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Original article

Needle use and dosimetric evaluation in cervical cancer brachytherapy using the Utrecht applicator

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ABSTRACT

Background and purpose: To analyse the clinical use of needles and examine the feasibility to meet the planning criteria in three fractions of cervical cancer brachytherapy. Furthermore, to investigate whether the needles with the largest discrepancy between application and loading are essential to treatment planning.

Materials and methods: For 22 patients we analysed the applied and loaded needle patterns, and examined the dosimetric results for small (<30 cm^3) and large (≥30 cm^3) CTV_{HR}. We removed from the clinical plans (CP) the needles applied most, but with the lowest loading frequency and intensity and re-optimized these plans (RP).

Results: On average 5.8 needles were applied and 4.8 loaded per fraction, with average intensity 22% (17% for small, 29% for large CTV_{HR}). Mid-lateral needles were applied and loaded most frequently and intensely. The average CTV_{HR} $D_{90\%}$ prescribed dose was 88.8 Gy (SD 4.2) $EQD2_{10}$, the average OAR D_{2cm^3} limit was respected. Omitting the mid-ventral needles, minimal statistically significant differences were found in dose distributions between RP and CP.

Conclusions: Applying on average 5.8 needles per fraction it was possible to meet the planning criteria for targets and OARs in three BT fractions for both small and large CTV_{HR}. The mid-ventral needles were not essential in treatment planning, unless situated in the vicinity of the GTV_{res}.

The current paradigm for the treatment of locally advanced cervical cancer (LACC) is radio-chemotherapy, involving external-beam radiotherapy (EBRT) and brachytherapy (BT) with concomitant chemotherapy. Magnetic resonance imaging (MRI) [1] has allowed the development of image-guided adaptive brachytherapy (IGABT) [2–5]. Recommendations for target delineation and dose reporting as provided by the GYN GEC-ESTRO Working Group [6–9] have served as a framework for these developments. These recommendations have been included in the ICRU/GEC-ESTRO report 89 [10], which describes standards for prescribing and reporting in cervical cancer brachytherapy.

Numerous studies involving IGABT, most notably EMBRACE and retroEMBRACE (www.embracestudy.dk), show a distinct improvement in local and pelvic control and survival as compared to non-IGABT treatments, as well as a reduction in treatment-related morbidity, and have managed to relate various dose–volume histogram (DVH) parameters and clinical outcome [4,11–19]. Our treatment planning criteria stem from EMBRACE and retroEMBRACE results, and involve the same planning aim for the high-risk clinical target volume (CTV_{HR}) and limits for the OAR prescribed dose as proposed in the recently initiated EMBRACE II study. We administer three fractions of BT, which requires a higher prescribed dose per BT fraction to achieve the target planning aim than when four fractions are applied.

MR-compatible intracavitary/interstitial (IC/IS) applicators, such as the tandem-ovoid Utrecht applicator (Elekta, Veenendaal, NL) (in use in our clinic since 2011), have been shown to provide substantial dosimetric gains compared to traditional IC applicators [15,20,21]. The clinical use of Utrecht applicator needles was analysed in [20]. However, there is currently no consensus on the optimal method for choosing needles to be applied, especially in the first BT fraction, and to date no studies have been performed with regard to which needles are non-essential to treatment planning.

In this study we analysed our clinical use of needles, and examined the dosimetric results of our treatment planning, to gauge if it was feasible to meet the planning criteria in three fractions of BT.

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We investigated whether the needles which were applied most often but which subsequently had the lowest loading frequency and intensity were essential to treatment planning.

Materials and methods

Patients and treatment

The study included 22 subsequent cervical cancer patients, ranging from International Federation of Gynecology and Obstetrics (FIGO) Stages IB to IIIB, treated with EBRT followed by three fractions of weekly high dose rate (HDR) BT between September 2015 and June 2016. Fifteen of the 22 patients received concomitant chemotherapy, which consisted of up to six weekly cycles of cisplatinum monotherapy (40 mg/m^2). The EBRT dose was 46 Gy in 23 fractions given over the course of five weeks, with BT starting in the fifth week of EBRT. For nine patients EBRT included a sequential lymph node boost.

The Utrecht applicator consists of an intra-uterine tube and two ovoids, and allows up to ten additional needles to be placed interstitially. We label the needle positions in the ovoids anticlockwise from A to J, starting with the mid-ventral position in the right ovoid. For the patients in this study, we used 15°, 30° and 45° intra-uterine tubes, and 20 and 25 mm ovoids.

The position and depth of needles to be applied in the first BT fraction were determined using interdisciplinary consensus, making use of a non-delineated MRI from the fourth week of EBRT without applicator *in situ*. This MRI was acquired to assess the tumour response, and used to determine which ovoid sizes and intra-uterine tube angle to use in the first fraction. For subsequent fractions, the needle application and applicator components were determined by reviewing the treatment plan from the previous fraction.

MR images were obtained for each BT fraction using a 1.5-T Philips Achieva MRI scanner. Sequences included axial, sagittal and coronal T2-weighted turbo spin-echo (TSE) images with 3 mm slice thickness, and a fast field echo (FFE) 3D scan with 1.5 × 1.5 × 1.5 mm^3 voxel resolution to aid in the reconstruction of needles. We used a standard bladder filling of 180 ml just prior to the MRI scan (and again just prior to treatment) to push the small bowel away, unless there was a medical reason to use another filling.

