Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Technical note

Influence of optimizing protocol choice on the integral dose value in prostate radiotherapy planning by dynamic techniques – Pilot study

Anna Zaleska [a,b,*], *Krzysztof Bogaczyk* [c], *Tomasz Piotrowski* [a,d]

[a] *Department of Medical Physics, Greater Poland Cancer Centre, Poznan, Poland*
[b] *Faculty of Physics, University of Warsaw, Warsaw, Poland*
[c] *Fryderic Chopin State Clinical Hospital, Rzeszow, Poland*
[d] *Department of Electroradiology, University of Medical Sciences, Poznan, Poland*

ARTICLE INFO

Article history:
Received 17 September 2016
Received in revised form
27 December 2016
Accepted 19 April 2017
Available online 17 August 2017

Keywords:
Integral dose
Prostate
IMRT
VMAT
HT

ABSTRACT

Aim: The purpose of this study was to compare the values of integral dose, calculated for treatment plans of dynamic radiotherapy techniques prepared with two different optimization protocols.
Background: Delivering radiation by IMRT, VMAT and also HT techniques has an influence on the low dose deposition of large areas of the patient body. Delivery of low dose can induce injury of healthy cells. In this situation, a good solution would be to reduce the area, which receives a low dose, but with appropriate dose level for the target volume.
Materials and methods: To calculate integral dose values of plans structures, we used 90 external beam radiotherapy plans prepared for three techniques (intensity modulated radiotherapy, volumetric modulated arc therapy and helical tomotherapy). One technique includes three different geometry combinations. 45 plans were prepared with classic optimization protocol and 45 with rings optimization protocol which should reduce the low doses in the normal tissue.
Results: Differences in values of the integral dose depend on the geometry and technique of irradiation, as well as optimization protocol used in preparing treatment plans. The application of the rings optimization caused the value of normal tissue integral dose (NTID) to decrease.
Conclusion: It is possible to limit the area of low dose irradiation and reduce NTID in dynamic techniques with the same clinical constraints for OAR and PTV volumes by using an optimization protocol other than the classic one.

1. Introduction

In recent years, techniques using beam intensity modulation, both intensity modulated radiotherapy (IMRT), volumetric

* *Corresponding author*. Tel.: +48 785 617 141.
E-mail address: anna.zaleska@o2.pl (A. Zaleska).

http://dx.doi.org/10.1016/j.rpor.2017.04.003
1507-1367/

modulated arc therapy (VMAT) and helical tomotherapy (HT), have become frequently used in clinical practice. One can say that in some locations, on account of dose distribution conformality to the target area, better dose reduction in organs at risk or shorter therapy sessions, IMRT techniques substitute conventional three dimensional conformal radiotherapy (3DCRT).[1–3]

Despite significant advantages, there is a problem associated with the use of both IMRT, VMAT and HT as they have the dose bath effect.[4] Dose bath effect or low radiation dose in normal tissue area is clearly observable when low isodose on CT scans are compared between the 3DCRT and IMRT techniques as is dose reduction in the organ at risk (OAR) volume for IMRT techniques plans towards 3DCRT.

Integral dose (ID) is defined as a product of mean dose and tissue volume for contemplated organs or structure (1).[5]

$$ID = D_{\text{mean of structure}} \times V_{\text{structure}} \quad (1)$$

In the case of normal tissue, the term normal tissue integral dose (NTID) is used, defined as a difference between ID deposited in the body (in healthy tissue) and ID deposited in the clinical target volume (CTV) (2).

$$NTID = ID_{\text{normal tissue}} - ID_{\text{CTV}} \quad (2)$$

In prostate location, both the bladder and the rectal wall are in close proximity or they have a common part with the planning target volume. It is very important in the case of prostate cancer therapy, on account of patients' quality of life and side effects, to reduce high dose to the bladder and rectal wall,[6,7] but integral dose reduction in these organs would also be beneficial.

According to As Low As Reasonably Achievable rule, it would also be ideal to reduce as much as possible dose delivered to healthy tissue.

