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Original Research Article

Impact of discrete source step size on the 3D dosimetry of interstitial implants with high dose rate brachytherapy

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ABSTRACT

Background: High dose rate remote after loading brachytherapy machines have seen tremendous advancement both technologically and their clinical applications during the last 25 years. With the introduction of computerized remote after loading machines and computerized planning system, stepping source dosimetry system (SSDS) has become the system of choice making almost all traditional dosimetry systems obsolete. In this study we evaluated the impact of source step size on dosimetry of interstitial implant using parameters of ICRU-58 and various quality indices (QI).
Methods: For this study, 10 implant cases which have 3-D CT image-based planning were selected. Contouring of clinical target volume and various organs were done following standard guidelines for the same. Plans were optimized to achieve the desired clinical outcome using different source step sizes of 2.5, 5 and 10 mm respectively. Cumulative DVH's were calculated for the estimation of various ICRU-58 parameters and quality indices.
Results: The mean values of the target volumes, minimum target doses, treated volumes, low dose volumes; high dose volumes, overdose volumes, reference volumes, coverage, external volume, relative dose homogeneity, overdose volume and COIN indices have been presented for the source step sizes of 2.5 mm, 5 mm and 10 mm respectively. Among source step sizes used in this study, most favorable clinically acceptable dose distributions and dose homogeneity occurs around step size of 5 mm as predicted by the various parameters of ICRU-58 and dose quality indices.
Conclusions: Research study conclude that better dose distribution and dose homogeneity occurs for the source step size of 5 mm as predicted by the various parameters widely used for evaluating interstitial implant brachytherapy.

Keywords: Brachytherapy, Optimization, Quality indices, Remote after loading, Source step-size

INTRODUCTION

The practice of brachytherapy started soon after the discovery of radium (Ra-226) by Madam Curie in the last decade of nineteenth century. In the early years of twentieth century researchers realized the efficacy of radiation therapy in treating a number of malignant diseases. Brachytherapy (from the Greek word brachys, meaning "short-distance"), also known as internal radiotherapy, sealed source radiotherapy, curie therapy or endocurie therapy, is that form of radiotherapy where a radioactive source is placed in close vicinity or inside of the area requiring treatment. Brachytherapy is commonly used for effective treatment of cervical, prostate, breast and skin cancers and can also be used to treat tumours in many other body sites.[1-5] Brachytherapy can be used alone or in combination with other modalities such as surgery, chemotherapy and external beam radiotherapy (EBRT). Initially treatments were given based on individual experiences and clinical judgment ability. The

methods for intracavitary radiation were described in 1914 and 1919 by the Stockholm and Paris then the rules of the Manchester System for interstitial radium therapy were published by Patterson and Parker later by Meredith during the 1930s.[6,7] A new era of brachytherapy using artificial radio-nuclides opened with the discovery of artificial radioactivity by Pierre and Curie's daughter, Irene Curie and her husband Frederick Joliot in 1934.

High dose rate remote after loading brachytherapy machines have seen tremendous advancement both technologically and their clinical applications during the last 25 years. With the introduction of computerized remote after loading machines and computerized planning system, stepping source dosimetry system (SSDS) has become the system of choice making almost all traditional dosimetry systems obsolete. Modern imaging facilities allow more accurate definition of target volume and the localization of adjacent normal tissue and can also be used to guide after loading source devices.[8-10]

These machines ensure accurate source positioning, a time control structure and an automatic source removal. HDR remote after loading implants are treated by moving a single high activity (typically 10 Ci of ^{192}Ir or 2 Ci of ^{60}Co) source, welded to the end of a flexible cable, through many available channels. The source can be precisely positioned at any point in the implanted catheters or applicators. By programming dwell position and dwell time of the source, desired isodose distributions can be obtained. The tolerance of the patient was improved, and the irradiation is perfectly tailored case by case.[11-13]

