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DOSE AND VOLUME PARAMETERS FOR CT BASED TREATMENT PLANNING IN INTRACAVITARY BRACHYTHERAPY FOR CERVICAL CANCER. A COMPARISON BETWEEN 2D AND 3D BRACHYTHERAPY

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Abstract. CT-imaging based planning in intracavitary brachytherapy allows optimization of the dose distribution by patient basis. In addition to classical used point dose, the dose-volume histogram (DVH) analysis enables further possibilities for prescribing and reporting the correct dose. A group of 18 patients were treated with 38 fractions using different applicators and CT-based treatment planning. Each application was analyzed in detail. The clinical target volumes were contoured and also the organs at risk. The dose administered to bladder and rectum was analyzed according to ICRU Reports 38 and dose-volume parameters (*e.g.* D2cc represents the minimal dose for the most irradiated 2 cm^3). The values of the doses were analyzed including the external beam radiotherapy. Total doses were biologically normalized to conventional 2 Gy fractions (α/β = 10 Gy for target and 3 Gy for organs at risk). Individual changes for active dwell positions and dwell weights are guided by a concept of DVH constraints for target and organs at risk. This helps to detect and avoid the severe overdoses.

Key words: brachytherapy, applicators, organs at risk, dose-volume histogram.

1. INTRODUCTION

Derived from ancient Greek words for short distance (brachy) and treatment (therapy), the brachytherapy (BT) is sometimes called seed implantation and is an outpatient procedure used in the treatment of different kinds of cancer. Radioactive “seeds” are carefully placed inside of the cancerous tissue and positioned in a manner that attacks most efficiently the cancer. BT has been proven to be very effective and safe, providing a good alternative to surgical removal of the prostate, breast, and cervix, while reducing the risk of certain long-term side effects. Internal radiation is a form of treatment where a source of radiation is placed inside the body. This allows a higher dose of radiation to directly reach the area where the tumor is, or was prior to surgery. BT reduces the radiation exposure of the surrounding healthy tissues, such as the bowel and bladder [1].

External beam pelvic radiation therapy (EBRT) combined with intracavitary BT is the standard radiotherapeutic management for patients with carcinoma of the cervix. Low dose rate (LDR) brachytherapy has been used since the early 1900s but starting in the late 1950s with the "Cathetron" cobalt-60, high dose rate (HDR), the brachytherapy has become an acceptable treatment modality [2].

HDR brachytherapy is more advantageous, because the treatment time is shorter (of the order of minutes rather than days). Treatments are performed on an ambulatory basis, and there is no need for hospitalization implying less patient discomfort, too. Modern HDR devices utilize a small diameter source used with a thinner tandem, thus reducing the need for dilation of the cervical canal. Modern treatment planning systems for brachytherapy permit dose distribution optimization. Because the cervix is located close to the bladder and rectum, it is important for radiation treatment to be tightly focused on the cervix to avoid serious side effects. Radiation beams are precisely targeted inside the cervix, controlling the location and intensity, and offering excellent precision and maximum dose concentration. Radiation exposure to healthy cervical tissue and nearby organs is minimized or eliminated, reducing gastrointestinal and sexual function side effects. Common treatment options for cervical cancer include surgery, radiation therapy, and chemotherapy, often in combination.

Surgical options for cervical cancer include radical hysterectomy, or removal of the uterus, cervix, and part of the vagina. Women who undergo this procedure can no longer have children. Radical trachelectomy, or removal of the cervix, is a more conservative surgical option that helps fertility preservation. Precancerous cervical abnormalities can be treated with conization, or cone biopsy, a procedure that involves the removal of a cone-shaped wedge from the cervix [3]. Our group of patients was treated with external beam therapy in combination with BT.

