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DOSIMETRIC ANALYSIS OF TREATMENT PLANNING OPTIMIZATION TECHNIQUES FOR CO-60 AND IR-192 HDR BRACHYTHERAPY SOURCES IN CARCINOMA CERVIX PATIENTS

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Summary

Introduction: The study was designed to dosimetrically compare the treatment planning optimization techniques to analyze the equivalence of Co-60 and Ir-192 HDR Brachytherapy sources. Further, the present study planned to analyze the equivalence on the basis of technical, logistical and clinical aspects for both the sources.

Methods: Thirty-two patients with confirmed diagnosis of carcinoma cervix were included in the study. Comparative treatment plans were made for three different treatment planning optimization techniques for both the sources Co-60 and Ir-192 i.e. (a) plans with prescription on Point A (Manchester system) with identical dwell position, (b) plans with inverse planning and (c) plans with prescription on HR-CTV with manual optimization. Treatment plans were evaluated on the basis of clinical parameters HR-CTV V200%, V150%, V100%, D95%, D50%, D2cc Bladder, D2cc rectum and point dose on ICRU Rectum and Bladder reference point.

Results: For the plans with prescription on Point A with identical dwell position, the average percentage difference were found HR-CTV V200% (6.3%), V150% (5.1%), V100% (1.8%), D2cc rectum (2.3%) and ICRU Rectum reference point (2.1%) and all these parameters were statistically significant for both the sources. For the Plans with inverse planning optimization, these parameters were found significant with average percentage difference HR-CTV V200% (6.1%), V150% (4.9%), D50% (2.1%) and ICRU Rectum reference point (2.3%). For the plans with dose prescription on HR-CTV and manual optimization, most of the average percentage differences were found non-significant and clinical parameters were observed clinically comparable to each other for both the sources. Further, it was also observed that on an average Ir-192 source required only 42% of the treatment time required by Co-60 for the same treatment plan delivery.

Conclusion: Among all the three planning techniques, the planning technique with prescription on HR-CTV & manual optimization was found to have comparable clinical quality for both the sources. This analysis revealed that geometry of source placement can overcome the differences in individual source characteristics.

KEYWORDS: *cobalt-60, iridium-192, high dose rate brachytherapy, cervical cancer*

INTRODUCTION

High dose rate (HDR) brachytherapy in combination with external beam therapy is widely accepted practice for the management of cervical cancer worldwide. This combination treatment has shown better clinical outcomes in comparison to external beam therapy alone in cervical cancer management(1,2). It has been observed that the size of the source is a crucial parameter, having a direct impact on dose optimization and delivery. Specific activity plays a key role in deciding the size of the radioisotope. Ir-192 is commonly used radioisotope in brachytherapy with high specific activity, which allows manufacturing of miniaturized sources(3,4). Co-60 radioisotope also has long history in brachytherapy, however its use got lim-

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ited with time due to limitation of source size. Recent advancements in nuclear technology have allowed high specific activities for other gamma-emitting radioisotopes including Co-60. Presently, Co-60 radioisotope with high specific activity is commercially available in new HDR brachytherapy units with source size comparable to Ir-192.

Ir-192 is deemed to be quite close to the ideal source for brachytherapy applications, but it needs to be replaced very frequently due to short half-life (74 days) as compared to Co-60 (5.26 years). This has given logistic advantages to Co-60 over Ir-192 source in terms of operating cost and frequency of source replacement(5). However, Co-60 (1.25 MeV) have relatively high average energy almost three-fold to Ir-192 (0.38 MeV). This comparative higher average energy is presented with a concern of radiation protection while switching from Ir-192 to Co-60 HDR brachytherapy source in medical radiation facility. The average energy of Co-60 source always poses a major question about its clinical impact, which needs to be answered in a clinical setting. However, the literature showed that the biological impact of different energy spectra of Co-60 and Ir-192 on the tissue of varying density is clinically non-significant(6).

