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Comparison of dose and catheter optimization algorithms in prostate high-dose-rate brachytherapy

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ABSTRACT

PURPOSE: The purpose of this work was to compare the hybrid inverse treatment planning optimization (HIPO), inverse dose−volume histogram-based optimization (DVHO), and fast simulated annealing stochastic algorithm (IPSA). The catheter optimization algorithm HIPO was also compared with the Centroidal Voronoi Tessellation (CVT) algorithm.

METHODS AND MATERIALS: In this study, eight high-dose-rate prostate cases were randomly selected from an anonymized bank of patients. Oncentra Prostate v4.1 was used to run DVHO and the HIPO catheter optimization (HIPO_cat), whereas Oncentra Brachy v4.3 was used for the remaining. For fixed catheter configurations, DVHO plans were compared with IPSA and HIPO. For catheter positions optimization, CVT and HIPO_cat algorithms were compared with standard clinical template plans. CVT catheters were further restrained to the template grid (CVT_grid) and compared with HIPO_cat.

RESULTS: For dose optimization, IPSA and HIPO were not different from each other. The urethra D_{10} and the computation time were found significantly better with IPSA and HIPO compared with DVHO ($p < 0.0001$). All other dosimetric indices were not statistically different from each others ($p > 0.05$). For catheter placement, CVT plans were better, whereas HIPO_cat plans were significantly worse ($p < 0.05$) than standard clinical plans. CVT_grid plans were similar to clinical plans and fulfilling American Brachytherapy Society guidelines down to 12 catheters, whereas HIPO_cat plans do not for all catheter numbers. The CVT algorithm run time was significantly faster than HIPO_cat ($p < 0.0001$).

CONCLUSIONS: Dose optimization engines IPSA, DVHO, and HIPO give similar dosimetric results. The CVT approach was found to be better than HIPO_cat and was able to reduce the number of catheters significantly.

Keywords: HDR brachytherapy; Dose optimization; Needle planning; Inverse planning

Introduction

High-dose-rate (HDR) brachytherapy has proven itself to be a treatment method of choice for many men with localized prostate cancer (1). The survival and local control rate are excellent (2). HDR brachytherapy may be used as a monotherapy; however, it is usually combined with external beam radiation. Excellent results are observed for both monotherapy (3−5) and boost (2, 6, 7). Over the last decade, HDR brachytherapy treatment went through a revolution and several techniques were developed to optimize planning and treatment delivery. Three-dimensional ultrasound now allows real-time planning and real-time guidance during insertion (8). A fast simulated annealing stochastic algorithm (IPSA) was developed by Lessard and Pouliot (9) for anatomy-based inverse planning and is capable of generating an optimized plan in less than 1 min. IPSA is also capable of producing plans with high target coverage, low dose to organs at risk (OAR) and a high dose homogeneity (10, 11). It is widely used in the clinic and was shown to be efficient

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(9−13). As stochastic algorithms are known to be slow, several other investigators have worked on combining deterministic and stochastic algorithms. Multiobjective optimization using dose−volume histogram (DVH) and dose variance-based objective functions has been published (14, 15). However, the final result of these algorithms can depend on the initial starting point, and they can be trapped in a local minimum. The hybrid inverse treatment planning optimization algorithm (HIPO) (16) was recently proposed as an alternative to IPSA. There is, however, limited data showing the longer-term efficiency in the clinic.

In current prostate clinical procedures, a predetermined number of catheters are implanted with a template, without considerations for tumor size or shape (17). Although this method is clinically proven, there are indications that chronic urinary toxicity could be related to the number of catheters used (18−20) and there would be an advantage to optimize the number of catheters and their positions. The study by Vargas *et al.* (18) has also shown that an implant of 14 catheters and more is associated with an increase in the toxicity. Recent studies have focused their work in developing algorithms to optimize the catheters within the prostate, and they all showed the feasibility of reducing the number of catheters (16,21−26). Recently, the uniform catheter distribution of the Centroidal Voronoi Tessellation (CVT) algorithm was shown to be robust to catheter insertion errors and faster than other algorithms (26). Furthermore, the algorithm has the advantage of being independent of dose optimization engines (26).

