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Treatment Planning and Optimization in High-dose-rate Brachytherapy

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Abstract High-dose-rate (HDR) brachytherapy is typically used for the treatment of lung, esophagus, breast, bronchus, and prostate cancer as well as gynecological cancers. In HDR brachytherapy, radiation is delivered to the tumor through the catheters placed in or adjacent to the tumor. The primary goal of this article is to provide the overview of current literature regarding the application of HDR planning and optimization techniques. A summary of commonly used optimization technique known as heuristics method (stochastic and deterministic) is also provided.

Keywords: *HDR, brachytherapy, treatment planning, optimization*

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1. Introduction

Among the treatment options available for the cancer management of the cancer, radiation therapy is commonly used technique. The method of delivering an ionizing radiation can be external or internal. The external beam radiation therapy (EBRT) involves the radiation dose delivery to the tumor in multiple directions from outside the body; whereas in internal radiation therapy, which is also known as brachytherapy, radioactive source is placed inside the body to irradiate the tumor. Generally, brachytherapy is categorized into two groups: high-dose-rate (HDR) brachytherapy and low-dose-rate (LDR) brachytherapy. This article is focused on HDR brachytherapy since it is more commonly used modality compared to the LDR brachytherapy.

HDR brachytherapy is a technique which delivers high-dose-rate radiation, often greater than 12 Gy/hr, to the tumor temporarily using the catheters placed in or adjacent to the tumor. Iridium-192 (Ir-192) is a commonly used isotope in HDR brachytherapy. Radiation dose is delivered to the tumor based on the pre-defined dwell time and dwell locations in the catheters, which are removed after the completion of the radiation delivery. [1] HDR brachytherapy can be performed either as a monotherapy or as a boost treatment after an EBRT. HDR brachytherapy is typically used to treat lung, esophagus, breast, bronchus, and prostate cancer as well as gynecological cancers. [2] An example of HDR procedure flow is shown in Figure 1.

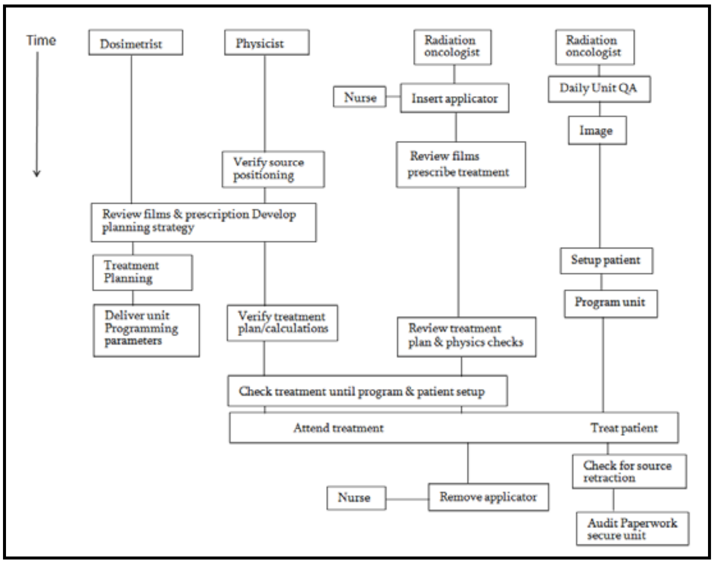

Figure 1. An example of HDR brachytherapy procedure flow

While HDR brachyherapy can spare the health tissues, treatment outcome is dependent on the accuracy of the treatment plan, which contains the patient-specific dose distributions. Several treatment planning systems (TPS) in HDR brachytherapy implement quantitative models, which can optimize the dose distribution by varying the dwell times throughout the catheters. This process can increase the dose to the tumor, but it will also increase in dose to the organs at risk (OAR), thus resulting conflicting objectives in the treatment plan [3].

There are several optimization algorithms, which can help in achieving the optimal dose distribution. The advancement in optimization algorithms for HDR brachytherapy has led to growing number of literature on this topic. The main purpose of this study is to review the current literature on treatment planning and dose optimization in HDR prostate brachytherapy.

