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Intrafractional organs movement in three-dimensional image-guided adaptive pulsed-dose-rate cervical cancer brachytherapy: Assessment and dosimetric impact

Renaud Mazeron[1,2,*], Jérôme Champoudry[3], Jennifer Gilmore[1], Isabelle Dumas[3], Jennifer Goulart[1], Anne-Sophie Oberlander[1], Eleonor Rivin del Campo[1], Ibrahima Diallo[2,4], Dimitri Lefkopoulos[2,3], Christine Haie-Meder[1]

[1]*Department of Radiation Oncology, Gustave Roussy Cancer Campus, Villejuif, France*
[2]*Laboratory of Molecular Radiotherapy, UMR1030, Gustave Roussy Cancer Campus, Villejuif, France*
[3]*Department of Medical Physics, Gustave Roussy Cancer Campus, Villejuif, France*
[4]*Radiation Epidemiology Group - INSERM U1018, Gustave Roussy Cancer Campus, Villejuif, France*

ABSTRACT

PURPOSE: To prospectively evaluate the intrafractional movements of organs at risk (OARs) and their dosimetric impact during the delivery of pulsed-dose-rate brachytherapy in cervical cancer.

PATIENTS AND METHODS: An MRI on Day 1 was used for treatment planning in 19 patients. CT scans were acquired at Days 1, 2, and 3 with delineation of the OARs. The MRI plan was transferred to each CT. The intersection volume between the 10 Gy isodose and the OARs were monitored, reflecting movement. Lower dose evaluated in the maximally exposed 0.1 cm^3 of an organ and lower dose evaluated in the maximally exposed 2 cm^3 of an organ (D_{2cm3}) were evaluated on each CT and compared. Results were averaged considering that each CT reflected one-third of the treatment course to evaluate the delivered dose.

RESULTS: No major movements of the sigmoid and bladder were observed, whereas the rectum got significantly closer to the implant at Day 2. The consequence was an increase of 6% ± 5.3 (3.7 Gy, $\alpha/\beta = 3$ Gy) of the delivered D_{2cm3} from the planned dose, in contrast to 0.2% ± 6.1 for the bladder and 1.1% ± 6.4 for the sigmoid. The increase of the D_{2cm3} of the rectum was reported in 17 patients, ranging from 0.4 to 9.4 Gy, leading to a 10.5% overcoming of the dose constraint (75 Gy). Similar tendencies were reported for lower dose evaluated in the maximally exposed 0.1 cm^3 of an organ.

CONCLUSIONS: A significant systematic variation was observed for the rectum (+3.7 Gy). As significant random variations were observed, caution should be exercised when the planned D_{2cm3} is close to the dose constraints.

Keywords: Cervical cancer; Organs at risk; Movements; Image-guided adaptive brachytherapy; Uncertainty

Introduction

Internal organ motion remains an important issue in radiotherapy, particularly in the treatment of locally advanced cervical cancer where the cervix and the uterus are known to have large amplitude movements (1). With brachytherapy, a cornerstone of the treatment of cervical cancers (2, 3), the movements of the target are considered to be negligible, as the implant is fixed to the cervix and follows its movements. However, the organs at risk (OARs) are moving around the implant, and because of their close vicinity to the target volume, and thus to the sources, the dose evaluated at their level has a strong influence on the treatment planning process. The optimization of the plan is based on an accurate evaluation of their position. Therefore, motion between the planning process and treatment

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* Corresponding author. Department of Radiation Oncology, Gustave Roussy Cancer Campus, 114 rue Edouard Vaillant, 94805 Villejuif Cedex, France. Tel.: +33-1-42114566; fax: +33-1-42115208.

E-mail address: renaud.mazeron@gustaveroussy.fr (R. Mazeron).

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delivery, and during the treatment itself, may have a major impact on the accuracy of the dosimetry. Most of the studies led in brachytherapy focused on the dosimetric consequences of interfractional organ movements between image acquisition and the treatment delivery, either for one application (intraapplication) or between the image acquisition and a second application (interapplication) (4). The purpose of this study was to evaluate the intrafractional movements of the rectum, bladder, and sigmoid colon during pulsed-dose-rate (PDR) brachytherapy, by using the implant itself as a reference and to report their dosimetric implications.