By contrast with BT, the EBRT is a method for delivering a beam of high-energy X-rays or proton beams to the location of the tumor. The beam is generated outside the patient (usually by an X-ray linear accelerator and cyclotron or synchrotron for proton beam) and is targeted to the tumor site. The X-rays can destroy the cancer cells and careful treatment planning allows the surrounding normal tissues to be protected. No radioactive sources are placed inside the patient's body. Treatment recommendations for cervical cancer are primarily based on the stage of the cancer. Other factors include the age, health, personal preferences, and desire to have children. Radiation therapy works as well as surgery for treating early-stage cervical cancers. Larger cancers are best treated with combined therapy using radiation, surgery, and chemotherapy.

Side effects of radiation treatment include problems that occur as a result of the treatment itself as well as of radiation damage to healthy cells in the treatment area. The number and severity of side effects depend on the type of radiation and dosage the patient receives and the part of the body being treated. Radiation therapy can cause early and late side effects. Early side effects occur during or immediately after treatment and are typically abolished within a few weeks. Commonly, early side effects of radiation therapy include tiredness or fatigue and skin problems. In the treatment area, the skin may become more sensitive, red, irritated, or swollen. Other skin changes include dryness, itching, peeling, and blistering.

2. MATERIALS AND METHODS

A group of 18 patients were treated with 38 fractions of HDR brachytherapy using different applicators and CT based treatment planning. For each patient and for the same application, two types of BT methods were performed: 2D BT and 3D BT. The patients were treated only by 2D BT. We scanned the patients by CT to make a comparison between the two BT techniques in order to improve them.

The aim of this study is to compare and analyze the tumor dose coverage and the dose to organs at risk which are obtained by using 2D and 3D treatment planning, according to ICRU (International Commission of Radiation Units) Reports 38 and dose – volume parameters.

Before BT, the patients were first treated by EBRT. The prescribed dose for EBRT was 50 Gy: 25 fractions with 2 Gy per day. The prescribed dose for BT was 7.5 Gy, once a week for two weeks.

BT for cervical or endometrial (uterine) cancers is typically performed using a “tandem and ovoid” (T&O) applicator or a “tandem and ring” (T&R) applicator, which reaches both the cervix and uterus. The tandem is a long, thin metal tube that is passed through the cervix, into the uterus. The ovoids are circular hollow capsules and the ring is a hollow ring, which are placed in the vagina and pressed against the cervix.

2D TREATMENT PLANNING

For 2D treatment planning we used projection imaging methods, such as radiography. These images are used for verifying and documenting the placement of usually a single catheter or applicator. This is the case for the “standard treatments” using simple standard applicators as in the case of a cylinder applicator for the postoperative intracavitary brachytherapy of corpus uteri carcinomas [4]. We used this method for all the applicators. The treatment delivery itself is then based on preexisting standard plans with isodose distribution documentation. Due to the rigidity of such kind of applicators, the main challenge here is the check of the correct placement of the catheter in the patient. We first validate the place of the applicator by simple X-ray images. We take 3 pictures from different angles and then export the pictures in the treatment planning system. When the applicator is found to be located at the adequate position, we make the applicator reconstruction as seen in Fig. 1. After the reconstruction, the dose delivery to the anatomy around the applicator can be assumed. Because of the missing correlation between anatomy and dosimetry, when one uses conventional X-ray radiography, it is presently common to use 3D sectional imaging such as CT [5]. This procedure is becoming increasingly more popular and tends to replace the traditional methods.