Contouring included the residual gross tumour volume (GTV_{res}), CTV_{HR}, intermediate-risk clinical target volume (CTV_{IR}), as well as OARs, namely bladder, rectum, sigmoid and small bowel [6–9]. Oncentra Brachytherapy Planning System (BPS) (Elekta, Veenendaal, NL) was used for treatment planning. Dose optimization involved activating all source positions within the CTV_{HR}, and manually adjusting dwell times in the intra-uterine and ovoid channels, followed by the needle channels.

Total (EBRT + BT) biologically equivalent doses in 2-Gy fractions were calculated with $\alpha/\beta = 10$ ($EQD2_{10}$) for CTV_{HR} and $\alpha/\beta = 3$ ($EQD2_3$) for OARs. Our planning aim was a total dose to 90% of the CTV_{HR} ($D_{90\%}$) of 90 Gy $EQD2_{10}$, with lower limit 85 Gy $EQD2_{10}$ and upper limit 95 Gy $EQD2_{10}$. The limits for the OAR prescribed doses were: a total dose to 2 cm^3 (D_{2cm^3}) of the bladder of no more than 90 Gy $EQD2_3$, and a rectum, sigmoid and small bowel D_{2cm^3} of no more than 75 Gy $EQD2_3$, respectively, as in the EMBRACE II protocol. We used visual inspection of the dose distribution to determine if a treatment plan was clinically acceptable: the 7 Gy reference isodose (100%) should be conformal with the CTV_{HR}, and intrude as little as possible into the OARs; the 14 Gy isodose should remain inside the CTV_{HR} and ovoids; the GTV_{res} should be completely inside the 7 Gy isodose. Any deviations from these criteria were only accepted in consultation with the radiation oncologist.

Study

For the dosimetric evaluation, we examined the prescribed DVH parameters for the target and OARs for both large (≥30 cm^3) and small (<30 cm^3) CTV_{HR} as delineated in the first BT fraction, grouped according to the approximate median CTV_{HR} volume [15].

Furthermore, we examined the clinical use of needles, namely how often each of the ten possible needles was applied and the frequency with which it was loaded in treatment planning. A loaded needle had a non-zero channel dwell time at the time of treatment. The frequency with which a needle was loaded was calculated as the number of times it was loaded as a percentage of the number of times it was applied. We also examined the average intensity of each needle's loading, given by the average ratio of needle channel dwell time as a percentage of the total dwell time. In addition, we compared the applied needles with the location of CTV_{HR} extension. To determine the location of the CTV_{HR}, we divided the planes perpendicular to the intra-uterine tube into ten sectors, each sector corresponding to a needle position, as shown in Supplementary Fig. 1. We used the projected position of each needle as a distance cutoff. We scored this sector as positive when the CTV_{HR} contour exceeded this cutoff anywhere between 5 and 20 mm above the ovoids (the latter coinciding with our most commonly applied needle depth). This gives an indication of CTV_{HR} extensions that would fall within a particular needle's range. We used the same method to determine the location of GTV_{res}.

We then investigated whether the needles applied most often but with subsequently the lowest loading frequency and intensity are essential for treatment planning. We did this by removing the contributions of these needles from the optimized clinical plans (CP) and re-optimizing using the other applied channels (RP). We aimed to obtain identical CTV_{HR} $D_{90\%}$ values while achieving similar OAR prescribed doses and dose distribution conformality as in the CP.

We compared RP and CP for DVH parameters (GTV_{res} $D_{98\%}$, CTV_{HR} $D_{98\%}$ and OAR D_{2cm^3}, as well as the ratio OAR D_{2cm^3} to CTV_{HR} $D_{90\%}$) and dose distributions, characterized by high dose volume CTV_{HR} $V_{200\%}$, the dose homogeneity index ($DHI = 1 - V_{150\%}/V_{100\%}$) and conformal index ($COIN = CTV_{HR}$ $V_{100\%}$ (cm^3)/CTV_{HR} Volume (cm^3) × CTV_{HR} $V_{100\%}$ (cm^3)/Implant $V_{100\%}$ (cm^3)) [22]. The ratio OAR D_{2cm^3} to CTV_{HR} $D_{90\%}$ is used as a measure of DVH parameter favourability: a low ratio suggests a low OAR D_{2cm^3} and a high CTV_{HR} $D_{90\%}$. Target coverage was additionally assessed by looking at the CTV_{HR} $V_{100\%}$. Significance was determined using the Wilcoxon signed-rank test, with $p < 0.05$ considered significant.

Results

Prescribed DVH parameters

Table 1 shows the average total treatment DVH parameters for large and small CTV_{HR} volumes. The average total CTV_{HR} $D_{90\%}$ prescribed dose of 88.8 (SD 4.2) Gy $EQD2_{10}$ was very close to our planning aim of 90 Gy $EQD2_{10}$, while the average total OAR D_{2cm^3} stayed below the respective limits for each OAR.

The median CTV_{HR} volume at the time of the first fraction was 28.9 cm^3 (range, 9.1–74.3 cm^3), which for the second and third fractions decreased to 24.0 cm^3 (range, 7.5–59.0 cm^3) and 21.9 cm^3 (range, 9.5–50.7 cm^3), respectively. Thirteen patients had a small CTV_{HR} and nine patients had a large CTV_{HR}. The average total CTV_{HR} $D_{90\%}$ for small CTV_{HR} was only 0.3 Gy higher than for large, while for large CTV_{HR} the average total OAR D_{2cm^3} values were higher, especially for bladder and rectum. However, for all CTV_{HR} sizes, the OAR constraints were well met on average. Fig. 1 shows that it was possible to prescribe close to the CTV_{HR} $D_{90\%}$ planning

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