Physica Medica 44 (2017) 58–65

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original paper

Comparison of different treatment planning optimization methods for vaginal HDR brachytherapy with multichannel applicators: A reduction of the high doses to the vaginal mucosa is possible

Mauro Carrara[a,*], Davide Cusumano[b,1], Tommaso Giandini[a], Chiara Tenconi[a], Ester Mazzarella[a], Simone Grisotto[a], Eleonora Massari[a], Davide Mazzeo[a], Annamaria Cerrotta[c], Brigida Pappalardi[c], Carlo Fallai[c], Emanuele Pignoli[a]

[a] Medical Physics Unit, IRCCS Istituto Nazionale dei Tumori, via Venezian 1, 20133 Milan, Italy
[b] Unità Operativa Complessa di Fisica Sanitaria, Fondazione Policlinico Universitario Agostino Gemelli, Largo Agostino Gemelli 8, 00168 Roma, Italy
[c] Radiotherapy Unit, IRCCS Istituto Nazionale dei Tumori, via Venezian 1, 20133 Milan, Italy

ARTICLE INFO

Keywords:
HDR brachytherapy
Multichannel applicator
Vaginal cancer
HIPO
IPSA

ABSTRACT

Purpose: A direct planning approach with multi-channel vaginal cylinders (MVCs) used for HDR brachytherapy of vaginal cancers is particularly challenging. Purpose of this study was to compare the dosimetric performances of different forward and inverse methods used for the optimization of MVC-based vaginal treatments for endometrial cancer, with a particular attention to the definition of strategies useful to limit the high doses to the vaginal mucosa.

Methods: Twelve postoperative vaginal HDR brachytherapy treatments performed with MVCs were considered. Plans were retrospectively optimized with three different methods: Dose Point Optimization followed by Graphical Optimization (DPO + GrO), Inverse Planning Simulated Annealing with two different class solutions as starting conditions (surflPSA and homogIPSA) and Hybrid Inverse Planning Optimization (HIPO). Several dosimetric parameters related to target coverage, hot spot extensions and sparing of organs at risk were analyzed to evaluate the quality of the achieved treatment plans. Dose homogeneity index (DHI), conformal index (COIN) and a further parameter quantifying the proportion of the central catheter loading with respect to the overall loading (i.e., the central catheter loading index: CCLI) were also quantified.

Results: The achieved PTV coverage parameters were highly correlated with each other but uncorrelated with the hot spot quantifiers. HomogIPSA and HIPO achieved higher DHIs and CCLIs and lower volumes of high doses than DPO + GrO and surflPSA.

Conclusions: Within the investigated optimization methods, HIPO and homoglPSA showed the highest dose homogeneity to the target. In particular, homogIPSA resulted also the most effective in reducing hot spots to the vaginal mucosa.

1. Introduction

High dose rate (HDR) brachytherapy (BT) is today one of the most widely used treatment techniques for vaginal and endometrial cancer, aiming at obtain high local tumor control while ensuring a significant sparing of the involved organs at risk (OARs). Gynecological BT is usually exploited as adjuvant therapy after external beam radiation therapy (EBRT) because of the ability to deliver high doses with extremely steep dose gradients, with a resulting sparing of healthy tissues that already suffer the consequences of the primary EBRT treatment [1,2].

Depending on the location and the extent of the residual disease after EBRT, intracavitary or combined intracavitary-interstitial applications can be adopted [3,4]. In particular, interstitial needles are required for deep lesions (i.e., > 5 mm depth) to achieve adequate coverage, whereas for superficial lesions of the vagina (i.e., ≤5 mm depth) BT treatments are usually delivered by means of intracavitary cylindrical applicators only [5].

* Corresponding author at: Medical Physics Unit, Dept. of Diagnostic Imaging and Radiotherapy, Fondazione IRCCS Istituto Nazionale dei Tumori, Via Venezian, 1, 20133 Milano, Italy.
E-mail address: mauro.carrara@istitutotumori.mi.it (M. Carrara).
[1] This work was partially carried out when the author was working for the: Medical Physics Unit, Dept. of Diagnostic Imaging and Radiotherapy Fondazione IRCCS Istituto Nazionale dei TumoriVia Venezian, 1, 20133 Milano, Italy.

https://doi.org/10.1016/j.ejmp.2017.11.007
Received 17 August 2017; Received in revised form 20 October 2017; Accepted 9 November 2017
Available online 20 November 2017

The simplest cylindrical applicator currently available is the traditional single-channel vaginal cylinder (SVC), consisting of a single central catheter located inside a cylinder and able to provide dose distributions with radial symmetry. If on the one hand this applicator is very easy to be used, on the other hand the degrees of freedom for the optimization of a treatment plan (i.e., source dwell positions and times for central channel) according to the anatomy of a specific patient are very limited, since only symmetrical dose distributions around the catheter are achievable.

With the increasing availability of imaging techniques such as Computed Tomography (CT) and Magnetic Resonance (MR), and the consequent development of 3D treatment planning systems (TPSs), which have led to the modern image-guided adaptive BT, the major challenge has become the achievement of personalized therapies [6] and the delivery of more conformal dose distributions to the target volume. To this aim, the multi-channel vaginal cylinder (MVC) applicator was developed, consisting of a cylindrical applicator with a central catheter surrounded by a fixed number of equally spaced peripheral channels. If compared to SVC, the MVC geometry provides more degrees of freedom (i.e., source dwell positions and times not only for central channel but also for peripheral channels) to customize the dose distribution to each patient, maximizing dose to the target while reducing dose to the OARs [7–11]. Its clinical implementation has already shown promising early clinical outcomes with high rates of local control and reduced toxicity [12], in particular potential late rectal complications were minimized [13].