Value of Integral Dose for given organs depends on many factors, including the beam energy, density of surrounding tissue, dose calculating algorithm, margin size,[5,8–10] but, primarily, on the choice of radiation technique.

In prostate cancer therapy, in dynamic techniques, ID and low isodose location may be different depending on the number of beams for IMRT, number of arcs for VMAT, and the pitch factor for HT. Another factor, determining the value of ID may be the choice of an optimization process.

In this pilot study, we report the use of two optimization processes for planning of the same patient to explore their influence over the value of the integral dose in the volume of healthy tissue and OAR.

2. Materials and methods

To prepare plans, five prostate cancer patients were selected. The patients had been previously treated with external beam radiotherapy. CTV was defined between 28 and 51 cm^3 (entire prostate – without nodes and seminal vesicles). CTV with 1 cm margin (unsymmetrical to the rectum site 0.7 cm) creating PTV extent 120–160 cm^3. Common part PTV and rectum did not exceed 15% of the volume of the rectum and the common part of the PTV and bladder did not exceed 25% of the volume of the bladder.

The criterion for patients selection, besides PTV and CTV volumes, was organs at risk volume. Bladder filling was defined between 150 and 250 cm^3, rectum volume between 65 and 90 cm^3, femoral heads between 60 and 80 cm^3. Organs at risk and CTV contouring was performed by the same doctor.

To determine normal tissue volume, which ranged from 17 to 25 l, two limits were used: the upper one – between third and fourth lumbar vertebrae, and the lower one – three CT scans below the biggest ring.

To optimize data collection, five auxiliary structures were created: body ID volume (normal tissue volume defined earlier), a sphere with a margin of 1 mm around the PTV, created to make a high dose gradient between the target and healthy tissue volumes during the optimization process (used in IMRT and VMAT) and three rings. First ring of 2 cm around PTV, second of 2 cm around the first one and third of 2 cm around the second one. Ring structures were used to plan optimization by reducing the dose to healthy tissue.

IMRT plan was made with the following geometry: 5 beams (0, 60, 110, 250, 300 deg), 7 beams (0, 50, 100, 150, 210, 260, 310 deg), 9 beams (0, 40, 70, 110, 150, 210, 250, 290, 320 deg).

VMAT plans have been prepared with 1 arc (160–200 deg), 2 arcs (170–190 and 160–200 deg) and 3 arcs (181–179 deg and two previous combinations) geometry.

Tomotherapy plans were prepared using three pitch factors: 0.215; 0.287 and 0.430. Parameters used in HT plans were the Modulation Factor (MF) = 2.6; Field Width (FW) = 1.0 cm and pitch factors defined earlier.

For all 5 patients, unified optimization protocols were used for planning. Structures weight during the optimization were identical for IMRT and VMAT, and different for HT, because another treatment planning system was used for HT. Criteria of clinical constraints for OARs and PTV in all techniques were the same.

For one patient, 18 plans were prepared (6 IMRT, 6 VMAT, 6 HT plans) – 9 with normal optimization (only one auxiliary structure – 1 mm around PTV for IMRT and VMAT and without this structure for HT) and 9 with rings optimization.

Dose calculation algorithm in IMRT and VMAT optimization was AAA version 10.0.28 in the Eclipse treatment planning system by Varian, in Tomtherapy CCC version 4.3 in TomoTherapy Planning System by Accuracy.

6 MV X-ray beam was used in all prepared plans, and for IMRT and VMAT FF beam with Millennium 120 Leaf MLC.

To calculate integral dose values for each patient, Aoyama formula was used, and the difference between normal tissue and CTV integral dose to calculate NTID.

3. Results

Differences in values of integral dose between techniques are not great, but we can point to lower ID in some of these groups and to some trends (Fig. 1).

In the bladder, integral doses are similar for IMRT and HT techniques. For VMAT technique in this structure, they are slightly higher.