Implementation of International Commission on Radiation Units and Measurements (ICRU) guidelines had been a challenge basically due to use of orthogonal radiographs for brachytherapy planning.[14,15] Because it was not possible to visualize various volumes on radiographs, so practically these guidelines were very rarely practiced in brachytherapy clinics in its completeness. With the advancement of 3D imaging modalities especially CT and MRI scanners and their availability in a number of radiotherapy clinics have become preferred imaging modality for brachytherapy planning. With the use of CT/MRI images, now it is possible to identify various organs of interest and target volume and assess the quality of implant using various volumetric parameters as recommended by ICRU-58 and other international brachytherapy societies/scientific organizations.[16-21]

Therefore present study has been undertaken to assess the impact of source step size on achieving optimal dose distribution in different brachytherapy interstitial implant procedures with high dose rate remote after loading unit consisting ^{192}Ir radioactive source as predicted by various parameters recommended by ICRU-58 and dose quality indices.[22]

METHODS

For this study, 10 interstitial implant cases (4 Ca breast, 4 Ca Cervix and 2 Ca tongue) that had undergone computerized axial imaging (CT) after catheter/applicator implant were included. Breast implants were performed using Rowland adjustable breast implant template (RABIT) three plane (Nucletron, an Elekta Company) having holes to insert needles in triangular geometry and stainless-steel needles having length 200 mm were used. Ca cervix cases had undergone perineal implant with MUPIT template (Nucletron, an Elekta Company) having holes to insert needles in square geometry and 200 mm stainless steel needles were used. Tongue implants were done in a very complex geometry with stainless needles having length 120 mm. Axial CT images were acquired with implanted catheter/applicator in-situ on a wide bore multi-detector (40) CT scanner (Somatom Sensation Open, Siemens) with 3 mm slice thickness with extended field of view (FOV) to avoid clipping of body contour. These axial images were transferred to the three-dimensional brachytherapy treatment planning system (Plato BPS v 13.6, Nucletron) via network cable. Contouring for body, organs at risk and tumor (target) were done on axial CT images. For the delineation of the target help of pre-implant CT/MR images were taken in the cases it was available. Marker points were also placed to define the boundaries of the clinical target volume (CTV) on the surgical clips in ca breast cases when it was implanted and could be visualized on the axial images.

Localization and reconstruction of the catheters/applicators were also done on axial CT images. To avoid any ambiguity in catheter identification, a fixed catheter numbering system was adapted for all the plans. Catheters were numbered from lateral to medial, posterior to anterior and from inferior to superior direction. All the catheters were followed from connector end to tip end. As it was difficult to locate the first dwell position of a catheter in an axial image, the catheters were followed till the end having solid metallic closing represented by hyper-dense impression on the axial CT image. Then a known value offset (measured in a separate study) was used to correct for the location of the first dwell position.

In addition, skin entry and exit points were also marked for all breast cases. The active dwell positions were defined in such a manner that extreme dwell positions remained at least 5 mm inside from the skin entry/exit point. For tongue and cervix cases, the dwell positions were defined from top i.e. from first dwell position to the inferior extent of the CTV. Dose points were calculated using triangular geometry for all breast cases all along the active length of the catheters. For all cervix cases square geometry was used to calculate dose points all along the active length of the catheters. For tongue cases due to very complex geometry dose points were calculated on the target surface using a distance grid of 3 mm.

The initial prescriptions for all the cases were 6 Gy to dose points. The Plato treatment planning system calculated the dose distribution using the algorithm recommended by American Association of Physicists in Medicine (AAPM) task Group-43 reports.[23] The plan was further optimized on dose points with a dwell time gradient of 0.25 to improve the dose distribution. Cumulative dose volume histograms were estimated for a dose ratio of 3 and 100000 sample points for both body and target. Each case was planned for three source step sizes namely 2.5 mm, 5 mm and 10 mm. Thus, a total of 30 plans (10 cases x 3 plan) were generated and analyzed for the various parameters of ICRU-58 and quality indices. A brief description of the relevant ICRU-58 parameters used in the study is given below:

Mean Central Dose: The mean central dose (MCD) is taken to be the arithmetic mean of the local minimum doses between sources, in the central plane, or in the central planes if there is more than one.

