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Technical Note

Introduction of inverse dose optimization for ultrasound-based high-dose-rate boost brachytherapy: How we do it in Kiel

Frank-André Siebert[1,*], Sabine Wolf[1], Hagen Bertermann[2], Nils Nürnberg[2], Gunnar Bockelmann[1], Bernhard Kimmig[1]

[1]University Hospital of Schleswig-Holstein, Campus Kiel, Clinic of Radiotherapy, Kiel, Germany
[2]Urologische Gemeinschaftspraxis, Kiel, Germany

ABSTRACT

OBJECTIVES: To describe the introduction of inverse planning optimization for a two clinical target volume (CTV) concept in the online planning technique of temporary high-dose-rate brachytherapy for prostate cancer.

METHODS AND MATERIALS: Dose−volume constraints were defined delivering a prescription dose of 8.5 Gy for CTV_1 (whole prostate) and 15 Gy for CTV_2 (peripheral zone). A total of 38 implants of 20 patients were inversely planned using the constraints and dose indices (D_{90} $CTV_{1,2}$; V_{200} $CTV_{1,2}$; $D_{2\ cc}$ rectum; $D_{0.1\ cc}$ urethra; dose nonhomogeneity ratio; and conformal index) compared against those derived from conventional planning (CP).

RESULTS: The inversely planned (IP) treatment plans showed similar target volume coverage than by CP. The value of D_{90} CTV_1 for CP was 5.62 Gy and 5.63 Gy for IPs. For CTV_2, the D_{90} was also similar between both methods: 11.03 Gy and 10.89 Gy, respectively. Only V_{200} CTV_2 was found to be significantly lower for CP than for IP: 5.76% vs. 8.14% ($p < 0.01$). Values for $D_{0.1\ cc}$ urethra were found to be: 9.57 Gy and 9.02 Gy, respectively. Rectal dosimetry: $D_{2\ cc}$ Rectum was quite stable with 6.04 Gy and 6.12 Gy for CP and IP, respectively. The conformal index and dose nonhomogeneity ratio values for CTV_1 and CTV_2 for both planning types were very similar.

CONCLUSIONS: After defining an objective second target volume CTV_2 and introducing adequate IP constraints to the treatment planning system, clinically applicable treatment plans could be created by an IP approach. They feature user independency, time saving, and good preservation of the OARs.

Keywords: High-dose-rate brachytherapy; Inverse dose optimization; Prostate cancer

Introduction

Radiotherapy is an alternative treatment option for the treatment of localized prostate cancer. Brachytherapy (BT) can be applied as temporary high dose rate (HDR) or as permanent (seeds) implantation. A common treatment option, especially in intermediate- and high- risk cases—prostate-specific antigen level higher than 10 ng/mL, Gleason sum greater than seven, T-stage minimal T2b—is the application of HDR-BT using typically an ^{192}Ir stepping source afterloader (1−3). In our clinic, intermediate- and high-risk prostate cancers are generally treated in combination of external beam radiation therapy giving 50 Gy in a four-field box technique (15MV photons) to the pelvis, delivering only 40 Gy to the prostate by external beam radiation therapy using individual blocks sparing the prostate in the anterior and posterior fields (4). Two complementary HDR-BT fractions, each of 15 Gy, are delivered 2 weeks apart. Dose is prescribed to the periphery of the prostate gland—the clinical target volume two (CTV_2). The CTV_1 is defined as the dose prescribed to the whole prostate and should be encompassed by 8.5 Gy. This treatment strategy started in 1986 using a preplanning method (4). In the present report, the recent improvement for our technique, application of inverse dose optimization for our HDR boost technique is described.

* Corresponding author. University Hospital of Schleswig-Holstein, Campus Kiel, Clinic of Radiotherapy, Arnold-Heller-Str 3, Haus 50, 24105 Kiel, Germany. Tel.: +49-0-431-597-3022; fax: +49-0-431-597-3110.

E-mail address: Frank-Andre.Siebert@uksh.de (F.-A. Siebert).

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Methods and materials

The technique of HDR-prostate BT using preplanning is already well covered in the literature (4–6). To improve the quality of temporary HDR implantations of the prostate, our clinic introduced a real-time planning protocol in 2003 (7), which was refined and improved within the following years. The recent implant procedure used in our clinic is outlined in the following paragraphs.

Needle implantation and imaging

Patient setup and general needle implantation are described in previous publications (4, 8). The needles are arranged in a U-shaped form in the periphery of the prostate without performing a preplan. According to the International Commission on Radiation Units and Measurements Report 58 (9), CTVs were defined. For our treatment strategy, the CTV is being split in two parts, namely CTV_1 and CTV_2. The prescribed dose of the U-shaped CTV_2 is 15 Gy. Furthermore, the whole prostate gland, often denoted as CTV_1, should be treated with 8.5 Gy. As an organ at risk (OAR), the urethra dose should not exceed 10 Gy per fraction.