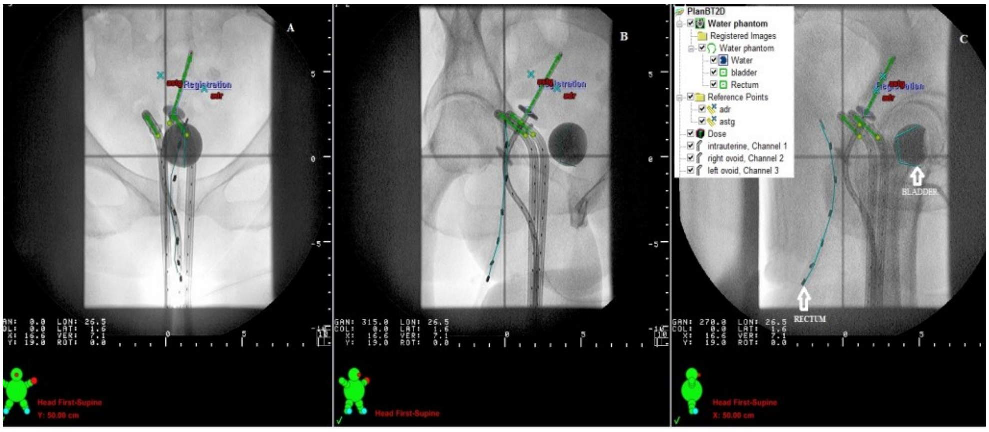

Fig. 1 – Image reconstruction from different angles of a "tandem and ovoid applicator".

3D TREATMENT PLANNING

Planning target volume. Point A represents the point for dose specification at 2 cm above the external cervical os (flange) and 2 cm lateral to midline along the plane of the tandem. Point A should be reported for all cases regardless of the imaging modality. We utilize CT images for performing the 3D treatment plan. We scanned the patient after the physician had inserted the applicators. Delineation of target volumes to be treated after insertion of tandem and vaginal applicators on images in the treatment planning is performed by the physician as seen in Fig. 2. The planning for intracavitary applications should be performed after the patient is CT scanned with applicators inserted. Image-based volumetric information consist of CT using contiguous slice acquisition with slice thicknesses smaller than 3 mm. Organs at risk (including bladder, rectum, and sigmoid) were contoured, too. DVH (dose-volume histogram) information is used for assessment of coverage of the target and dose to organs at risk. The use of 3D imaging enables an anatomy-adapted implantation and anatomy-based treatment planning and optimization in BT [6]. 90 % of the tumoral volume should be covered with 100 % of prescribed dose. Recommended dosimetric parameters for organs at risk are: D2cc (dose for the most exposed 2 cm^3 from the organ) to the rectum where it must be < 75 Gy and for the bladder < 95 Gy [7]. Here, the standard tools, known as the external beam planning systems, were also used for effective and accurate 3D delineation of tissues and organs.

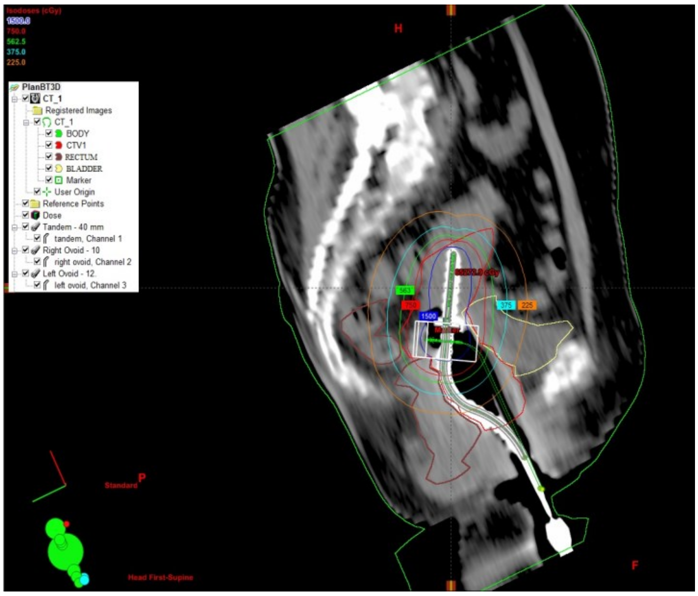

Fig. 2 – Example of "tandem and a scanned CT ovoid" applicator. The isodose lines are observed: the blue line represents 1500 cGy, the red line represents 750 cGy , the green line represents 562 cGy, the light blue line represents 375 cGy and the orange line represents 225 cGy (Color online).

