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Comparison of dose distribution in IMRT and RapidArc technique in prostate radiotherapy

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ABSTRACT

Aim: The aim was to provide a dosimetric comparison between IMRT and RapidArc treatment plans with RPI index with simultaneous comparison of the treatment delivery time.

Background: IMRT and RapidArc provide highly conformal dose distribution with good sparing of normal tissues. However, a complex spatial dosimetry of IMRT and RapidArc plans hampers the evaluation and comparison between plans calculated for the two modalities. RPI was used in this paper for treatment plan comparisons. The duration of the therapeutic session in RapidArc is reported to be shorter in comparison to therapeutic time of the other dynamic techniques. For this reasons, total treatment delivery time in both techniques was compared and discussed.

Materials and methods: 15 patients with prostate carcinoma were randomly selected for the analysis. Two competitive treatment plans using respectively the IMRT and RapidArc techniques were computed for each patient in Eclipse planning system v. 8.6.15. RPIwin® application was used for RPI calculations for each treatment plan.

Additionally, total treatment time was compared between IMRT and RapidArc plans. Total treatment time was a sum of monitor units (MU) for each treated field.

Results: The mean values of the RPI indices were insignificantly higher for IMRT plans in comparison to rotational therapy. Comparison of the mean numbers of monitor units confirmed that the use of rotational technique instead of conventional static field IMRT can significantly reduce the treatment time.

Conclusion: Analysis presented in this paper, demonstrated that RapidArc can compete with the IMRT technique in the field of treatment plan dosimetry reducing the time required for dose delivery.

1. Background

Nowadays, intensity-modulated radiation therapy (IMRT) is still an advanced method of radiotherapy which increases dose distribution conformity by modulating the intensity of the radiation beam in each treated subvolumes. IMRT has a potential to minimize doses to surrounding normal or critical structures and can be safely delivered with a minimum risk of side effects. However, both fraction time and exposure of normal tissue to low doses are significantly higher for IMRT than in conventional radiotherapy.[1–6]

Precise dose adjustment to the tumor geometry is usually achieved with combinations of several intensity-modulated

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fields distributed among different beam directions.[1] Dose distribution calculation and optimization processes are highly computerized. Typically, IMRT dose maps are inversely planned using dose and volume constraints, as well as priority factors for each structures which define acceptable and penalized dose ranges.

Technological fusion of IMRT and Arc modalities resulted in the RapidArc® (Varian Medical Systems) technique which provides comparable or sometimes even better dosimetric parameters of dose distribution than IMRT alone. Beam intensity is modulated continuously during gantry rotation around the patient's body. Algorithm for dose calculation in RapidArc includes angular velocity of the gantry, accelerator mode (MU/min) and movement of collimator's leaves (MLC).

In IMRT and RapidArc, treatment plans are reported to provide highly conformal dose distribution with good sparing of normal tissues.[3] However, the duration of the therapeutic session in RapidArc is reported to be even 8 times shorter in comparison to therapeutic time of the other dynamic techniques, which benefits the quality of treatment delivery. Therefore, RapidArc is presented by some authors as a fast and simple treatment modality, with precision that matches or exceeds dose conformity of the IMRT technique.[3,7–10] However, unambiguous analysis should be done to point whether RapidArc plans are superior to the IMRT in respect to dosimetric parameters for a specific patient plan.

Complex spatial dosimetry of the IMRT and RapidArc plans hamper the evaluation and comparison between plans calculated for the two modalities. DVH (Dose Volume Histogram) analysis reduces spatial dose distribution to the simple graph and facilitates plan evaluation but not comparison. One dimensional indices calculated based on selected dosimetric and volumetric parameters of dose distribution are assumed to provide ranking tools to assist in selecting an optimal plan among the alternative ones. Numerous factors and indices, e.g. *conformity index*, *conformal index*, *homogeneity index*, etc. were specified in the literature to distinguish between plans.[11,12] The formulas of the indices mentioned before, are based mainly on simple rates of selected dosimetric parameters for target volume and healthy tissue. More appropriate analysis of dose distribution, which takes into account complex shape of the DVH curves and the priority of each structure, is very often impossible with available indices.