Minimum Target Dose: The Minimum Target Dose is the dose selected and specified by the radiation oncologist as adequate to treat the CTV. It corresponds to the prescribed dose in many instances. It is related to the source arrangement and is the dose delivered at the periphery of the CTV. The application is planned in such a way that all points of the CTV receive a dose (at least) equal to the Minimum Target Dose. The Minimum Target Dose is known in some American centers as the 'minimum peripheral dose.[34] It is equal to about 90% of the prescribed dose in the Manchester System for interstitial therapy. It is known as the 'reference dose' in the Paris System, where it is equal to 85% of the mean basal dose.

Treated volume: The Treated Volume is the tissue volume that, based on the actual implant, receives at least a dose selected and specified by the radiation oncologist as appropriate to achieve the purpose of the treatment (e.g., tumor eradication or palliation). Following the definition of the Minimum Target Dose, the Treated Volume is the volume encompassed by an isodose surface, the value of which is the Minimum Target Dose. The Treated Volume should, in principle, entirely encompass the CTV however; this may not necessarily always be the case.

Low Dose Volume: A low-dose volume is defined as a region, within the CTV, where the dose is less than 90% of the prescribed dose. The maximum dimension of the low-dose region in any plane calculated should be reported. In implants for which the CTV is included within the Minimum Target Dose isodose, the occurrence of a low-dose region is exceptional. If the CTV is not covered by the Minimum Target Dose isodose, there will be low-dose regions due to geographical miss. Low-dose regions should be reported in order to correlate the local recurrence rate with the dose distribution.

High Dose Volume: The high-dose region should be defined as that volume encompassed by the isodose corresponding to 150% of the Mean Central Dose (MCD) around the sources in any plane parallel to the central plane where a high-dose region is suspected. The maximum dimensions of all regions, in all planes calculated, should be reported. In order to correlate radiation dose with late damage, the high-dose regions around sources should be assessed.

Over Dose Volume: The over dose region should be defined as that volume encompassed by the isodose line corresponding to 200% of the Mean Central Dose (MCD). The maximum dimensions of all regions, in all planes calculated, should be reported. In order to correlate radiation dose with late damage, the high-dose regions around sources should be assessed.

Reference Volume: The Reference Volume is the volume encompassed by an isodose defined in relation to the Mean Central Dose. At present, there is no general agreement on how to relate reference volume and Mean Central Dose. For example, in the Paris System, the reference dose is 85% of the Mean Central Dose. In using a reference volume for reporting, the relation of the reference dose to the Mean Central Dose should always be given (e.g. 90%, 80%, 75%). A relevant comparison must use the same relationship between the Mean Central Dose and the dimension of the reference volume. If this is done, it is possible to compare dose and volume between different treatments for a fixed relation between the reference isodose and the Mean Central Dose. If this is not done, an apparently similar prescribed dose and volume may correspond to totally different implants.

In the present study, the quality indices used are the coverage index (CI), the external volume index (EI), the relative dose homogeneity index (DHI), the overdose volume index (ODI), and the confirmality index (COIN). A brief definition of these parameters has been given below.

- Coverage Index (CI): The fraction of the target volume that receives a dose equal to or greater than the reference dose.

$$CoverageIndex(CI) = \frac{\text{Target volume encompassed by reference isodose } (TV_{dref})}{\text{Target Volume (TV)}} \quad \text{.....(1)}$$

- External Volume Index (EI): The ratio of the volume of normal tissue that receives a dose equal to or greater than the reference dose to the volume of the target.

$$ExternalVolumeIndex(EI) = \frac{\text{Normal tissue volume encompassed by reference isodose } (NTV_{dref})}{\text{Target Volume (TV)}} \quad \text{.....(2)}$$

- Relative Dose Homogeneity Index (DHI): This is defined as the ratio of the target volume which receives a dose in the range of 1.0 to 1.5 times of the

reference dose to the volume of the target that receives a dose equal to or greater than the reference dose.

$$Dose Homogeneity Index (DHI) = \frac{TV_{dref} - TV_{d150\%}}{TV_{dref}} \quad \text{.....(3)}$$