2. Methods

The research was conducted based on the literature review using PubMed and Google Scholar. The terms used for the literature search were "brachytherapy", "HDR", "planning', and "optimization". The literature review showed two types of HDR brachytherapy treatment: (1) interstitial (catheters placed in the tumor tissue, such as prostate tumor), and (2) intracavitary (catheters placed in the body cavity, such as uterus). Only the literature relevant to the main goal of this article are discussed.

3. Results and Discussion

3.1. Treatment Planning

In the earlier days, the HDR optimization was performed mainly on the principle of conventional forward planning method. In this method, the optimization process does not include the information on the OARs and other normal tissues, thus resulting in homogeneous dose distributions to the target volume. However, in reality, the target volume may have tissues that have different electron density, which may cause inhomogeneous dose distributions. [4] It is imperative to know the location of OARs for a better approximations of the target volume. Several authors have studied the geometric optimization to adjust the treatment plan for breast cancer patients [5] and prostate cancer patients [6]. Although the location of the target and OARs can be available from the computed tomography (CT) image of the patients, those information may not be used during the optimization process; hence, it may lead to under-dose to the target volume and over-dose to the OARs. [5,6] Such situation typically requires the manual adjustments of the dwell times followed by the recalculation of the dose distribution by the TPS. This process is repeated until the generation of the optimal treatment plan. Such trial and error method could be a problem for the busy cancer centers where treatment planning time is limited, and the generation of optimal treatment plan is dependent on the experience of the treatment planner [7].

In the recent years, a number of mathematical models, such as inverse planning [4], have been introduced with an objective of placing the restrictions on the target volume and OARs prior to the optimization processes. The inverse planning technique considers patient anatomy during the optimization process; thus, eliminating the manual adjustment of the dwell times. For instance, Lessard *et al.* [8] have done the CT based inverse planning, in which possible dwell locations are automatically selected and a set of dwell times meeting the treatment planning criteria (constraints to the target and OARs) are determined.

3.2. Optimization

The current literature reveals several mathematical models to optimize the dose distribution automatically in HDR brachytherapy, and the automatic optimization is mainly classified into heuristic and exact methods. [Table 6] It has been reported that the heuristics, which may not provide the optimal solution, is more realistic with reasonable computation time and its results being close to the optimal solution. Colaco et al. [9] reported that the stochastic heuristics have a probability aspect in their search process and converge towards a global optimum. An example of stochastic heuristics is the inverse planning by simulated annealing (IPSA) [2], in which the objective function is a cost function associated with dose objectives for each target and OAR. The treatment planner needs to define the upper and lower limits of the acceptable dose in the dose points for each tissue type (target and OAR) and the weights associated with exceeding these limits. During the optimization, dose outside the range is linearly penalized. Furthermore, objective function value changes by allowing the dwell times to decrease or increase randomly in each iteration, thus resulting a new set of the dwell times with an acceptance of better objective function. The simultaneous optimization of several objectives is now possible using the multicriteria evolutionary algorithms, which can generate a wide range of optimal solutions. [10] The mathematical interpretation of multicriteria evolutionary algorithms is beyond the scope of the paper, and readers may want to refer to the publication by Laahanas *et al.* [10] for better understanding of these algorithms.

Several authors [11,12,13] have also reported the deterministic heuristics, which are related to the variance-based objectives. In deterministic algorithms, the optimization process is repeated several times for the optimized weighted sum based on the dose variance objectives for dose points in and on the target volume. The solution from such optimization is convex, which leads to the rapid convergence of deterministic heuristics towards a global Pareto front by using gradient methods: Broyden-Fletcher-Goldfarb-Shanno (BFGS) quasi-Newton algorithm and the Fletcher-Reeves-Polak-Ribiere (FRPR) algorithm [11,12,13].