In 2008, *Radiation Planning Index* (RPI) was created in the Radiotherapy and Brachytherapy Planning Department (Center of Oncology – Institute Gliwice branch) for treatment plan comparisons.[13] RPI evaluates simultaneously the dose distribution in the set of *Planning Treatment Volumes* (PTVs) and *Organs at Risk* (OaR) Moreover, it takes into account dose homogeneity in the targets and structure's priority. It was adapted to compare the treatment plans computed for more then one target volume and for a large number of irradiated structures with different radiosensitivity and risk of injury. RPI was used in this paper as an unambiguous tool to compare IMRT and RapidArc treatment plans, so as to verify the hypothesis of the RapidArc superiority in respect to spatial dose distribution. Moreover, a comparison of time in delivery of IMRT and RapidArc dose distribution was also provided in this paper.

2. Aim

The aim of this paper was to compare IMRT and RapidArc treatment plans for prostate radiotherapy in respect to RPI index values and number of monitor units.

3. Materials and methods

15 patients with prostate carcinoma were randomly selected for analysis. Two competitive treatment plans using respectively the IMRT and RapidArc technique were computed for each patient in Radiotherapy and Brachytherapy Planning Department. Dose distributions were calculated with Eclipse system version 8.6.15. In IMRT, 6 MV and 20 MV photon beams were planned for treatment depending on the gantry angle, while in RapidArc only 6 MV photon beams were used for planning. Total dose of 76 Gy in 2 Gy fractions was delivered in each technique. Mean number of 9 beams (ranging from 7 to 10) and not more than 2 arcs were used respectively in the IMRT and RapidArc techniques.

RPIwin® application, designed and developed in 2009 by W. Osewski, K. Ślosarek and J. Guzek in the Center of Oncology Gliwice Branch (RT and BT Planning Department) was used for RPI calculations for each treatment plan. RPI values were assessed basing on each set of DVH curves collected for targets and OaR structures (Eq. (1)).

$$\mathrm{RPI} = \sqrt[n+m]{\prod_{i}^{m}\left\{\prod_{j}^{n}\left[\left(1-\frac{w_j\cdot\int_0^{D_{\max \mathrm{OaR}}} V_j\mathrm{OaR}\,\mathrm{d}D_{\mathrm{OaR}}}{\int_0^{D_{\max \mathrm{OaR}}} V_j\mathrm{OaR}\cdot 100\%\,\mathrm{d}D_{\mathrm{OaR}}}\right)\cdot\left(\frac{\int_0^{D_{\max \mathrm{PTV}}} V_i\mathrm{PTV}\,\mathrm{d}D_{\mathrm{PTV}}}{\int_0^{D_{\max \mathrm{PTV}}} V_i\mathrm{PTV}\cdot 100\%\,\mathrm{d}D_{\mathrm{PTV}}}\right)\cdot(1-S_{\mathrm{Dev}}\cdot p_i)\right]\right\}} \quad (1)$$

Weight factors (w_j parameter in Eq. (1)) in RPIwin application, which were user-defined input data were established for each structure. These priority factors which influence the RPI values rank the structures from the most important (weight factor is 1) to the least important (weight factor close to 0). In RPI formula n is the number of critical structures and m is the number of treated volumes. RPI assumes calculation of the integral doses that cover each of the i-th PTV and j-th OaR structure. S_{Dev} determines the standard deviation of the dose distribution in PTV, while p_i is a weight factor of the dose distribution homogeneity for the PTV_i. RPI allows comparing treatment

Table 1 – RPI_{IMRT} and RPI_{Arc} values calculated for each treatment plan in the IMRT and RapidArc techniques. Weight factors for each group of RPI values represent the criteria of the plan evaluation. Mean values of RPI_{IMRT} and RPI_{Arc} calculated in each group of weight factors are presented on the bottom of the table.