- Overdose Volume Index (ODI): This is the ratio of the target volume which receives a dose equal to or more than 2.0 times of the reference dose to the volume of the target that receives a dose equal to or greater than the reference dose.

$$Overdose Volume Index (ODI) = \frac{TV_{d200\%}}{TV_{dref}} \quad \text{.....(4)}$$

- Confirmality Index (COIN): The confirmality index as described by D. Baltas et al is the product of two coefficients c1 and c2. c1 is the fraction of CTV that is enclosed by the reference isodose volume and c2 is the fraction of Vref that is covered by CTV and also a measure of how accurately the CTV is covered by Dref. It is also a measure of how much normal tissue volume outside CTV is covered by Dref.

$$Confirmality Index (COIN) = \frac{V_{CTVref}}{V_{CTV}} X \frac{V_{CTVref}}{V_{ref}} \quad \text{.....(5)}$$

Assume a hypothetical implant geometry optimized to encompass the target volume by reference isodose and with no spillage of reference isodose to the normal tissue or any organ at risk, no high or low dose regions, the values of above mentioned quality indices should be as

CI = 1, EI = 0, DHI = 1, ODI = 0, and COIN = 1.

Statistical analysis

The data of the study have been handled using Microsoft Excel 2007 and all statistical analysis also have been performed using the same including plotting of various scatter curves. Second order polynomial function has been fitted as trend line and values of the coefficients and R2 have been recorded.

RESULTS

The results of the study have been summarized below

Target Volume: The mean target volume (mean ± SD) for all the 10 cases was 41.15 ± 54.35 cm^3 with a varying range from 5.54 to 183 cm^3. The mean target volume of cervix cases was 86.72 ± 64.84 cm^3. The mean target volume of the breast cases was 13.25 ± 4.25 cm^3 and that of the tongue cases was 5.82 ± 0.39 cm^3.

Mean Central Dose (MCD): The mean central doses calculated for 8 patients (4 breast+4 Cervix) were 758.63±131.61 cGy, 723.59±94.47 cGy and 731.67±162.87 cGy for the source step size of 2.5mm, 5mm and 10mm respectively. The mean central dose vs. source step size scatter plot resulted a second order polynomial curve $y = 2.084x^2-29.64x+819.7$ ($R^2 = 1$). Graph shows a minimum value of MCD for source step size of approximately 7 mm.

Minimum Target Dose (MTD): The mean minimum target doses were 426.7±190.92 cGy, 429.7±185.94 cGy and 417.3±173.24 cGy for the source step sizes of 2.5 mm, 5 mm and 10 mm respectively. The mean of the MTD plotted vs. source step size resulted a second order polynomial curve $y = -0.4907x^2 + 4.88x + 417.57$ ($R^2 = 1$). Graph shows a peak value of MTD for 5 mm step size (Figure 2).

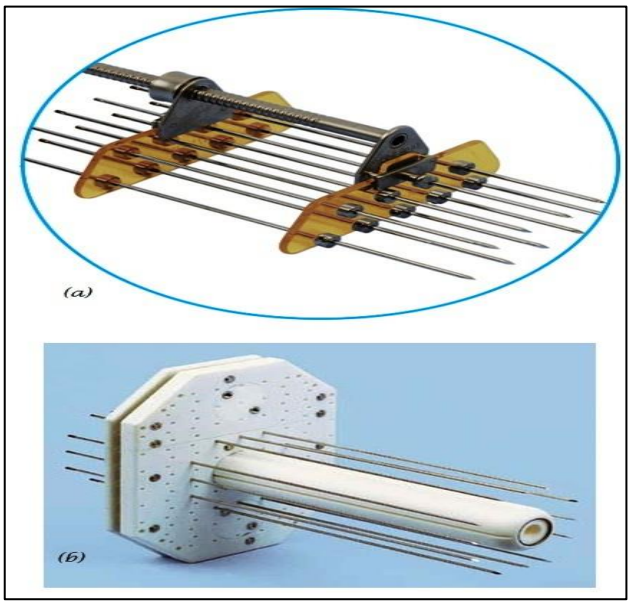

Figure 1: Implant templates (a) Rowland breast implant template, (b) MUPIT perineal template.