The treatment planning system Oncentra Prostate, from Elekta Brachytherapy, is equipped with a preimplant optimization algorithm, HIPO (16, 25), which optimizes the catheter distribution. The treatment planning system is also equipped with a postimplant optimization algorithm using an inverse dose−volume histogram-based optimization (DVHO). Oncentra Brachy, also from Elekta Brachytherapy, is on the other hand equipped with two dose optimization algorithms: HIPO and IPSA.

The purpose of this work was to compare HIPO and DVHO to the well-known IPSA dose optimization algorithm. The catheter optimization algorithm HIPO was also compared with the newly proposed CVT algorithm. Those comparisons were performed by extracting clinically relevant dose parameters from DVH.

Methods and materials

DVHO and HIPO vs. IPSA

In this study, eight HDR prostate cases were randomly chosen from an anonymized bank of treated HDR prostate patients and used in a previous study (26). All patients were treated with the microSelectron HDR ^{192}Ir v2 source. The mean prostate volume was 51 cm^3 (standard deviation = 11 cm^3; range, 37−65 cm^3). The Radiation Therapy Oncology Group 0321 protocol was used for the treatment (19). The 16-slice Philips Brilliance Big Bore system (Philips Medical, Amsterdam, The Netherlands) was used to image the patients using 2-mm-thick slices with 0.371-mm resolution for X and Y. The target (prostate) and the OAR were contoured, and the catheters reconstructed, using Oncentra Brachy (OcB) v4.3 (Elekta Brachytherapy, Veneedal, The Netherlands). The OAR included the rectum, bladder, and urethra. Oncentra Prostate (OcP) v4.1 (Elekta Brachytherapy, Veneedal, The Netherlands) was used to perform DVHO dose optimizations (25, 27) and HIPO catheter optimizations (16, 25, 28). At this time, the DICOM RT plan files created in OcB are not compatible with OcP; however, it is possible to import catheters manually in OcB. Therefore, the OcP catheter optimization algorithm HIPO, hereafter HIPO_cat, was used to optimize 17 catheters within the prostate, with the urethra and region anterior to it excluded. Those catheters were used for dose optimizations in OcB with both HIPO and IPSA algorithms and in OcP for the DVHO algorithm. Treatment plans were generated with a prescription dose of 15 Gy per fraction, and a 1-mm dose margin was used for the prostate in each dose optimization engine. The algorithm parameters were optimized to give clinically acceptable dosimetric results and are presented in Table 1. The HIPO dose optimization algorithm (16, 28) was used with 1000 volume points and 10 surface points per cm^2. Those parameters were then used for planning in the rest of the study. Clinically relevant dose parameters were extracted from the DVHs for each dose optimization algorithm and used to compare the algorithms. A verification of the guidelines of the American Brachytherapy Society (ABS) (29) was also performed to identify plans that fail these criteria. Computation times for dose optimization, including DVH and dose calculation, from each algorithm were also compared. OcB was run on a Dell Precision Workstation T7500 (Intel Xeon CPU E5620, 2.40 GHz, four cores, 6 GB of RAM), whereas OcP is running on an HP EliteBook 8530w (Intel core 2 duo CPU T9600, 2.80 GHz, two cores, 4 GB of RAM).

Finally, for IPSA, the impact of a normal tissue objective on OAR was studied, as it is present and mandatory in both DVHO and HIPO. Furthermore, the influence of an IPSA dose−volume constraint on the bladder was evaluated (max dose of 7.5 Gy with a weight of 50). For these two studies, 4 patients were chosen based on the fact that the bladder was present in the anterior part of the prostate or almost touching it, leading to higher dose to the bladder in IPSA. The normal tissue was constructed from a margin of 2 cm around the prostate with both the prostate and OAR excluded from the new volume. A maximum dose of 18 Gy with a weight of 50 was used in IPSA. This choice was motivated by the DVHO normal tissue parameter.

CVT vs. HIPO_cat

To compare the HIPO_cat (25) and CVT algorithm (26), plans were generated, using the same structures as the