3. RESULTS AND DISCUSSION

Physical dose values are converted to biologically effective dose. The total dose, combining EBRT and BT, was always normalized to the conventional 2 Gy/fraction using the linear quadratic model for incomplete sublethal damage repair and was sometimes called the "isoeffective dose". Tissue values of parameters applied in clinical routine are $\alpha/\beta = 10$ Gy for the tumor and clinical target volume (CTV); $\alpha/\beta = 3$Gy for the late effects of organs at risk.

BT alone was characterized by the total reference air kerma for each application and as the sum of all fractions for one patient. The dose to point A left, point A right, and on average was given for each fraction and combined with EBRT. For the bladder and rectum the minimal dose values received by the most irradiated 2 cm^3 were determined for the cumulative DVHs. Volumes are reported as the average values based on each fraction of one patient. The following dose–volume constraints were applied: < 75 $Gy_{\alpha/\beta=3}$ in 2 cm^3 of the rectum and < 90 $Gy_{\alpha/\beta=3}$ in 2 cm^3 of the bladder.

The prescribed dose to the high-risk CTV of BT, combining BT and EBRT was around 86 $Gy_{\alpha/\beta=10}$ which was mainly achieved by 50 Gy of EBRT plus 2 × 7.5 Gy of BT. Two of the patients received 3 fractions of BT with 7.5 Gy per fraction for all 3 fractions.

The average D2cc for the rectum was 60 Gy and the mean D2cc for the bladder was 78 Gy.

RESULTS TO CTV AND ORGANS AT RISK BY COMPARING THE TWO BT METHODS

For the intracavitary BT of the primary cervix carcinoma, a set of discrete anatomical points has been used and is continuously used for documenting the dose distribution to the patient anatomy. 3D optimization was done to improve target coverage and decrease the dose at critical organs and compared with the 2D orthogonal radiography based plan.

We analyzed CTV dose coverage from 2D BT planning and 3D BT planning. Using Microsoft Excel software, we calculated the CTV median dose for each application. The median dose for CTV performing the 2D BT was 681.72 cGy with a minimum dose of 600 cGy and the median dose for CTV performing 3D BT was 731.38 cGy with a minimum dose of 700 cGy. The CTV was covered with 90 % of prescribed dose for 2D BT and with 97 % for 3D BT.

The mean dose for rectum performing 2D BT was 275 cGy and the performing 3D BT was 248.33 cGy. The mean dose for the bladder performing 2D BT was 263.33 cGy and the performing 3D BT was 248.33 cGy.

3D image based BT allows volumetric optimization improving tumor coverage and critical organ sparing which potentially increases local control, reduces toxicities and helps predict outcomes. Data for 3D planning have substantiated the potential improvements of 3D over 2D planning overcoming challenges in optimizing technique, reproducibility, uncertainties in target delineation, and the dosimetric planning processes [8].

3D BT presents an advantage as compared to 2D BT planning for cervical cancer. For instance, 3D BT planning additionally offers clinical advantages including: confirmation of applicator placement decreased critical organs at risk dose for patients with a small cervix, accounting for sigmoid colon dose, and improved coverage for large volume disease while maintaining critical organ dosimetry. Image-based planning and optimization allowed the dose reducing to all the critical organs without compromising target coverage [9].

4. CONCLUSION

Image guided brachytherapy is a promising radiotherapy technique that can improve local control and decrease complication rates in patients with cervical carcinoma. The dose at critical organs was reduced by 3D BT optimization for rectum and bladder.

Compared to the 3D volume dose, the prescription points overestimated the dose to the target volume. 3D planning reduces the dose at critical organs without compromising the target coverage.

A pattern should be used as the starting point for CT based optimization. Individual changes of active dwell positions and dwell weights are guided by a concept of DVH constraints for target and organs at risk.

The DVH constraints for organs at risk allow reproducible treatment plans, helping to detect and avoid the severe overdoses.

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