

Comparison of 2D and 3D planning in HDR brachytherapy in oesophageal cancer, with consideration of isodose distribution in PTV and OAR

KATARZYNA MATERA¹, ŁUKASZ KOWALIK²

JAROSŁAW ŁYCZEK²

¹Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Cracow, Poland; ²Brachytherapy Department, Subcarpathian Cancer Center, 18 Bielańskiego Street, 36-200 Brzozów, Poland

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Introduction

For brachytherapy, 3D treatment planning did not gain too much credit in Poland and around the world. However, 2D planning is used extensively.

2D planning for oesophageal cancer High dose-rate (HDR) brachytherapy is performed using a template of a single applicator. Active length of such an applicator is planned, and the reference points are 1 cm from the source axis. The aim is to obtain a reference dose for critical organs at risk lower than 90%. Dose optimisation is performed based on source dwell time in dwell positions on its way in the applicator. The calculation result is imaged as isodoses in a freely selected plane. A protocol with doses in reference points and in critical organ landmarks is also generated.

In our Brachytherapy Department, HDR brachytherapy procedures based on 3D images are performed.

In this centre, treatment is performed in an operation room equipped with HDR instrument (mikroSelectron Digital Afterloader, Nucletron, Elekta AB, Stockholm, Sweden), CT scanner and complete equipment necessary for monitoring of patient's vital parameters during treatment. Radioactive source is introduced by afterloading. Tumour and applicator locations, as well as location of critical organs at risk are determined based on CT imaging [1].

Correspondence to: Dr. Katarzyna Matera

Email: katarzyna.mater@gmail.com

ABSTRACT

Objective: The HDR brachytherapy obtained by 3D planning meets with considerable risk by many specialists. However, the advantages of this therapy may outweigh the disadvantages. The aim of the work is to compare 3D planning with standard 2D planning for palliative treatment of oesophageal cancer and intended for HDR brachytherapy.

Methods: We used radioactive Ir-192 source, HDR device, CT scanner. The plans were prepared using Oncentra Brachyplan with 3D and 2D reconstruction module. In both methods, source dwell positions every 0.5 cm were considered. To compare both methods, doses per each organ in a volume of 0.01 ccm, 2 ccm and 5 ccm were calculated. Also V100, V120, V90, V150 and V200 in PTV was estimated. For consistency of the results, a therapeutic dose of 100 cGy was used.

Results: For the 3D method, the reference dose covers PTV in 72.56% of the total area volume, whereas for 2D, this is only 55.98%. Results for the other equivalents of reference dose are similar. Significantly lower values were obtained for dose equal to 200% of the reference dose, as compared to other doses. For the 3D method, 25.12% covering of PTV was obtained, while it was only 19.73% for the 2D method.

Conclusion: As compared to 2D method, the 3D method is more accurate and provides better dose covering of PTV. It allows constant monitoring of doses delivered to organs at risk. This research prove that 3D planning makes HDR brachytherapy in palliative treatment of oesophageal cancer more effective.

KEY WORDS: HDR brachytherapy
Radioactive source
2D treatment planning
3D treatment planning

In oesophageal cancer brachytherapy, two methods of treatment planning are currently used; both allow for appropriate definition of Planning Target Volume (PTV) and Organ at Risk (OAR) regions. These are 2D and 3D planning [2].