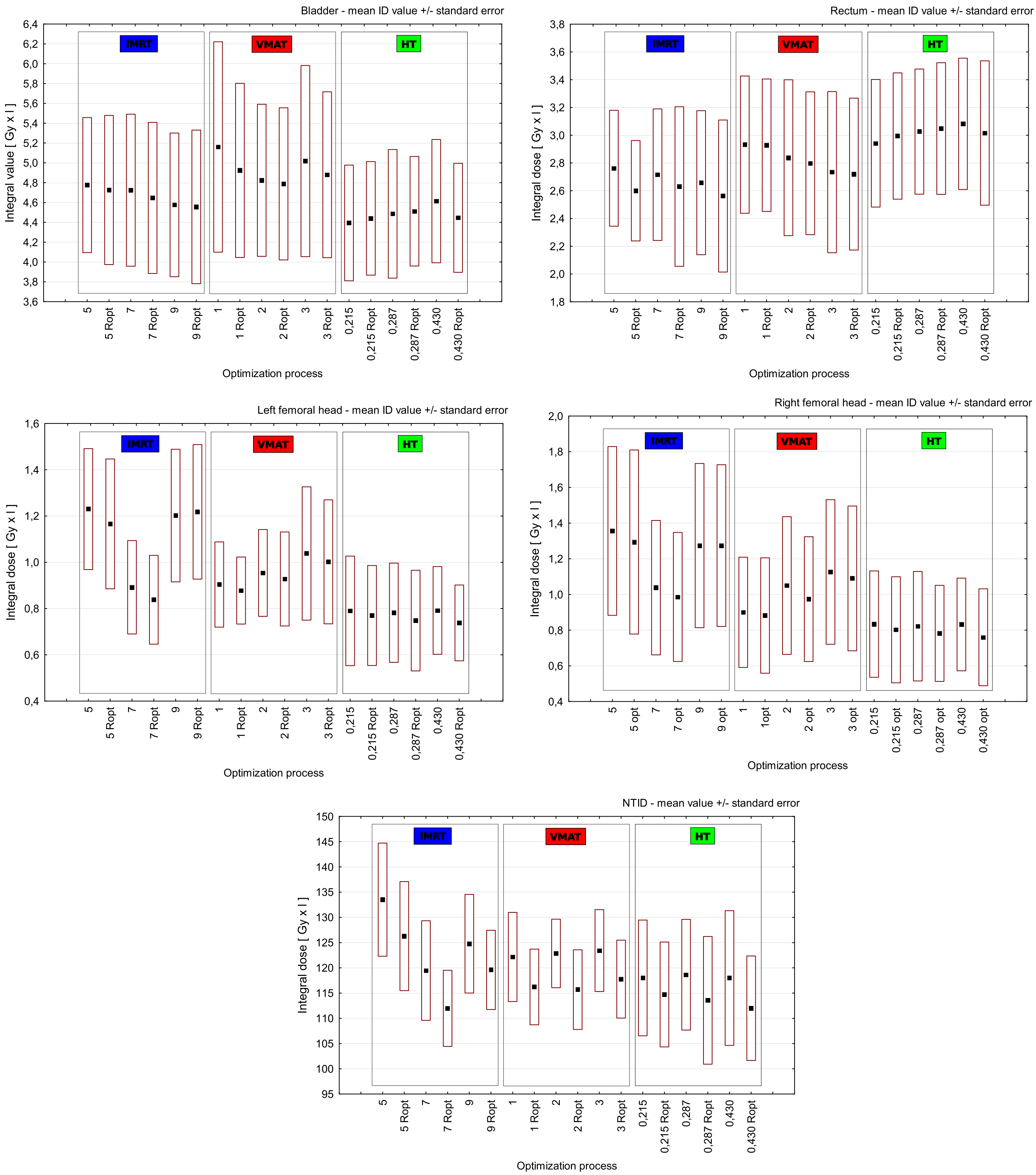

Fig. 1 – Mean integral dose values (point) with standard error (frame) of organs at risk and normal tissue (NTID) for all five patients. 5, 7, 9 = numbers of beams; 1, 2, 3 = numbers of arcs; 0.215, 0.287, 0.430 = pitch factor; Ropt = rings optimization.