There is an ample amount of literature available on dosimetric and technical comparison of these two sources in terms of physical parameters like anisotropy, radial dose function and isodose curves(7-9). Along the source axis, physical parameters have shown significant variations between both the sources; however, point dose analysis has not revealed any considerable differences among both the sources(7). Clinical implication of these variations and role of treatment planning optimization techniques is to get clinically comparable treatment plan has not been fully explored in the available literature. However, several studies reported that the adoption of Co-60 source was clinically acceptable on the basis of acute toxicity analysis in gynecological cancer patient for Co-60 source and was shown to be clinically comparable to Ir-192 source(10-12).

In the present work, it was attempted to dosimetrically analyze various treatment planning optimization techniques for both the sources Co-60 and Ir-192 in carcinoma cervix patients on the basis of various clinical and dosimetric parameters. The three treatment planning techniques were (a) plans with dose prescription on Point A (Manchester system) with identical dwell position, (b) plans with inverse planning and (c) plans with dose prescription on high-risk clinical target volume (HR-CTV) with manually optimization. The comparisons were made on the basis of various clinical and dosimetric parameters i.e. dose-volume and dose statistics parameters, which are widely used for evaluation of the treatment plan. Treatment time and logistics were also analyzed for both Co-60 and Ir-192 radioactive sources.

MATERIALS & METHODS

The HDR remote afterloading brachytherapy unit Bebig Saginova, Eckert & Ziegler, Germany was employed in the study. Retrospectively thirty two carcinoma cervix patients were included in the study. The treatment planning system (TPS) Bebig SagiPlan version 2.1 was used to make treatment plans with two source models i.e. Co-60, Model Co0. A86 and Ir-192, Model Ir2.A85 from Eckert and Ziegler, Bebig, Germany. Both the sources had identical active length i.e. 3.5 cm but their active diameter have difference of 0.1 mm, which were 0.5 mm and 0.6 mm for Co-60 and Ir-192 respectively. On the basis of source dimension, both the sources were considered identical.

Treatment planning system provides the opportunity to optimize the treatment plan automatically through both the techniques i.e. inverse planning optimization and manual optimization. The manufacturer claimed that the planning system is compliant with the American Association of Physicists in Medicine Task Group No. 43 (AAPM TG 43) and High Energy Brachytherapy source Dosimetry (HEBD) working group recommendations. Along with this, it is well reported that commercially available HDR brachytherapy planning systems address the source attenuation and shielding, but do not consider the heterogeneity of the media(13,14).

The present study included 32 patients who were carcinoma cervix cases. Computed tomography (CT) scans of all patients were obtained with 3 mm thickness and magnetic resonance imaging (MRI) scans were also obtained due to poor tissue differentiation as standard practice. Planning structures were delineated by experienced radiation oncologist single-handedly for all the cases to

Table 1.

Average percentage difference between the dose-volume and point dose parameters for both the sources Co-60 & Ir-192 for all the three treatment planning optimization techniques. (A) plan with dose prescription on Point A (Manchester system) with identical dwell position, (B) plan with inverse planning optimization, (C) plan with dos prescription on HR-CTV with manual optimization.

