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RESEARCH PAPER

Optimization of catheter's implementation in the mold, in the case of vaginal HDR brachytherapy treatment

Mirna Samir Jreij, Ali El Ahmar, Jamal Charara

Doctoral School of Science and Technology, Lebanese University, Campus Hadat, Lebanon

ABSTRACT

Background: The purpose of this study was to evaluate and compare results obtained in high dose rate (HDR) brachytherapy treatment of vaginal cancer. Different catheters distributions inside the custom mold were explored. The difference between those distributions is the position of the posterior catheter located near the rectum in the actual custom mold applicator used in different hospitals, each one having a catheter displacement of 0.5 which is equal to the length of a step position. The best catheters distribution offering an optimal dose distribution: better coverage of the clinical target volume (CTV), while reducing the dose received by organs at risk (OARs), were discussed.

Materials and methods: A group of 60 patients treated with HDR brachytherapy, alone or in combination with external radiotherapy, was investigated. A custom mold is normally used for HDR brachytherapy vaginal cancer treatment. Three different geometrical positions of the catheters (G1, G2 and G3) and, consequently, 3 different dosimetries were simulated out for each patient on the CT images, using the Oncentra planning system. The coverage of the CTV was studied.

Results: The average volume treated was 30.46 cc (min = 9.8 cc, max = 70.86 cc). The total prescribed dose, including external and internal radiotherapy, was 80 Gy. We evaluated conformity index (CI), dose homogeneity index (DHI) and conformality index (COIN) indices for the three implantation geometries to reach the same coverage criteria of the CTV. The D2cc parameter allowed the evaluation of the dose received by the OARs. For the rectum, a dose reduction of 9.67% (range 0.29–32.86) was obtained with the second geometry of implantation compared to 10.14% (range 1.43–28.33) with the third geometry. For the bladder, the second geometry of implantation showed a better preservation for this organ [15.93% (range 0.86–58.71) *vs.* 8.35% (range 0.33–30.43) with the third geometry]. The sigmoid was more protected using the second plan of implantation as well [6.33% (range 0.14–40.71) for the second implantation compared to 5.95% (range 0.33–36) for the third implantation].

Conclusions: G2 and G3 catheters' distribution, having catheter position farther from the mold wall and so from the vaginal wall compared to the catheter position applied showed a better protection for the OARs while giving the same prescribed dose for the CTV.

Key words: brachytherapy; cancer treatment; dose distribution

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Introduction

High dose rate (HDR) brachytherapy, introduced by Henschke et al. in the early sixties [1, 2], plays a primordial role and is the best technique for small cancerous local volumes [3] that are directly accessible or preceded by surgical intervention. For primary or recurrent vaginal carcinoma, radiotherapy is the most used standard treatment [4–6]. However, the choice of the treatment depends on

Address for correspondence: Mirna Samir Jreij, Université Libanaise, Ecole Doctorale des Sciences et Technologies, Campus Hadat, Liban ; e-mail: mirnajreije@gmail.com

the stage of the disease, specified according to the international classification. A complementary treatment by HDR brachytherapy makes a better control of the disease than external radiotherapy [7–9].

HDR vaginal brachytherapy and its role in the vaginal cancer treatment, depending on its stage and the complement of treatment used, have been discussed in several studies [4, 10–12]. HDR brachytherapy treatment and optimization of the dosimetry were investigated utilizing different applicators. Bahadur et al. [13] discussed the dosimetric advantages of the multi-channel applicator against single-channel applicator, where a limited improvement in the clinical target volume (CTV) coverage was achieved against a significant reduction of the dose received by 2 cc of the rectum and 2 cc of the bladder. Similar results have been shown by Tanderup et al. [14], making it possible to spare the rectum and bladder at the expense of increasing the dose to the vaginal mucosa. Shin et al. [15] discussed the advantage of using the multi-channel inflatable applicator versus the single-channel applicator and its advantages over the CTV coverage and the protection of surrounding organs. Magné et al. [16] investigated the technical aspects of using the custom mold for the treatment of gynecological cancers. Khoury et al. [17] studied the advantage of the custom mold seen in the decrease of air pockets that caused an average dose reduction of 25.6% (range 6–45.5%).