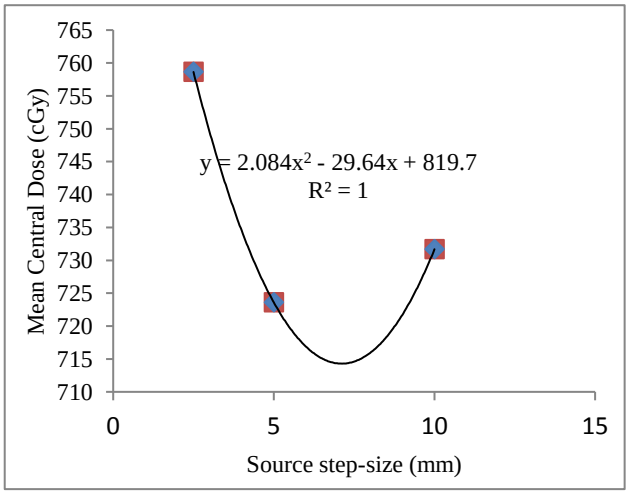

Figure 2: Source step-size vs. mean central dose.

Treated Volume (TV): The mean treated volumes were 33.5±42.69 cm^3, 33.92±44.10 cm^3 and 33.58±44.14 cm^3 for 2.5 mm, 5 mm and 10 mm source step sizes. A scatter plot of TV vs. source step size resulted a second order polynomial $y = -0.0311x^2 + 0.399x + 32.701$ ($R^2 = 1$). It is evident from the graph that treated volume increases very fast as step size increases and attains a highest value corresponding to source step size of 6.5mm and then falls down on increasing the step size further (Figure 3).

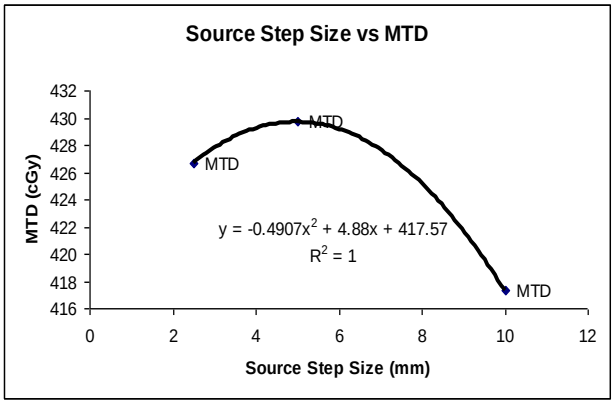

Figure 3: Minimum target dose vs. source step size.

Low Dose Volume (LDV): The mean low dose volumes were 4.77±8.83, 4.01±7.62 and 4.67±7.55 cm^3 for the source step sizes of 2.5, 5 and 10 mm respectively. A plot of LDV vs. step size resulted a second order polynomial $y = 0.0577x^2 - 0.7342x + 6.245$ ($R^2 = 1$). Curve shows lowest value of LDV corresponding to step size of approximately 6.5 mm (Figure 3).

High Dose Volume (HDV): The mean high dose volumes (HDV) were 15.63±25.07, 15.30±25.22 and 14.86±24.46 cm^3 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of HDV vs. source step size resulted a second order polynomial curve $y = 0.0056x^2 - 0.173x + 16.026$ ($R^2 = 1$). It is quite evident from the curve that high dose volume reduces very rapidly on increasing the source step size (Figure 3).

Over Dose Volume (ODV): The mean over dose volumes were 7.85±12.73, 7.85±13.02 and 7.56±12.49 cm^3 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of ODV vs. source step size was fitted to second order polynomial $y = -0.0079x^2 + 0.0606x + 7.7489$ ($R^2 = 1$). The trend line indicates a slight increase in the over dose volume reaching to a maximum value for the 3.5mm step size and then falls off rapidly with increasing source step size (Figure 3).