Methods and materials

A prospective cohort of 19 patients with locally advanced cervical cancer (staged 1B2 to IVA according to the Fédération Internationale de Gynécologie Obstétrique classification) and treated with curative intent was included. The study was approved by the institutional ethics committee, and all patients gave their written consent. They had previously undergone pelvic chemoradiation delivering 45 Gy in 25 fractions with a three-dimensional conformal technique. Brachytherapy consisted of PDR intracavitary MRI-guided adaptive brachytherapy. For the purposes of the study, three CT scans were performed: one before the treatment delivery and after the postimplantation MRI (Day 1), and two during the treatment delivery (Days 2 and 3).

Brachytherapy procedure

A personalized vaginal mold was used in all patients. The procedure has been reported in detail elsewhere (5). Briefly, for each patient, a customized vaginal mold was created from a vaginal impression, containing one intrauterine and two vaginal catheters (6). The day before and a few hours prior the implantation, a rectal enema was performed. A residua-free diet was introduced at admission and continued throughout the treatment delivery. The bladder was systematically catheterized during the implantation and left on free drainage during the treatment and during image acquisition. Patients were treated continuously with hourly pulses. Once the insertion was performed, the patient was transferred to an MRI scanner (1.5 T). T2 sagittal, axial, and coronal images were acquired. Then, the patient underwent a CT planning scan. Two additional CT scans were acquired on Days 2 and 3 of the treatment. Images were transferred to Brachyvision 8.9 platform (Varian Medical Systems, Palo Alto, CA). On MRI, used for treatment planning, the gross tumor volume, high-risk clinical target volume (HR-CTV), and intermediate-risk CTV (IR-CTV) were delineated according to the Groupe Européen de Curiethérapie–European Society for Radiation Oncology recommendations, as well as the rectum, sigmoid colon, and bladder (7, 8). The dwell positions were activated according to the CTVs delineated. Planning began with a standard loading pattern and a prescription of a physical dose of 15 Gy normalized to Point As. Then, optimization was performed manually to reach the planning aims: D_{90} of the IR-CTV ≥60 Gy and D_{90} of the HR-CTV ≥85 Gy (summing BT and external beam radiotherapy [EBRT], doses in 2 Gy equivalent [EqD2], applying the linear quadratic model with an α/β of 10 Gy and a half-time repair of 1.5 h). The dose constraints were 75 Gy EqD2 to the maximally exposed 2 cm^3 (D_{2cm3}) of the rectum and sigmoid and 85 Gy for the D_{2cm3} of the bladder (α/β of 3 Gy). The final step consisted in adapting the fractionation to limit the dose per pulse to 0.6 Gy to D_{2cm3} of each OAR by modifying the number of pulses while maintaining the same physical dose (9). Therefore, among the patients, the number of pulses varied from 30 to 60, and the dose rate of the prescription isodose varied from 25 to 50 cGy/h.

Evaluation of movements

Different methods have already been described to quantify organ motion during EBRT. In most of them, a system

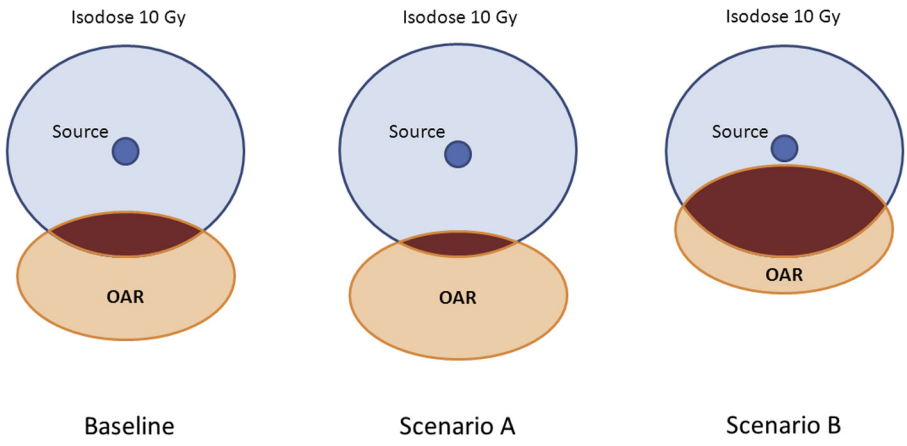

Fig. 1. Concept of using the intersection volume between the 10 Gy isodose and the OARs for evaluation of the movements of the organs. Situation A: The intersection volume decreased, and the OAR got farther from the implant than previously (baseline). Situation B: The intersection volume increased, and the organ got closer to the implant. OARs = organs at risk.