Rectum integral doses are the lowest for IMRT techniques and the highest for VMAT and HT.

Lowest integral doses for the femoral heads are for HT, then for VMAT and for IMRT. Only in 7-beam IMRT plans, values are similar to HT and VMAT techniques, in 5- and 9-beam plans, values of integral dose are higher.

NTIDs in VMAT, HT and 9-beam IMRT plans are similar, but higher in VMAT and 9-beam IMRT than HT in context of the value. Quite a high value of NTID can be seen in 5-beam IMRT plans, and a little bit lower in 7-beam plans.

A trend to decrease ID value can be observed in the rectum with the number of beams and arcs increasing in IMRT and

Table 1 – Mean ID values of normal and rings (Ropt) optimization, for all 5 patients.

Technique and geometry		Mean [Gy × l]				
		Rectum	Bladder	Left femoral heads	Right femoral heads	Normal tissue (NTID)
IMRT	5/5 Ropt	2.76/2.60	4.78/4.73	1.23/1.16	1.36/1.30	133.5/126.3
	7/7 Ropt	2.72/2.63	4.72/4.64	0.89/0.84	1.04/0.98	119.5/112.0
	9/9 Ropt	2.66/2.56	4.58/4.55	1.20/1.22	1.27/1.26	124.8/119.6
VMAT	1/1 Ropt	2.93/2.92	5.16/4.93	0.91/0.88	0.90/0.88	122.2/116.2
	2/2 Ropt	2.84/2.80	4.83/4.79	0.95/0.93	1.05/0.97	122.9/115.7
	3/3 Ropt	2.73/2.72	5.02/4.88	1.04/1.00	1.13/1.09	123.4/117.8
HT	0.215/0.215 Ropt	2.94/3.00	4.40/4.44	0.79/0.77	0.83/0.80	118.0/114.7
	0.287/0.287 Ropt	3.02/3.05	4.49/4.51	0.78/0.75	0.82/0.78	118.6/113.6
	0.430/0.430 Ropt	3.08/3.02	4.62/4.45	0.79/0.74	0.83/0.76	118.0/112.0

VMAT techniques. The same can be seen in the bladder. In HT we have a poorly visible rising trend of integral doses with the increasing of the pitch factor value.

In the femoral heads, a trend can be observed for the ID value to grow with the increasing number of arches in the VMAT technique, but in HT they are at the same level. The drop of ID value in 7-beam IMRT plans is strongly dependent on the plans geometry in the IMRT techniques. If the femoral heads are not directly in the axis of the beam, the ID value will be lower.

A noticeable decrease in the value of the integral dose always occurs after rings optimization for every structure (Table 1).

The differences between the mean values of the integral dose before and after rings optimization is well noticeable in the case of NTID, except for 0.215 and 0.430 pitch factor optimization of HT.

Isolated cases of ring structures properly worked are also found in the OARs, for the bladder in the 0.430 pitch plans and for the rectum in 5- and 9-beam plans.

The greater differences in the context of one technique are visible in the IMRT, particularly in the femoral heads and normal tissue dose value, but they are not observed in VMAT and HT.

All analyses were prepared in Statistica 12 by StatSoft.

4. Discussion

Value of integral dose is closely linked with the volume which was calculated. To compare doses in a given location, we should know the volume of analyzed organs and the presented group should be uniform by volume.

Other influencing factors are clinical constraints, priorities and weights used during the optimization process. They may affect the organs at risk, integral dose values and, indirectly, also the normal tissue integral dose value (NTID).

Compared with Ślosarek et al. paper, in our patient group differences between the planning techniques used in the NTID value are not so large, with the smallest one for HT.

In our pilot study, we observed a decrease in the dose to OARs and normal tissue in the dose volume histograms and in the isodose distribution of the CT scans, but we did not observe statistical significance for all test volumes, techniques, geometries and factors. All we can say is that there are clear trends.