Reference Volume (RV): The mean reference volumes were 67.87±47.15, 67.4±44.10 and 58.58±45.40 cm^3 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of RV vs. source step size resulted a second order polynomial $y = -0.2101x^2 + 1.388x + 65.713$ ($R^2 = 1$). The reference volume shows higher value for smaller source step sizes up to 3-3.5 mm then it drops down with further increase in the source step size (Figure 3).

Coverage Index (CI): The mean coverage indices were 0.8589±0.1072, 0.8591±0.1076 and 0.8524±0.1215 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of CI vs. source step size resulted a second order polynomial $y = -0.0002x^2 + 0.0014x + 0.8566$ ($R^2 = 1$). The curve shows initially slight improvement in coverage of the target with source step size giving best CI around 4 mm step size then drops down rapidly (Figure 4).

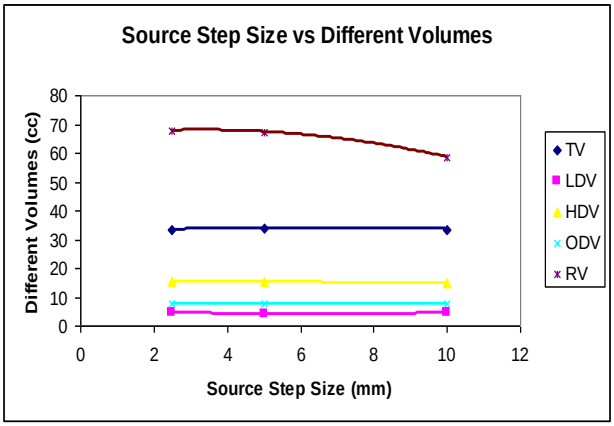

Figure 4: Source step size vs. different volumes.

External Volume Index (EI): The mean external volume indices were 2.2282±1.6079, 2.2199±1.8220 and 2.2564±1.7837 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of EI vs. source step size resulted a second order polynomial $y = 0.0014x^2 - 0.0139x + 2.2542$ ($R^2 = 1$). The curve shows lowest value of EI corresponding to source step size of 5 mm and an increase for smaller or larger step sizes (Figure 4).

Relative Dose Homogeneity Index (HI): The mean relative dose homogeneity indices were 0.5766±0.3386, 0.5438±0.3359 and 0.5540±0.3617 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of HI vs. source step size resulted a second order polynomial $y = 0.002x^2 - 0.0283x + 0.6346$ ($R^2 = 1$). The curve shows better dose homogeneity as indicated by HI for smaller source step sizes and approaches to worst dose homogeneity for source step size of approximately 7 mm and slight improvement after that (Figure 4).

Over Dose Volume Index (OI): The mean over dose volume indices were 0.2204±0.2865, 0.3772±0.4862 and 0.2300±0.2823 for the source step sizes of 2.5, 5 and 10 mm respectively. Scatter plot of OI vs. source step size resulted a second order polynomial $y = -0.0123x^2 + 0.1549x - 0.0901$ ($R^2 = 1$) (Figure 4).

Conformality Index (COIN): The mean COIN indices were 0.3215±0.1658, 0.3226±0.1831 and 0.3127±0.1757 for the source step sizes of 2.5, 5 and 10 mm respectively.

Scatter plot of COIN vs. source step size resulted a second order polynomial $y = -0.0003x^2 + 0.0028x + 0.3164$ ($R^2 = 1$). The curve indicates best confirmality for source step size of 4.5 mm (Figure 4).

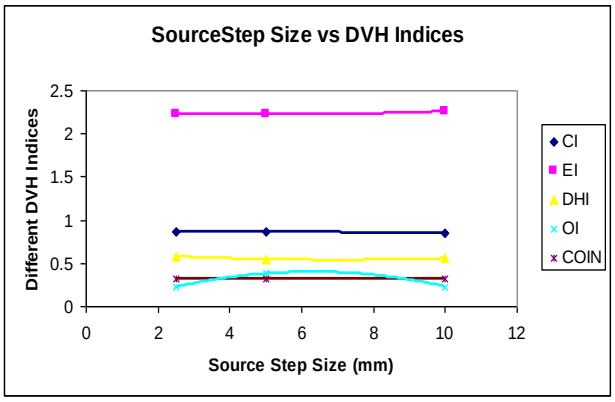

Figure 5: Source step size vs. different DVH indices.

