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Short Review Article

Dose calculations in high-dose rate brachytherapy planning for cancer treatment

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ABSTRACT

This article provides the overview of current literature regarding the application of high-dose rate planning and optimization techniques. A summary of commonly used optimization technique known as heuristics method (stochastic and deterministic) is also provided.

Keywords: Brachytherapy, high-dose rate, optimization, treatment planning

INTRODUCTION

Among the treatment options available for the cancer management of 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. In general, 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 common used modality compared to the LDR brachytherapy. HDR brachytherapy is a technique which delivers HDR radiation, often >12 Gy/h, to the tumor temporarily using the catheters placed in or adjacent to the tumor. Iridium-192 is a commonly used isotope in HDR brachytherapy. The 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] While HDR brachytherapy can spare the health tissues, and 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. Hence, it is essential to understand the commonly used optimization algorithms in HDR brachytherapy. The main purpose of this study is to review the current literature on treatment planning and dose optimization in HDR prostate brachytherapy.

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 literatures relevant to the main goal of this article are discussed.

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RESULTS AND DISCUSSION

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.

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 1). 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. Colaço and Dulikravich[9] reported that the stochastic heuristics have a probability aspect in their search process and converge toward a global optimum. An example of stochastic heuristics is the inverse planning by simulated annealing,[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 Lahanas *et al*.[10] for a better understanding of these algorithms.

Several authors have also reported the deterministic heuristics, which are related to the variance-based objectives.[11-13] 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 toward a global Pareto front by using gradient methods: Broyden-Fletcher-Goldfarb-Shanno (BFGS) quasi-Newton algorithm and the Fletcher-Reeves-Polak-Ribiere algorithm.[11-13]

Recently, a number of studies have been done using hybrid inverse planning and optimization (HIPO) algorithm, which includes both the stochastic and a deterministic heuristic.[1,14-21] 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 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 regard 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 a quite complicated system, which requires special training to operate the system. HDR dose optimization codes are also quite difficult to understand for 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.

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 use 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.

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PEER REVIEW

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CONFLICTS OF INTEREST

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