Plan with dose prescription on Point A with identical dwell positions				
	Average percentage Difference Co-60 to Ir-192 (%)	**Standard deviation of Average**	***p* - value**	**Level of significance**
HR-CTV V200%	6.3	3.7	< 0.01	Significant
HR-CTV V150%	5.1	2.8	< 0.01	Significant
HR-CTV V100%	1.8	1.1	< 0.05	Significant
HR-CTVD95%	0.7	1.3	> 0.05	Non-Significant
HR-CTVD50%	1.6	1.5	> 0.05	Non-Significant
D2cc bladder	0.9	1.3	> 0.05	Non-Significant
D2cc rectum	2.3	1.9	< 0.05	Significant
ICRU bladder ref. point	1.1	1.2	> 0.05	Non-Significant
ICRU rectum ref. point	2.1	1.8	< 0.05	Significant
Plans with inverse planning optimization				
	Average percentage Difference Co-60 to Ir-192 (%)	**Standard deviation of Average**	***p* - value**	**Level of significance**
HR-CTV V200%	6.1	3.1	< 0.01	Very Significant
HR-CTV V150%	4.9	2.3	< 0.05	Very Significant
HR-CTV V100%	1.3	1.3	> 0.05	Non-Significant
HR-CTVD95%	0.5	1.5	> 0.05	Non-Significant
HR-CTVD50%	2.1	2.1	< 0.05	Significant
D2cc bladder	0.5	1.4	> 0.05	Non-Significant
D2cc rectum	0.8	2.3	> 0.05	Non-Significant
ICRU bladder ref. point	0.9	1.5	> 0.05	Non-Significant
ICRU rectum ref. point	2.3	2.2	< 0.05	Significant
Plans with dose prescription on HR-CTV with manual optimization				
	Average percentage Difference Co-60 to Ir-192 (%)	**Standard deviation of Average**	***p* - value**	**Level of significance**
HR-CTV V200%	4.6	3.9	< 0.05	Significant
HR-CTV V150%	4.3	2.9	< 0.05	Significant
HR-CTV V100%	0.9	1.3	> 0.05	Non-Significant
HR-CTVD95%	0.4	1.1	> 0.05	Non-Significant
HR-CTVD50%	1.5	1.1	> 0.05	Non-Significant
D2cc bladder	0.3	1.9	> 0.05	Non-Significant
D2cc rectum	0.7	2.1	> 0.05	Non-Significant
ICRU bladder ref. point	1.2	1.8	> 0.05	Non-Significant
ICRU rectum ref. point	1.7	2	> 0.05	Non-Significant

avoid any interpersonal errors. Structures delineated were HR-CTV, bladder and rectum. All the patients were treated with the institutional protocol of five HDR brachytherapy fractions of 7 Gy each in combination with external beam therapy.

Treatment plans were made for both Co-60 and Ir-192 sources with all the three treatment planning techniques for each patient. For the first technique, the plans were made with prescription on point A (Manchester system) with identical