DISCUSSION

Target delineation has become a reality with the introduction of CT to radiotherapy planning. Direct visualization of dose distributions within the target volume could be evaluated instead of indirect ways to calculate doses received by the target. Furthermore; instead of assessment through reference points; organs at risk could now be delineated. Kestin LL published the results of improved coverage with CT image-based planning of breast implants.[24] Nag et al published guidelines for Image-Guided Brachytherapy in carcinoma of uterine cervix in 2004.[25] Many studies comparing image-based planning techniques with conventional BT planning were published since then and the common findings focus around accurate target delineation, better tumor coverage, accurate OARs dose determination and lower normal tissue doses. M. Tibor et al in their study reported average minimum target and reference doses were 69% and 86% and mean confirmality, homogeneity, external volume and overdose volume indices were 0.78, 0.67, 0.22 and 0.13 respectively.[26] They concluded that geometrical optimization resulted in superior confirmality and slightly inferior homogeneity as compared to non-optimized plans. T.S. Kehwar et al on the basis of quality indices and radiobiological modeling have shown that that inter source spacing = 1.0 cm, inter catheter spacing = 1.0 cm, for single-plane implant and inter plane separation between 0.75 cm to 1.25 cm provide better dose conformity and uniformity. S. J. Park et al in their work on effect of source step size have concluded that the optimal step sizes which provide the most homogenous dose distributions are 4-6 mm.[27,28] Moreover they find that finer step sizes (1-3 mm) do not improve dose homogeneity whereas coarser step sizes (7-10 mm) provide lower dose homogeneity the findings of our study are more or less in good agreement with the published studies.

CONCLUSION

So, we may conclude that better dose distribution and dose homogeneity occurs for the source step size of 5 mm as predicted by the various parameters widely used for evaluating interstitial implant brachytherapy. However, for the validation of the results, further study based on a large number of plans needs to be analyzed as statistical variations are very high in this small group of cases included into the present study.

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REFERENCES

1. Van Limbergen E, PÖTTER R, Gerbaulet A, Potter R, Van Limbergen E, Mazeron JJ, Meertens H. GEC-ESTRO Handbook of brachytherapy. GEC-ESTRO Handbook of brachytherapy; 2002.
2. Ash D, Al-Qaisieh B, Bottomley D, Carey B, Joseph J. The impact of hormone therapy on post-implant dosimetry and outcome following Iodine-125 implant monotherapy for localised prostate cancer. Radiotherapy and oncology. 2005;75(3):303-6.
3. Van Limbergen. "Breast cancer". In Gerbaulet A, Pötter R, Mazeron J, Limbergen EV. The GEC ESTRO handbook of brachytherapy. Belgium: ACCO; 2005.
4. Van Limbergen. "Skin cancer". In Gerbaulet A, Pötter R, Mazeron J, Limbergen EV. The GEC ESTRO handbook of brachytherapy. Belgium: ACCO; 2005.
5. Gerbaulet A. "General aspects". In Gerbaulet A, Pötter R, Mazeron J, Limbergen EV. The GEC ESTRO handbook of brachytherapy. Belgium: ACCO; 2005.
6. Paterson R, Parker HM. A dosage system for interstitial radium therapy. British J Radiology. 1938;11(124):252-66.
7. Meredith WJ. Radium Dosage: The Manchester System. Edinburgh: Livingston 1967.
8. Auer T, Hensler E, Eichberger P, Bluhm A, Gunkel A, Freysinger W, et al. 3D-Navigation in der interstitiellen stereotaktischen Brachytherapie. Strahlentherapie und Onkologie. 1998;174(2):82-7.
9. Mazeron JJ, Gerbaulet A, Simon JM, Hardiman C. How to optimize therapeutic ratio in brachytherapy of head and neck squamous cell carcinoma? Actual Oncol. 1998;37:583-91.
10. Thomas L, Chemin A, Lasbareilles O, Palussiére J, Ducassou M, Piqneux J, et al. 30 MRI and CT imaging during pulsed dose rate intra cavitary brachytherapy in carcinoma of the cervix. Radiotherapy and Oncology. 1998;47:S8.
11. Nag S, editor. Principles and practice of brachytherapy. Futura Publ.; 1997.
12. Resch A, Pötter R, Van Limbergen E, Biber E, Klein T, Fellner C, et al. Long-term results (10