Materials and methods

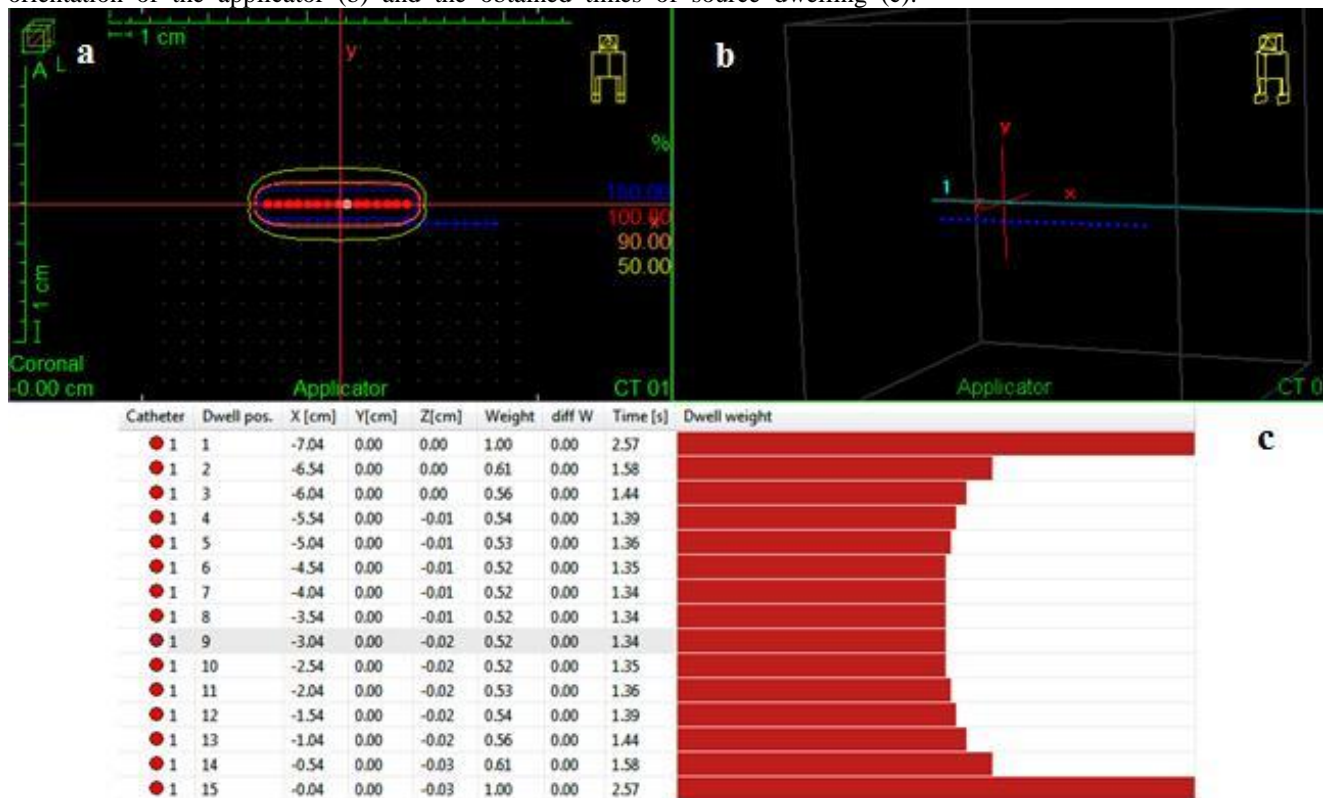
2D planning method

2D planning of HDR brachytherapy in oesophageal cancer begins with use of a single applicator template (Figure. 1, a). Based on the estimated length of PTV, active length of catheter is determined, i.e. path where the source travels with intervals of 5 mm. (Due to the imposed size and shape of the applicator, it is important

to mark its appropriate location.) Applicator design plane can be controlled using projection on a coordinate system (Figure. 1, b). Additionally, margins and source dwell positions must be determined, and potentially, applicator length must be corrected [3].

Dose optimisation is performed by defining source dwelling time in dwell positions in the applicator. (Figure. 1, c) [4].

Figure 1. Oncentra Brachyplan System **2D planning.** Applicator template and isodoses around it (a), spatial orientation of the applicator (b) and the obtained times of source dwelling (c).



3D planning method

Tumour geometry is a factor that defines the volume where the reference dose is determined. Detailed location of the tumour and the applicator placed in the oesophagus is obtained based on a diagnostic CT scan. Based on the obtained 3D images of the area to be treated, PTV and critical organs at risk are localised. In the case of oesophageal cancer brachytherapy, the OARs are heart, lungs, aorta, spinal cord, chest bones, liver. Determination of this area depends on the location of cancerous infiltration [5].

