직장에 들어가는 선량 지점은 microSelectron-v2 선원이 microSelectron-v1선원보다 평균 0.65%, 최대 약 1%까지 높게 평가되었다.

두 선원 간의 선량분포 차이는 주로 선원의 기하학적 차이와 선원을 감싸고 있는 스테인리스 스틸(stainless steel) 캡슐의 두께 차이로 발생되지만 두 선원에서의 선량분포 차이는 1% 이내이므로 새로운 모델의 선원으로 교체하여 사용하더라도 근접치료에서의 선량분포는 임상적으로 크지 않을 것으로 판단된다.

중심 단어: 근접치료, 고선량률 이리듐-192 선원, ICRU 38, 치료계획시스템