years) of intensive breast conserving therapy including a high-dose and large-volume interstitial brachytherapy boost (LDR/HDR) for T1/T2 breast cancer. Radiotherapy and oncology. 2002;63(1):47-58.
13. Saw CB, Suntharalingam N. Reference dose rate for single- and double-plane Ir-192 implants. Med Phys. 1988;15:391-6.
14. Bethesda, MD. ICRU report 38. International Commission on Radiation Units and Measurements. 1985;1-20.
15. ICRU. International Commission on Radiation Units and Measurements, "Dose and volume specification for reporting interstitial therapy". ICRU Report 58 1997; Bethesda, Maryland, USA.
16. Wambersie A, Battermann JJ. Dose specification and reporting: the ICRU recommendations. Principles and practice of brachytherapy, Joslin, CAF, Flynn, A., Hall, EJ (Eds), ARNOLD. 2001:91-102.
17. Saw CB, Suntharalingam N. Quantitative assessment of interstitial implants. Int J Radiat Oncol Biol Phys. 1991;20:135-9.
18. Wu A, Ulin K, Sternick ES. A dose homogeneity index for evaluating Ir-192 interstitial breast implants. Med Phys. 1988;15:104-7.
19. Meertens H, Borger J, Steggerda M, Blom A. Evaluation and optimization on interstitial brachytherapy dose distributions. In: Mould RF, Battermann JJ, Martinez AA, Speiser BL, editors. Brachytherapy from radium to optimization, Veenendaal: Nucletron International BV. 1994:300-6.
20. Mazeron JJ, Gerbaulet A, Simon JM, Hardiman C. How to optimize therapeutic ratio in brachytherapy of head and neck squamous cell carcinoma? Actual Oncol. 1998;37:583-91.
21. Baltas D, Kolotas C, Geramani K, Mould RF, Ioannidis G, Kekchidi M, et al. A conformal index (COIN) to evaluate implant quality and dose specification in brachytherapy. Inter J Radiation Oncology, Biology, Physics. 1998;40(2):515-24.
22. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: a review. International J Radiation Oncology, Biology, Physics. 2006;64(2):333-42.
23. Nath R, Anderson LL, Luxton G, Weaver KA, Williamson JF, Meigooni AS. Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. Medical physics. 1995;22(2):209-34.
24. Kestin LL, Jaffray DA, Edmundson GK, Martinez AA, Wong JW, Kini VR, et al. Improving the dosimetric coverage of interstitial high-dose-rate breast implants. International J Radiation Oncology, Biology, Physics. 2000;46(1):35-43.
25. Nag S. High dose rate brachytherapy: its clinical applications and treatment guidelines. Technology in cancer research & treatment. 2004;3(3):269-87.
26. Major T, Polgár C, Fodor J, Somogyi A, Németh G. Conformality and homogeneity of dose distributions in interstitial implants at idealized target volumes: a comparison between the Paris and dose-point optimized systems. Radiotherapy Oncology. 2002;62(1):103-11.
27. Kehwar TS, Akber SF, Passi K. Qualitative dosimetric and radiobiological evaluation of high-dose-rate interstitial brachytherapy implants. Inter J Medical Sci. 2008;5(1):41-9.
28. Park SJ, Kamrava M, Banerjee R, Demanes DJ. Effects of Source Step Size on Dose Distribution in High-Dose-Rate Brachytherapy for Esophageal Cancer. Brachytherapy. 2013;12:S60.

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