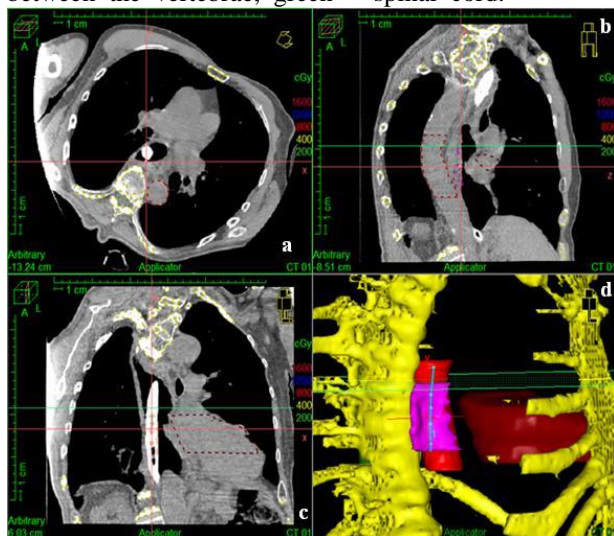
The first step in brachytherapy planning is PTV outlining by the physician (Figure. 2, d). The physician also outlines the critical organs at risk that must be

considered by a medical physicist upon dose optimisation. Then, applicator is reconstructed. When its individual elements are marked, a spatial image is created (Fig. 2, c). Appropriate margins on both ends are taken into account. Treatment planning using 3D CT images allows accurate dose fitting in the tumour volume with consideration of its peripheral part, as well as the biological appearance of all organs [6].

Within this project, we compared 30 treatment plans prepared using 2D and 3D planning methods. Each plan was prepared for the same patient undergoing palliative therapy due to oesophageal cancer. In most cases, the tumour was located in the thoracic segment of oesophagus. PTV length was between 5 and 25 cm.

Due to the size of the treated area, the following critical organs at risk were considered: heart, lungs, aorta (the descending part), spinal cord and chest bones [7].

Figure 2. Oncentra Brachyplan System 3D Images. (a) CT of the treated area, cross-section, (b) projection along the sagittal plane; critical organs at risk marked with colour dashed lines are visible in all images (a-c); (c) CT of the treated area, projection along the frontal plane, (d) reconstructed PTV in pink – a part of an oesophagus, critical organ areas: dark red – heart, red – aorta, yellow – chest bones and slightly visible between the vertebrae, green – spinal cord.



Irradiation using HDR brachytherapy was performed using afterloading method with controlled time of source dwelling. Iridium was used as radiation source (radioisotope with atomic mass of 192 u). Using gastroscop, applicator was introduced to the patient's oesophagus; the isotope travelled along the applicator. The process was programmed stepwise, with intervals of 5 mm between the dwell positions [8].

For consistency of the results, a standard dose of 100 cGy was used. The plans were prepared using Oncentra Brachy Planning System, v. 4.3 (Nucletron, Elekta Company, Elekta AB, Stockholm, Sweden), with 3D and 2D reconstruction modules.

In the 3D method, after identification of the tumour and OAR region, plastic applicator like Bugie®, (Nucletron, an Elekta Company, Elekta AB, Stockholm, Sweden) with diameter of 0.8–12 mm was introduced to the oesophagus lumen. Then, imaging with CT scanner (CT GE Brightspeed, Milwaukee, WI, U.S.) was performed [9].

The planning process was based on 3D reconstructions.

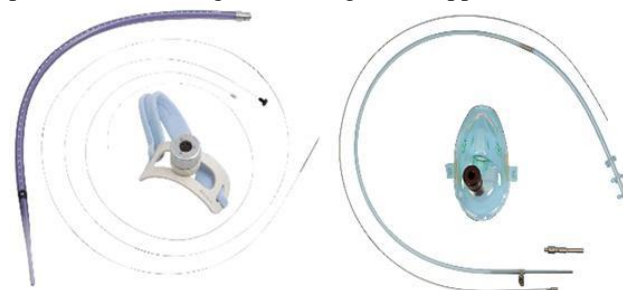
Using them, PTV and OAR regions were determined in the planning system, and applicator was reconstructed. The plans also considered the source dwell positions and desired dose values for the given regions. As a result, plans with detailed isodose distribution in all previously defined regions were prepared. Eventually, it was verified whether the maximum dose is accurately focused on the PTV and whether it does not exceed marginal values for critical organs at risk (optimisation) [10].

The 2D treatment plans took into account a template of a single applicator – Simulix Oldelft® (Nucletron, Elekta company, Elekta AB, Stockholm, Sweden). Times of source dwelling on its way in the applicator were determined using the same applicator lengths and dwell positions as defined using the 3D method. The 2D plan also considered a margin located 1 cm from the source axis, where the dose was lower than 100%. The times of source dwelling obtained in 2D method were transferred to 3D planning. After the times of source dwelling were updated, the reference doses covering PTV for both methods were compared.