One of possible reasons for the lack of statistical significance is the size of the patient group, which is small at the moment. In the future, the authors plan to increase patients group.

As D'Suoza and Aoyama showed, the total energy deposited in the patient during radiation is dependent on the treatment planning parameters.

Our study showed that planning parameters include not only the choice of planning geometry and planning technique, but also the choice of an optimization process, especially in the context of normal tissues.

In view of our and previous results, it is clear that the choice of a planning geometry and optimization process has an impact on the values of integral doses in organs at risk and NTID values. The most extreme example of this is the comparison of the values of ID for the femoral heads in IMRT plans, another may be the rectum ID values (when more beams or arcs are used in this area, the dose can be distributed more sparingly).

Probably due to the different algorithms used in the treatment planning systems in IMRT and VMAT, integral dose in all types of structures was smaller after rings optimization, and in HT it was not always smaller.

5. Conclusion

A general tendency can be observed for integral dose value to decrease in all structures after rings optimization. Better effect of rings optimization is noticeable in the IMRT and VMAT techniques. It is possible to satisfactorily reduce NTID without detriment to the PTV and OARs by the use of rings optimization.

Conflict of interest

None declared.

Financial disclosure

The study was funded by Greater Poland Cancer Centre, research task number 10/2015(102).

REFERENCES

1. Ost P, Speleers B, De Meerleer G, et al. Volumetric Arc Therapy and Intensity-Modulated radiotherapy for primary prostate radiotherapy with simultaneous integrated boost to intraprostatic lesion with 6 and 18 MV: a planning comparison study. *Int J Radiat Oncol Biol Phys* 2011;**79**(3):920–6.
2. Marnitz S, Wlodarczyk W, Neumann O, et al. Which technique for radiation is most beneficial for patients with locally advanced cervical cancer? Intensity modulated proton therapy versus intensity modulated photon treatment, helical tomotherapy and volumetric arc therapy for primary radiation – an intraindividual comparison. *Radiat Oncol* 2015;**10**:91.
3. Skórska M, Piotrowski T. Empirical estimation of beam-on time for prostate cancer patients treated on Tomotherapy. *Rep Pract Oncol Radiother* 2013;**18**(4):201–8.
4. Davidson MT, Blake SJ, Batchelar DL, Cheung P, Mah K. Assessing the role of volumetric modulated arc therapy (VMAT) relative to IMRT and helical tomotherapy in the management of localized, locally advanced, and post-operative prostate cancer. *Int J Radiat Oncol Biol Phys* 2011;**80**(5):1550–8.
5. Aoyama H, Westerly DC, Mackie TR, et al. Integral radiation dose to normal structures with conformal external beam radiation. *Int J Radiat Oncol Biol Phys* 2006;**64**(3):962–7.
6. Fuentes-Raspall R, Inoriza JM, Rosello-Serrano A, Auñón-Sanz C, Garcia-Martin P, Oliu-Isern G. Late rectal and bladder toxicity following radiation therapy for prostate cancer: predictive factors and treatment results. *Rep Pract Oncol Radiother* 2013;**18**(5):298–303.
7. Polkinghorn WR, Zelefsky MJ. Improving outcomes in high-risk prostate cancer with radiotherapy. *Rep Pract Oncol Radiother* 2013;**18**(6):333–7.
8. D'Souza WD, Rosen II. Nontumor integral dose variation in conventional radiotherapy treatment planning. *Med Phys* 2003;**30**(8):2065–71.
9. D'Arienzo M, Masciullo SG, de Sanctis V, Osti MF, Chiacchiararelli L, Enrici RM. Integral dose and radiation-induced secondary malignancies: comparison between stereotactic body radiation therapy and three-dimensional conformal radiotherapy. *Int J Environ Res Public Health* 2012;**9**(11):4223–40.
10. Ślosarek K, Osewski W, Grządziel A, et al. Integral dose: comparison between four techniques for prostate radiotherapy. *Rep Pract Oncol Radiother* 2014;**20**(2): 99–103.