Even for intensity-modulated BT (8), the geometry of the catheters is essential. To later obtain an adequate dose distribution, the implantation needles are normally positioned in distances of about 7 mm from one needle to another in the transversal plane. Because of the shadowing effect of the implant needles, first of all the ventral needles are then placed in the prostate, followed by the dorsal ones. If the prostate gland is large enough and the urethra remains in the anterior section of the gland normally, two more implant needles are inserted in the medium part of the prostate. These needles help to cover the dose in the middle section and in the apex of the gland (Figs. 1 and 2 for illustration of the implant geometry and the definition of the CTV_2). The exact depth and the curvature of the implant needles are determined by live longitudinal transrectal ultrasound (TRUS) imaging using the Vitesse v. 2.5 software (Varian Medical Systems, Inc., Palo Alto, CA). In a previous study, the accuracy (better than 1 mm) of the detection of the needle tips was investigated (10).

The transversal TRUS image data of the prostate is acquired in 2.5-mm step width via a video connection into the Vitesse (Varian) software from the bladder neck to the end of the prostatic apex. Contouring of the prostate, urethra, seminal vesicles, and the visible part of the rectal wall is manually performed according to the Groupe Européen de Curiethérapie and the European Society for Therapeutic Radiology and Oncology and European Association of Urology guidelines (1). Thereafter, images and structures are exported in DICOM format into the commercial treatment planning system (TPS), BrachyVision 8.1 (Varian). Shortly after the export of the image data set, the treatment planning procedure starts.

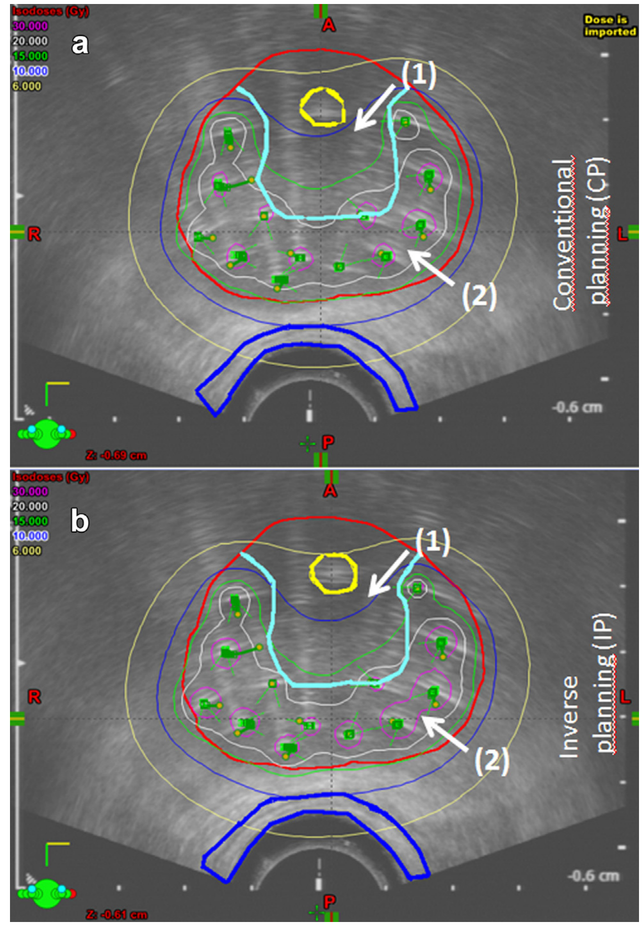

Fig. 1. Comparison of the dose distribution of an arbitrary patient using conventional planning (CP; a) and inverse planning (IP; b). White arrows outline the major differences between those two planning types: The CP leading to more dosage to the organs at risk (1), the IP creating hot spots within the clinical target volume (2).

Inverse planning approach

So far, a forward planning or conventional planning (CP) method of adjusting dwell times to optimize the dose distribution of an HDR-prostate implant has successfully been practiced (4) using distances between dwell positions of 5 mm in each catheter. Despite strong arguments suggest a mathematical approach to treatment planning, the former method of manual optimization keenly depends on the planning physicist's experience and consumes between 10 and 15 min time. Also, the latter accepted treatment plan will surely meet the therapist's requirements, but cannot account to be the truly optimal plan, so that there exists no better solution to escalate more dose to the target volume or less to the OAR. The mathematical approach to dose optimization defines dose constraints to all structures in advance, an optimization algorithm determines independently of the user and within short time (one minute) the best possible dwell time distribution according to those chosen boundary conditions. This change of perspective in planning organization has contributed to the term of