The effect of catheter positions inside the mold and their effect on dosimetry has never been investigated. In general, the dosimetry is obtained using a personalized mold according to a triangular shape of catheters implantation as illustrated in Figure 1. However, this geometry induces a high dose received by the rectum or the bladder [18]. This is related to the catheter localized in the posterior part of the mold, especially when HDR brachytherapy is complimentary to an external radiotherapy. In this configuration, the dose received by the rectum and other organs at risk (OAR) will be very close to, or higher than, the dose limits given by the American Brachytherapy Society (ABS) and GYN GEC-ESTRO recommendations [19, 20].

The main goal of the present study was to find a new distribution of the catheters in the personalized mold that allows the coverage of the CTV while decreasing the dose received by the OAR, especially the rectum.

Materials and methods

Between 2016 and 2018, 60 patients with vaginal cancer were treated with HDR brachytherapy. The personalized mold, prepared for each patient, was made from Palavit. For the HDR brachytherapy treatment a source projector "Flexitron Brachytherapy after loading platform" (Elekta) was used. For the dosimetry and its optimization, Oncentra Brachytherapy Comprehensive Treatment Planning System (Elekta) was employed. Three different catheter distributions in the personalized mold were investigated as shown in Figure 2.

The choice of these 3 configurations was based on a translation of about 0.5 cm (equivalent to the length of a step position) between the first and third distribution as well as between the second and the third one. It should be mentioned that the mean width of a personalized mold is about 2 cm, based on a statistical estimation considering the 60 patients included in this study.

The optimization of the dosimetry and its analysis require the study of multiple quantitative and qualitative dosimetric indicators. In qualitative analysis, the dose distribution across the OAR

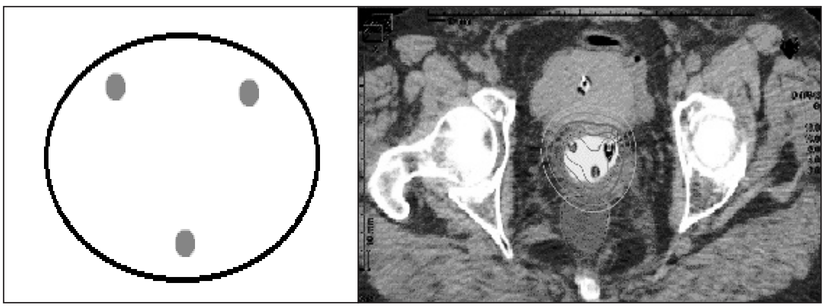

Figure 1. First catheter distribution G1 (triangular distribution) when using personalized mold to treat

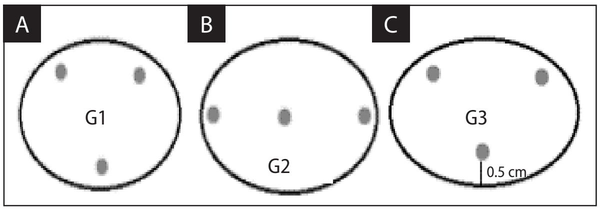

Figure 2. A. First catheters distribution G1(triangular distribution) currently used at different hospitals; **B.** Second catheters distribution G2 (rectilinear distribution); **C.** Third catheters distribution G3, where the posterior catheter was implanted inside the mold away from the posterior periphery of the mold and away from the patient's rectum (0.5 cm away from the position of the same catheter in the first distribution)