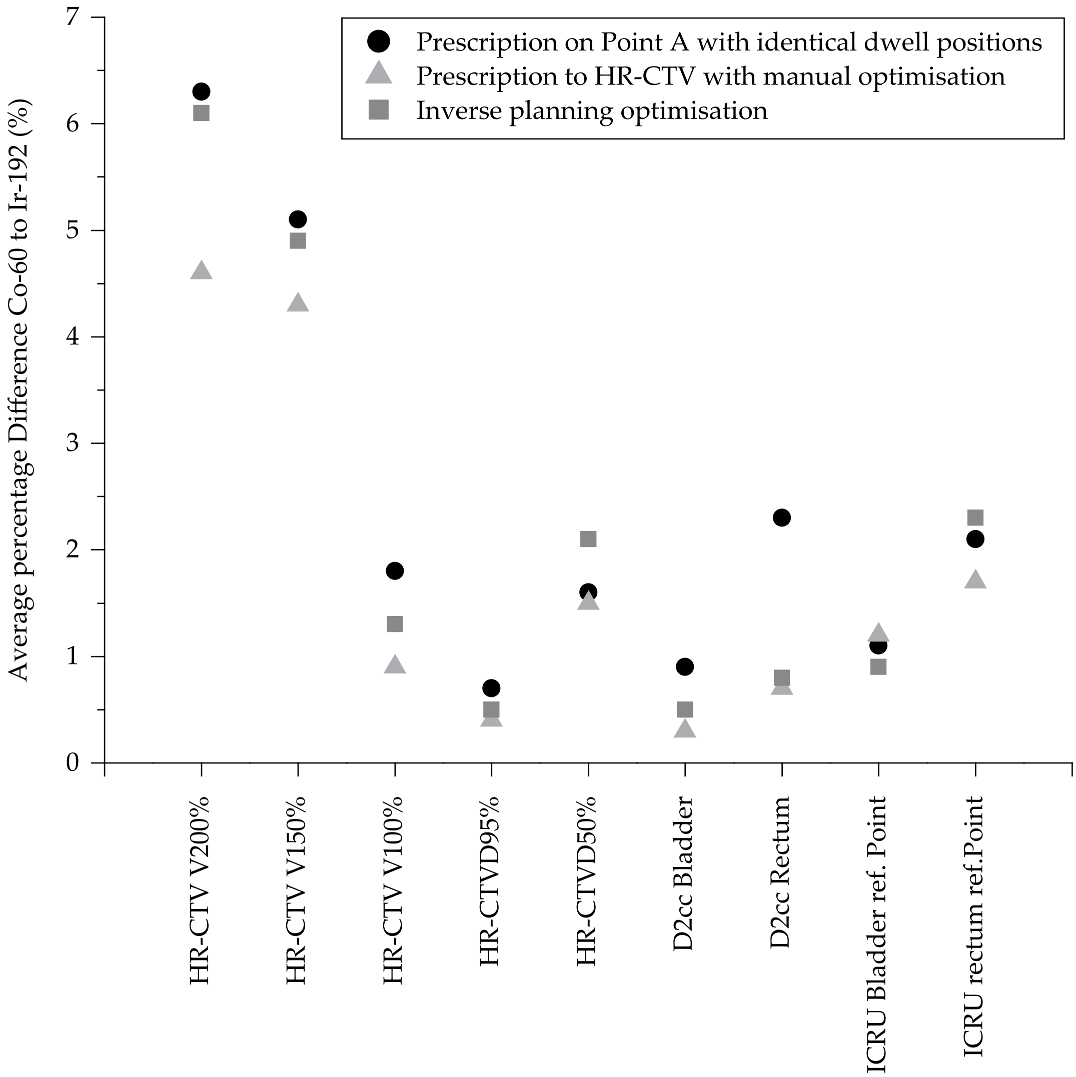

Figure 1. Comparative graphical interpretation of average percentage difference between all the clinical parameters for both the sources in all the three treatment planning techniques.

dwell positions for both the sources. For the second technique, plans were made with inverse planning optimization tool and for the third technique; the plans were made with prescription on HR-CTV with manual optimization of both the sources. All the three treatment planning optimization techniques were analyzed considering dosimetric and clinical aspects for both the sources Co-60 and Ir-192. Treatment time (sum of all dwell position times) and logistics were analyzed for both sources.

Clinical and dosimetric parameters studied were dose-volume and dose statistics parameters such as HR-CTV V200% (HR-CTV VX%: volume covered by the X percentage of prescription dose), V150%, V100%, D95% (HR-CTV DX%: dose to X% of the HR-CTV), D50%, D2cc (maximum dose to 2 cm^3 volume) bladder, D2cc rectum and point dose parameters for rectum & bladder reference points as recommended by the International Commission of Radiation Units (ICRU report 38) for both the sources Co-60 & Ir-192.

RESULTS

For the first treatment planning technique i.e. plans with dose prescription on Point A (Manchester system) with identical dwell position, it was observed that the average percentage difference (Co-60 to Ir-192) in dose-volume parameters found to have significant differences in HR-CTV V200% (6.3%, $p < 0.01$), HR-CTV V150% (5.1%, $p < 0.01$), HR-CTV V100% (1.8%, $p < 0.05$), D2cc rectum (2.3%, $p < 0.05$) and point dose ICRU rectum reference point (2.1%, $p < 0.05$). The remaining parameters were found in agreement with each other for both the sources. These observations were shown in Table 1(A). It was also observed that achieving a much desirable pear shape isodose for Co-60 was difficult in comparison to Ir-192 with the same planning source geometry.