To compare the two methods, doses per each critical organ in a volume of 0.01 ccm, 2 ccm and 5 ccm were calculated (as required by ICRU 58 and ICRU 38 reports). Also, dose distribution for 100%, 120%, 90%, 150% and 200% of maximum dose in PTV was estimated.

For this type of study formal consent from participants is not required.

Figure 3. Standard applicators used in intraluminal HDR brachytherapy. On the left, Bonvoisin-Gérard applicator, on the right Fritz regulated applicator [11].



Statistical Analysis

In statistical analysis the Statistica v. 12.0 software was applied. $P < 0.05$ was considered significant. For the purpose of analysis, linear correlation test and t-test were performed.

Results

Based on the data from the obtained treatment plans, results for 2D and 3D methods were compared.

Comparison analysis

Using comparison analysis, differences in target volume isodose distribution were obtained. Due to ICRU-38 report, distribution of 90, 100 and 200 isodoses (%) are the most important. However, the table 1 also covers the 120 and 150 isodoses (%).

Mean maximum dose in OAR

Comparison analysis combined with correlation allowed us also to compare appropriate volumes of critical organs at risk where equivalents of mean maximum dose were delivered (Table 2). Such a summary shows how accurately the doses cover the critical organs at risk.

Table 1. Doses delivered to 90%, 100%, 120%, 150% and 200% of PTV, along with their p-value.

PTV	90%		100%		120%		150%		200%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2D	63.04	23.04	55.98	23.01	43.27	21.50	32.35	17.06	19.73	11.14
3D	78.79	15.25	72.56	16.76	58.34	17.40	40.60	16.34	25.12	10.30
p-value	< 0.001		< 0.001		< 0.001		0.030		0.030	

Table 2. Dose comparison analysis for individual critical region volumes.

OAR	Spinal cord			Chest skeleton			Aorta			Heart			Right lung			Left lung		
V[ccm]	0.01	2.0	5.0	0.01	2.0	5.0	0.01	2.0	5.0	0.01	2.0	5.0	0.01	2.0	5.0	0.01	2.0	5.0
3D[cGy]	21.3	13.4	11.6	67.4	43.1	35.5	88.9	56.7	47.5	67.1	45.4	39.0	88.3	53.1	44.0	67.9	41.4	33.8
2D[cGy]	18.4	10.8	10.0	50.6	35.77	26.6	72.9	47.1	39.3	56.6	38.4	34.2	77.4	45.1	36.2	54.0	33.0	26.8
p-value	0.01	0.02	0.14	0.01	0.09	0.01	0.03			0.08	0.09	0.15	0.17	0.10	0.04	0.04	0.03	0.02

Discussion

Planning of intraluminal brachytherapy used for treatment of inoperable oesophageal cancer is more efficient when computed tomography and 3D method are used. Values for V100, V120 and V90 doses were significant. Lack of statistical significance was found for all studied volumes of heart as organ at risk in 2D and 3D planning. Hence, the safety of this organ is similar in both planning methods. Results of statistical analysis for the other organs at risk indicate that there are marked, statistically significant differences between plans prepared using both methods (2D and 3D). This is also true for the PTV dose. Here, differences up to 12% were observed.

Comparison of both methods shows that 3D planning method in HDR brachytherapy increases accuracy of dose distribution in the PTV. It provides better tumour covering with simultaneous limitation of OAR dose.

OAR doses obtained using 3D method are higher than those from 2D planning in most of the studied volumes.

Obtaining doses that exceed the limits for the individual organs at risk allows to correct the plan by means of optimisation. Such a plan shows the hot spots that can be eliminated. 2D plans do not offer this possibility [12].

In contrast to 3D planning, 2D planning is automated; it does not consider the anatomic shape of the organs nor the real limitation of radiation to the tumour-adjacent tissues.

When 3D method is used, covering PTV with the reference dose is more probable, which provides a better chance to obtain cancer remission with lower risk of both, early and late, relieve symptoms in the PTV and organs at risk. In conclusion, 3D planning for treatment of inoperable oesophageal cancer seems to be superior to 2D planning. Presented advantages of this method overgrow its disadvantages.

Conflict of Interest

I declare that we have no conflict of interest.

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