was determined. In quantitative analysis, the dose volume histogram (DVH) was obtained through dosimetric simulation. DHV provides both (i) the volume quantity of a given structure that receives a certain dose and (ii) the dose distribution for different volumes. The most used DVH is the cumulative one that measures the variation of the volume for the same isodose surface, thus ensuring that 100% of the tumor volume receives the prescribed dose (reference dose). DVH allows to determine (i) D2cc for the rectum, the sigmoid and the bladder and (ii) D90% and D100% for the CTV. DVH enables also to calculate dose homogeneity index (DHI), conformality index (COIN) and conformity index (CI), where:

$$DHI = \frac{V_{100} - V_{150}}{V_{100}} = \frac{PTV_{ref} - PTV_{1.5\,ref}}{PTV_{ref}} \quad [21] \qquad (1)$$

$$COIN = C^1 \times C^2, C_1 = \frac{PTV_{ref}}{V_{PTV}} \text{ and } C_1 = \frac{PTV_{ref}}{V_{ref}} \quad [22] \qquad (2)$$

$$CI = V_{100}/V_{CTV} \qquad (3)$$

V_{100} and V_{150} are, respectively, the volume receiving 100% and 150% of the prescribed dose, PTV_{ref} and PTV_{ref} are the planning tumor volume (CTV) receiving the prescribed dose and 1.5 times the prescribed dose, respectively. V_{ref} is the volume of the reference isoline [22], and V_{CTV} is the Volume of the CTV. The definitions of CTV and OAR are extremely important due to their substantial effects. The volumetric optimization gives a more homogeneous dose distribution, with no unacceptable overdose region. Therefore, the "Dwell Time" was manually varied, after applying the volumetric optimization, to reach a compromise between the best dose coverage and the dose received by the OARs. However, a solution will be considered satisfactory if it achieves a certain settlement between the different criteria. Indeed, according to the Pareto optimization principle, the solution of a multi-objective optimization problem (where several criteria are to be minimized) is considered optimal if there is no solution for which a criterion value can be decreased without causing an increase in another criterion [23]. The same percentage of CTV receiving 95% of the prescribed dose was maintained to analyze the dose received by each OAR.

Results and Discussion

To evaluate the dose distribution inside the CTV, the parameters D90% and D100% were analyzed as well as DHI, CI, and COIN indices. For the doses received by the OARs, D2cc was studied for each of the rectum, sigmoid and bladder. The results are presented in Table 1. This table shows an identical CTV coverage since the same CI was obtained for the three implantations. Similarly, the same COIN and DHI values for G1, G2 and G3 distributions were obtained.

The percentage of patients' benefit in terms of dose reduction to OARs, while respecting the same CTV coverage, is shown in Table 2. This table shows the superiority of G2 and G3 distributions compared to G1, which is actually applied at Tenon Hospital [18] in Paris as well as Gustave Roussy Institute [16] and many other cancer treatment institutes.

Table 3 presents the values of D2cc for the rectum, sigmoid and bladder, which are, respectively, 80.17%, 70.5% and 70.03% for G1, 71.24%, 64.91% and 65.29% for G2, and 93.74%, 77.81% and 85.39% for G3. These values show advantages when using the second and third implantations.

A D2cc reduction is noted for 82.2%, 97.1% and 95% of patients for the rectum, sigmoid and bladder, respectively, when comparing the first implementation to the second proposed one. When comparing the first implementation to the third one, a D2cc reduction is noted of 86.7%, 88.2% and 92.5% of patients for the rectum, sigmoid and bladder, respectively,.

Table 4 shows the mean advantages (percentage of D2cc decrease) for each of G2 and G3 compared to G1 and for each of the OARs.