Recently, a number of studies [1,14-21] have been done using hybrid inverse planning and optimization (HIPO) algorithm, which includes both the stochastic and a deterministic heuristic. The HIPO algorithm involves the pre-defined number of catheters by the user and these catheters are placed randomly in feasible template holes. [14] The HIPO algorithm can change one of the catheters to another unoccupied feasible position in a random manner. In that way, the HIPO algorithm optimizes both the dwell times of the dwell location in each catheter and the position of each catheter. [1] Furthermore, HIPO algorithm uses the limited-memory Broyden-Fletcher-Goldfarb-Shanno (L- BFGS) to optimize the dwell times and simulated annealing to change the catheter positions. [1] The catheter position distribution from such process can be accepted or rejected based on the objective function, which is the weighted sum of objectives for different anatomical structures. During this process, dose values for the OARs and normal tissues above a dose limit are penalized. However, for the target volume, dose values that are above or below a dose limit are penalized.

There is no doubt that HDR brachytherapy has become popular mainly for its advantages [22]: (a) better dose optimization capability with regards to shaping the isodose lines per treatment volume, (b) treatment procedure is shorter, (c) reduction of positioning errors during the treatment, (d) small applicators, thus less pain for the patient during the applicator insertion inside the patient, and (e) reduction of radiation exposure to the personnel. However, the HDR brachytherapy also has several limitations. [22] For example, HDR treatment is quite complicated system, which requires special training to operate the system. HDR dose optimization codes are also quite difficult to understand for an a new HDR personnel. Furthermore, since HDR is associated with the large dose delivery per fraction, an error during the delivery can cause severe consequences. Thus, an accurate treatment delivery is essential to protect the patients from unwanted high radiation dose in the HDR brachytherapy.

4. Conclusion

HDR brachytherapy is an internal radiation therapy, in which irradiation to the tumor occurs through the placement of radioactive source inside the patient body. Due to the accuracy of radiation delivery in HDR brachytherapy, an increasing number of patients are treated using this technique. The current literature review suggests that most of the mathematical models for HDR treatment planning uses the maximum and minimum weights and corresponding weights for the optimization process. However, the uncertainty involved in the HDR planning and optimization is yet to be addressed.

References

[1] Trnková P, Pötter R, Baltas D, Karabis A, Fidarova E, Dimopoulos J, Georg D, Kirisits C. New inverse planning technology for image-guided cervical cancer brachytherapy: description and evaluation within a clinical frame. Radiother Oncol. 2009 Nov;93(2):331-40.

[2] Jacob D, Raben A, Sarkar A, Grimm J, Simpson L. Anatomy-based inverse planning simulated annealing optimization in high-dose-rate prostate brachytherapy: significant dosimetric advantage over other optimization techniques. Int J Radiat Oncol Biol Phys. 2008 Nov 1;72(3):820-7.

[3] Baltas D, Zamboglou N. (2006). 2D and 3D planning in brachytherapy. In W. Schlegel, T. Bortfeld, & A. L. Grosu (Eds.), New technologies in radiation oncology (pp. 237-254). New York: Springer.

[4] Pouliot J, Lessard E, Hsu IC. (2005). Advanced 3D planning. In B. Thomadson, M. Rivard, & W. Butler (Eds.), Brachytherapy physics (2nd. ed., pp. 393-414). Seattle, WA: AAPM.

[5] Anacak Y, Esassolak M, Aydin A, Aras A, Olacak I, Haydaroğlu A. Effect of geometrical optimization on the treatment volumes and the dose homogeneity of biplane interstitial brachytherapy implants. Radiother Oncol. 1997 Oct;45(1):71-6.

[6] Charra-Brunaud C, Hsu IC, Weinberg V, Pouliot J. Analysis of interaction between number of implant catheters and dose-volume histograms in prostate high-dose-rate brachytherapy using a computer model. Int J Radiat Oncol Biol Phys. 2003 Jun 1;56(2):586-91.

[7] Giannouli S, Baltas D, Milickovic N, Lahanas M, Kolotas C, Zamboglou N, Uzunoglu N. Autoactivation of source dwell positions for HDR brachytherapy treatment planning. Med Phys. 2000 Nov;27(11):2517-20.

[8] Lessard E, Hsu IC, Pouliot J. Inverse planning for interstitial gynecologic template brachytherapy: truly anatomy-based planning. Int J Radiat Oncol Biol Phys. 2002 Nov 15;54(4):1243-51.