For the second planning technique i.e. plans with inverse planning optimization tool, it was observed that the average percentage difference (Co-60 to Ir-192) in dose-volume parameters found to have significant differences in HR-CTV V200% (6.1%, $p < 0.01$), HR-CTV V150% (4.9%, $p < 0.01$), HR-CTV D50% (1.8%, $p < 0.05$), D2cc rectum (2.3%, $p < 0.05$) and point dose ICRU Rectum reference point (2.1%, $p < 0.05$). The remaining parameters were found in agreement with each other for both sources as shown in Table 1(B).

For the third planning technique i.e. plans with dose prescription on high-risk clinical target volume (HR-CTV) with manually optimization, it was observed that the average percentage difference (Co-60 to Ir-192) in dose-volume parameters found to have significant differences only for two parameters HR-CTV V200% (4.6%, $p < 0.05$) and HR-CTV V150% (4.3%, $p < 0.05$). The remaining parameters were found in agreement with each other for both the sources. These observations were summarized in Table 1(C). Further, it was also observed that the effect of complete source placement geometry overcomes the difference in inherent characteristics of both the sources Co-192 and Ir-192 in this planning technique. Further, it was also observed that the low dose area in inverse planning optimization plans was quite large compared to manual optimization. However, manual optimization was observed to be far more effective to overcome the inherent differences between both the sources than system optimization in the inverse planning technique and these observations were presented in Table 1(C).

The comparative graphical analysis of all the three treatment planning optimization techniques for both the sources Co-60 and Ir-192 is illustrated in Figure 1. In addition, treatment time defined as the sum of all dwell position time was also analyzed and it was found that on an average, Ir-192 source only required 42% of treatment time as compared to Co-60 source.

DISCUSSION

Dosimetric, technical and economic differences between the two sources Ir-192 and Co-60 are well documented in the literature(7-9,15). However, the present study was planned to dosimetrically analyze various treatment planning optimization techniques for both the sources Co-60 and Ir-192 in carcinoma cervix patients on the basis of various clinical and dosimetric parameters. In the present study, it was observed that for the conventional method of dose prescription i.e. with dose prescription on point A (Manchester and identical dwell position) the differences between most of the clinical parameters were found very significant statistically. Similar observations were reported in the study by Park et al.(7) and Palmer et al.(15). These observations can be attributed to the negligence of isotropic dose distribution of Co-60 in comparison to Ir-192. This observed isotropic dose distribution of Co-60 is due to its much less self-absorption of photon energy within source encapsulation due to its higher energy in comparison to Ir-192. For all the three treatment planning techniques taken into account, there were statistically significant differences in dose-volume parameters HR-CTV V200%, HR-CTV V150% that were found in agreement with the study by Richter et al. They reported higher integral doses for Co-60 in comparison to Ir-192 source(8). Plans with inverse planning optimization were observed to be better in comparison to plans with dose prescription on point A on the basis of variations in clinical parameters for both the sources. However, the self-optimizing algorithm in inverse planning technique doesn't found to be clinically acceptable in all the planned cases.

All the treatment plans with dose prescription on HR-CTV and manual optimization were observed to be clinically superior to plans with other two planning techniques. This technique is also considered as an improved method of planning by recent guidelines of GEC-ASTRO(13). For this method, the clinical and dosimetric parameters found to be comparable for both the sources

Co-60 and Ir-192. This method observed to be the best of all the three with minimum percentage of differences among all clinical and dosimetric parameter. Further, it was observed that manual optimization gives liberty to use the individual source characteristics to get the clinically comparable plans. However, the isodose lines for the Co-60 source are relatively isotropic along the source axis in contrast to Ir-192(7,16,17). This characteristic needs to be accounted during manual optimization to get a proper pear shape isodose distribution for carcinoma cervix cases, which is recommended(18,19). Strohmaier et al.(3) and Shukla et al.(20) also concluded that both the sources Co-60 and Ir-192 are clinically comparable on the basis of point doses and DVH parameters with manual optimization technique. In present study, it was observed that the geometry of source placement plays a key role in overcoming the inherent difference in physical parameters for both the sources and provide clinically comparable treatment plans. Further, it was noted that the complete source placement geometry is more important to obtain clinically comparable plans in comparison to individual source characteristics.