Table 1. Values of dose homogeneity index (DHI), conformality index (COIN), and conformity index (CI) for each of the three implantations

Indices of dose distribution in CTV	Mean (G1 trial) ± SD (min– max)	Mean (G2 trial) ± SD (min – max)	Mean (G3 trial) ± SD (min–max)
DHI	0.23 ± 0.084 (0.04–0.511)	0.26 ± 0.05 (0.15–0.37)	0.25 ± 0.06 (0.15–0.36)
COIN	0.94 ± 0.006 (0.64–1)	0.94 ± 0.004 (0.83–0.1)	0.94 ± 0.002 (0.85–0.99)
CI	0.97 ± 0.034 (0.8–1)	0.97 ± 0.022 (0.91–1)	0.97 ± 0.019 (0.92–1)

CTV — clinical target volume; SD — standard deviation

Table 2. Percentage of patient having reduction of the dose received by each organ at risk (OAR)

Organ	Rectum		Sigmoid		Bladder	
Implantation	G2	G3	G2	G3	G2	G3
Percentage of patient	84.44%	88.9%	88.9%	91.1%	88.9%	91.1%

Table 3. Value of the different parameters for the clinical target volume (CTV) and each organ at risk (OAR)

Parameter		G1	G2	G3	El Khoury et al. Implantation [17]
CTV	Mean D90% (%) (min–max)	123.05% (102.96–171.34)	117.46% (101–134.18)	118.6% (103.06–134.93)	
	Mean D100% (%) (min–max)	78.69% (71.04–96.8)	79.6% (62.24–92.61)	79.31% (63.56–116.43)	
Rectum	Mean D2cc (%) (min–max)	80.17% (38.29–110.57)	70.5% (33.14–101.71)	70.03% (35–103.67)	100% (78.5–109.7)
Sigmoid	Mean D2cc (%) (min–max)	71.24% (6.33–144.5)	64.91% (5.83–132.67)	65.29% (6–137.67)	57.4% (19.7–97.6)
Bladder	Mean D2cc (%) (min–max)	93.74% (33.71–153.29)	77.81% (42.57–125.67)	85.39% (32.43–136.67)	91.6% (48.5–109.8)

Table 4. Representation of the mean advantage for each of G2 and G3 compared to G1

D2cc	Mean dose reduction value between G1 and G2	Mean dose reduction value between G1 and G3
Rectum	9.67% (0.29–32.86)	10.14% (1.43–28.33)
Sigmoid	6.33% (0.14–40.71)	5.95% (0.33–36)
Bladder	15.93% (0.86–58.71)	8.35% (0.33–30.43)

After obtaining the same CTV coverage, a reduction of the dose received by OARs was noted when comparing G2 and G3 with G1. The second implantation showed a reduction of 9.67%, 6.33% and 15.93%, compared to a reduction of 10.14%, 5.95% et 8.35% for the third implantation, for the rectum, sigmoid and bladder, respectively. G1 catheter implantation, that is the most used when treating with a personalized mold, was used by El Khoury et al. [17], which is the only similar study found in literature to investigate the advantages of the mold applicator in reducing the number of "air pockets". The D2cc obtained in this case shows a higher D2cc values (in percentage) when compared to those obtained with the proposed catheter implantations "G2 and G3".

In this study, while respecting the same CTV coverage criteria, a reduction of the dose received by the OARs was obtained when applying two new configurations of catheter implantation taken into consideration for the first time.

Conclusion

High dose rate brachytherapy is an effective treatment for vaginal cancer. However, this technique requires the reduction of the dose received by the OARs. While respecting the same CTV coverage, the new catheters' distributions G2 and G3 studied in this article demonstrated a better dose distribution as well as a better compromise between the dose received by the CTV and OARs.

A perspective study should be performed to consider the density of the customized mold. The mold is composed of both Palavit (1.35 g/cm^3) and air. The dose calculation performed does not consider the heterogeneities inside the mold. G2 when compared to G3, will require a higher density of the mold due to the presence of the catheters at midline of the mold.

A dose calculation via Monte Carlo code may provide a better estimation of the dose distribution and a better comparison between the second and third techniques of implantation. The catheter implantation control can be improved as well by using a 3D printing technique that allows an exact catheter's position to be determined.

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Conflict of interests

None declared.

Funding

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