Different optimization algorithms and strategies were implemented in the clinical practice and reported in literature to optimize the dose distribution with MVC. In fact, the high number of degrees of freedom available with the MVC applicator makes a direct planning approach particularly challenging, and the concept of dose optimization has become a topic for interesting studies. Palmqvist et al. [14] demonstrated that inverse planning is able to generate better treatment plans than those manually optimized. Lapuz et al. [15] showed that the best results could be obtained using a particular class solution of the Inverse Planning Simulated Annealing (IPSA), i.e. the inverse optimization algorithm developed by Lessard and Pouliot [16], based on fast simulated annealing, and implemented in the Oncentra Brachy TPS (Nucletron – an Elekta Company, Stockholm, Sweden). To the best of our knowledge, the application of another commercially available inverse planning algorithm, the Hybrid Inverse Planning Optimization (HIPO) algorithm recently added as a further optimization option in the Oncentra Brachy TPS [17], has instead never been reported for MVC applicator-based vaginal treatments.

Despite the interesting results in terms of target coverage and OAR sparing obtained with the MVC applicator, specific strategies to limit high doses to the vaginal mucosa without reducing the overall target coverage should be exhaustively investigated and could still be improved. Considering that early and late vaginal toxicity is a substantial problem in gynecological BT [18], with a mild to moderate morbidity (e.g., vaginal stenosis, dryness, mucositis and/or bleeding) occurring in the majority of patients within the first 2 years after the end of treatment [19], the balance between loading of the central channel and of the peripheral channels of the MVC applicator should be adequately optimized. In fact, an excessive loading of the peripheral channels may lead to very high doses to the applicator-vaginal mucosa interface.

The purpose of this study was to compare the dosimetric performances of different optimization methods implemented in the Oncentra Brachy TPS for MVC-based vaginal vault treatments, with particular attention to the definition of methods that might limit the very high doses to the vaginal mucosa.

2. Materials and methods

2.1. Patients selection

This retrospective study analyzes 12 vaginal treatments of patients with endometrial cancer treated with postoperative HDR intracavitary BT using the MVC applicator. BT was used as adjuvant treatment (i.e., 6 cases) and in the case of vaginal vault recurrences (i.e., 6 cases). The mean age of the patients was 56 years (range: 44–77). BT was an integral part of the treatment and was delivered as a boost after EBRT (prescription dose: 45 Gy in 25 fractions), with a dose of 2500 cGy subdivided in 5 fractions.

2.2. Treatment preparation

The MVCs used in this study (Multichannel Applicator, Elekta) are cylindrical MR/CT compatible applicators available in different diameters (i.e., 25 mm, 30 mm, 35 mm and 40 mm) and designed with a central catheter surrounded by a fixed number of equally spaced peripheral catheters. Although the central catheter could accommodate an intrauterine tube, for clinical reasons only the standard vaginal central catheter was used for the 12 treatments selected for this study. Six cases were treated with the 25 mm diameter applicator (i.e., with six peripheral catheters) ant the other six were treated with the 30 mm diameter applicator (i.e., with eight peripheral catheters).

The applicator size was chosen by the radiation oncologist, taking into account both the comfort of the patient and the best contact of the applicator surface with the vaginal mucosa. Local anesthetic gel was used as lubricant, and additional oral analgesia was provided to more suffering patients. Catheterization was performed for all patients before applicator insertion, and right before CT imaging of the pelvic district (3 mm slice thickness) the bladder was filled with 45 cc of 0.9% NaCl + 5 cc contrast agent solution (Gastrografin, Bayer). Imaging and replanning were repeated for each treatment fraction.

2.3. Contouring and applicator reconstruction

The CT images were imported in the TPS (Oncentra Brachy ver 4.5.2., Elekta, Sweden), and target and OARs were contoured by a radiation oncologist. Clinical Target Volume (CTV) was defined as the presumed residual tumor, estimable on CT images on the basis of clinical evaluations performed before and after EBRT. Without macroscopic disease, the maximum distance of the CTV from the applicator surface was 5 mm. In the presence of a local recurrence, the vaginal mucosa around the macroscopic disease was completely encompassed by the CTV contour, even if it was greater than 5 mm. The upper third of the vagina was usually treated except in three cases where the PTV longitudinal extension was longer.

No margin was added to the CTV for the definition of the Planning Target Volume (PTV). A further structure called PTV_{PLAN} was defined as the union of the applicator volume with the PTV to allow for the automatic activation of dwell positions within the target.

Vaginal mucosa, bladder and rectum were contoured as OARs. The bladder was entirely contoured, the rectum was contoured up to 1 cm cranially to the target and the vaginal mucosa was approximated to a 3 mm layer of tissue surrounding the applicator. Applicator reconstruction was performed using a digital library containing details about the outer shape of the applicator and all possible source paths inside it.

2.4. Treatment plan optimization

Plan optimization was performed with the three different methods objective of this study: Dose Point Optimization (DPO) followed by Graphical Optimization (GrO), IPSA with two different class solutions as starting conditions and HIPO. The DPO + GrO method is a