In the present study, it was observed that on average, Ir-192 source required 42% of treatment time as compared with Co-60 for the same treatment plan. The treatment time is a factor that is relatively less for Ir-192 source than Co-60 source for identical treatment delivery. However, a rigorous analysis of logistical aspects, Co-60 source was found to be favorable as it required less frequent source replacement. Typically, the Co-60 source recommended to be replaced within five years and the Ir-192 source is recommended to replace in 4 months. Moreover, this frequent source replacement of Ir-192 source also requires lots of manual work, radiation transport, time and regulatory clearances during source exchange.

CONCLUSION

The present study concludes that the treatment planning technique with manual optimization was found to be superior with clinically comparable plans for both the sources Co-60 and Ir-192. Switching from Ir-192 to Co-60 in HDR brachytherapy facility will bring advantage on logistical fronts without compromising clinical aspects.

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Sažetak

DOZIMETRIJSKA ANALIZA TEHNIKA OPTIMIZACIJE PLANIRANJA LIJEČENJA ZA IZVORE BRAHITERAPIJE CO-60 I IR-192 HDR U BOLESNICA S KARCINOMOM VRATA MATERNICE

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Uvod: Studija je osmišljena u svrhu dozimetrijske usporedbe tehnika optimizacije planiranja liječenja, radi analize ekvivalentnosti izvora Co-60 i Ir-192 HDR brahiterapije. Nadalje, ova studija planira analizirati ekvivalentnost na temelju tehničkih, logističkih i kliničkih aspekata za oba izvora.

Metode: U istraživanje su bile uključene 32 bolesnice s potvrđenom dijagnozom karcinoma vrata maternice. Napravljeni su usporedni planovi liječenja za tri različite tehnike optimizacije planiranja liječenja za izvore Co-60 i Ir-192, tj. (a) planovi s preskripcijom u točki A (sustav Manchester) s identičnim položajem zadržavanja izvora, (b) planovi s inverznim planiranjem i (c) planovi s preskripcijom na HR-CTV korištenjen ručne optimizacije. Planovi liječenja analizirani su na temelju kliničkih parametara HR-CTV V200%, V150%, V100%, D95%, D50%, D2cc mokraćnog mjehura, D2cc rektuma i doza na referentnim točkama prema ICRU za rektum i mokraćni mjehur.

Rezultati: Za planove s preskripcijom u točki A s identičnim položajem zadržavanja izvora, utvrđena je prosječna postotna razlika za HR-CTV V200% (6,3%), V150% (5,1%), V100% (1,8%), D2cc rektum (2,3%)) i referentnu točku prema ICRU za rektum (2,1%) i svi su parametri bili statistički značajni za oba izvora. Za planove s inverznom optimizacijom planiranja, ovi su parametri utvrđeni značajnim uz prosječnu postotnu razliku HR-CTV V200% (6,1%), V150% (4,9%), D50% (2,1%) i referentnu točku prema ICRU za rektum (2,3%). Za planove s preskripcijom doze na HR-CTV-u i ručnom optimizacijom, većina prosječnih postotnih razlika nije bila značajna, uz usporedive kliničke ishode za oba izvora. Nadalje, također je uočeno da je za prosječni izvor Ir-192 potrebno samo 42% vremena izvora Co-60 kod provedbe istog plana liječenja.

Zaključak: Među sve tri tehnike planiranja, tehnika planiranja s preskripcijom HR-CTV-a i ručnom optimizacijom pokazala se da ima usporedivu kliničku kvalitetu za oba izvora. Ova analiza pokazala je da geometrija postavljanja izvora može prevladati razlike u pojedinim značajkama izvora.

KLJUČNE RIJEČI: *kobalt-60, iridij-192, brahiterapija visoke brzine doze, rak vrata maternice*