[9] Colaço MJ, Dulikravich GS. (2009). A survey of basic deterministic, heuristic and hybrid methods for single objective optimization and response surface generation. Proceedings of Thermal Measurement and Inverse Techniques 4 (METTI 4). http://www.crcnetbase.com/doi/abs/10.1201/b10918-13.

[10] Lahanas M, Baltas D, Zamboglou N. A hybrid evolutionary algorithm for multi-objective anatomy-based dose optimization in high-dose-rate brachytherapy. Phys Med Biol. 2003 Feb 7;48(3):399-415.

[11] Milickovic, N., Lahanas, M., Papagiannopoulou, M., Karouzakis, K., Baltas, D., & Zamboglou, N. (2001). Application of multiobjective genetic algorithms in anatomy based dose optimization in brachytherapy and its comparison with deterministic algorithms. Conference 28 Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 4, 3919-3922.

[12] Milickovic N, Lahanas M, Baltas D, Zamboglou N. (2001). Comparison of evolutionary and deterministic multiobjective algorithms for dose optimization in brachytherapy. Proceedings of the First International Conference on Evolutionary Multi-Criterion Optimization, 1993, 167-180.

[13] Shwetha B, Ravikumar M, Katke A, Supe SS, Venkatagiri G, Ramanand N, Pasha T. Dosimetric comparison of various optimization techniques for high dose rate brachytherapy of interstitial cervix implants. J Appl Clin Med Phys. 2010 Jul 12;11(3):3227.

[14] Pokharel S, Rana S, Blikenstaff J, Sadeghi A, Prestidge B. Evaluation of hybrid inverse planning and optimization (HIPO) algorithm for optimization in real-time, high-dose-rate (HDR) brachytherapy for prostate. J Appl Clin Med Phys. 2013;14(4):4198.

[15] Baltas D, Katsilieri Z, Kefala V, Papaioannou S, Karabis A, Mavroidis P, Zamboglou N. (2009). Influence of modulation restriction in inverse optimization with HIPO of prostate implants on plan quality: Analysis using dosimetric and radiobiological indices. Proceedings of the 11th International Congress of the IUPESM (World Congress on Medical Physics and Biomedical Engineering), 25 (1), 283-286.

[16] Jamema SV, Kirisits C, Mahantshetty U, Trnkova P, Deshpande DD, Shrivastava SK, Pötter R. Comparison of DVH parameters and loading patterns of standard loading, manual and inverse optimization for intracavitary brachytherapy on a subset of tandem/ovoid cases. Radiother Oncol. 2010 Dec;97(3):501-6.

[17] Mavroidis P, Katsilieri Z, Kefala V, Milickovic N, Papanikolao N, Karabis A, Zamboglou N, Baltas D. Radiobiological evaluation of the influence of dwell time modulation restriction in HIPO optimized HDR prostate brachytherapy implants. Journal of Contemporary Brachytherapy 2010; 2(3): 117-128.

[18] Trnkov a P, Baltas D, Karabis A, Stock M, Dimopoulos J, Georg D, Pötter R, Kirisits C. A detailed dosimetric comparison between manual and inverse plans in HDR intracavitary/interstitial cervical cancer brachytherapy. Journal of Contemporary Brachytherapy, 2010; 2(4): 163-170.

[19] Moorthy S, Sakr H, Hasan S, Samuel J, Al-Janahi S, Murthy N. Dosimetric study of SIB-IMRT versus SIB-3DCRT for breast cancer with breath-hold gated technique. Int J Cancer Ther Oncol 2013;1(1):010110.

[20] Pokharel S, Rana SB. Feasibility of Multisolutions Optimization Technique for Real-Time HDR Brachytherapy of Prostate. American Journal of Cancer Science 2013; 2:135-146.

[21] Lu L. Dose calculation algorithms in external beam photon radiation therapy. Int J Cancer Ther Oncol 2013; 1(2):01025.

[22] Kubo HD, Glasgow GP, Pethel TD, et al. High dose-rate brachytherapy treatment delivery: report of the AAPM Radiation Therapy Committee Task Group No. 59. Med Phys 1998;25(4):375-403.