	[a]$OAR_w > PTV_w$		[b]$OAR_w = PTV_w$		[c]$OAR_w < PTV_w$	
	RPI_{IMRT}	RPI_{ARC}	RPI_{IMRT}	RPI_{ARC}	RPI_{IMRT}	RPI_{ARC}
1	0.624	0.491	0.619	0.487	0.663	0.547
2	0.644	0.517	0.639	0.515	0.681	0.573
3	0.623	0.584	0.620	0.582	0.662	0.634
4	0.636	0.669	0.634	0.667	0.660	0.714
5	0.647	0.678	0.644	0.676	0.683	0.719
6	0.459	0.485	0.456	0.483	0.524	0.549
7	0.643	0.503	0.639	0.501	0.674	0.557
8	0.744	0.620	0.739	0.616	0.768	0.658
9	0.535	0.382	0.532	0.378	0.589	0.488
10	0.597	0.356	0.593	0.353	0.651	0.460
11	0.615	0.645	0.612	0.622	0.647	0.689
12	0.696	0.598	0.690	0.595	0.717	0.640
13	0.519	0.341	0.515	0.339	0.581	0.440
14	0.623	0.606	0.617	0.603	0.648	0.634
15	0.579	0.526	0.574	0.521	0.617	0.588
Mean RPI	0.612	0.533	0.608	0.529	0.651	0.593

[a] Risk organs sparing was assumed to be more important than PTV coverage.
[b] Risk organs sparing and PTV coverage equally important.
[c] Risk organs sparing less important than PTV coverage.

plans calculated for the same patient. Superior plan is represented by higher values of the RPI. RPI near to 1 corresponds to a dose distribution that fulfils all requirements related to the PTV coverage of the prescribed dose and dose delivered to the organs at risk and healthy tissue. On the other hand, RPI values near 0 represent dose distribution of low conformity, homogeneity or undesirable high doses in healthy structures.

RPI calculations were performed three times for each treatment plan in order to obtain three groups of RPI values under different conditions. Three groups of RPI values were created depending on the values of weight factors that have been taken for calculations. Weight factors in these groups of plans were set to be:

1. higher for OaRs than for PTVs (the ratio $OaR_w/PTV_w > 1$),
2. equal for OaRs and PTVs ($OaR_w = PTV_w$) (the ratio $OaR_w/PTV_w = 1$),
3. lower for OaRs than PTVs (the ratio $OaR_w/PTV_w < 1$).

Priority index for caput femoris remained 0.5 for each RPI computation procedure. In the first group, the weight was 1 for OaR, while for PTV, it was set at 0.75. In the third group PTVs and OaRs were ranked with weight factors 1 and 0.75, respectively. In all groups, RPI_{IMRT}/RPI_{Arc} ratios were calculated to verify the hypothesis that ratio of the weight factors may influence the absolute difference between RPI_{IMRT} and RPI_{Arc}. The following assumptions were made to verify if the RPI index allows pointing out a delivery technique which has an absolute advantage over the other treatment delivery techniques:

(1) Mean value of $RPI_{IMRT}/RPI_{Arc} > 1$ in all three group means that IMRT has an absolute advantage over RapidArc treatment delivery technique in respect to both OaR sparing and PTV dose coverage and homogeneity.

(2) Mean $RPI_{IMRT}/RPI_{Arc} > 1$ in the first group and $RPI_{IMRT}/RPI_{Arc} < 1$ in the third group will show that the IMRT treatment delivery technique has a potential to spare healthy tissue better than the rotational technique, while better target coverage is achieved with the RapidArc technique.

In addition to the RPI analysis, total treatment time was compared between IMRT and RapidArc plans. Total treatment time was a sum of monitor units (MU) for each treated field. All graphs and statistics presented in Section 3 were performed with Microsoft Excel application.

4. Results

RPI values calculated for each competitive IMRT and RapidArc plans for three sets of weight factors are included in Table 1.

The mean values of the RPI indices in each group of weight factors are presented in Table 1. Statistical significance of the differences between RPI_{IMRT} and RPI_{Arc} was evaluated with the non-parametric method (*Sign test* was used to verify if there are differences between medians of the two variables). Differences were found to be statistically insignificant ($p = 0.12$). Fig. 1 illustrates differences between values of RPI_{IMRT} and RPI_{Arc} in each of the three groups of weight factors for each patient.

Total number of Monitor Units ($\sum$MU) in IMRT and RapidArc plans were evaluated for each patient. Mean number of monitor units for IMRT was 809 MU (ranging from 576 to 1234) and for RapidArc it was 442 MU (ranging from 253 to 982). The difference between $\sum MU_{IMRT}$ and $\sum MU_{Arc}$ was statistically significant (Sign test; $p = 0.01$) and illustrated in Fig. 2.

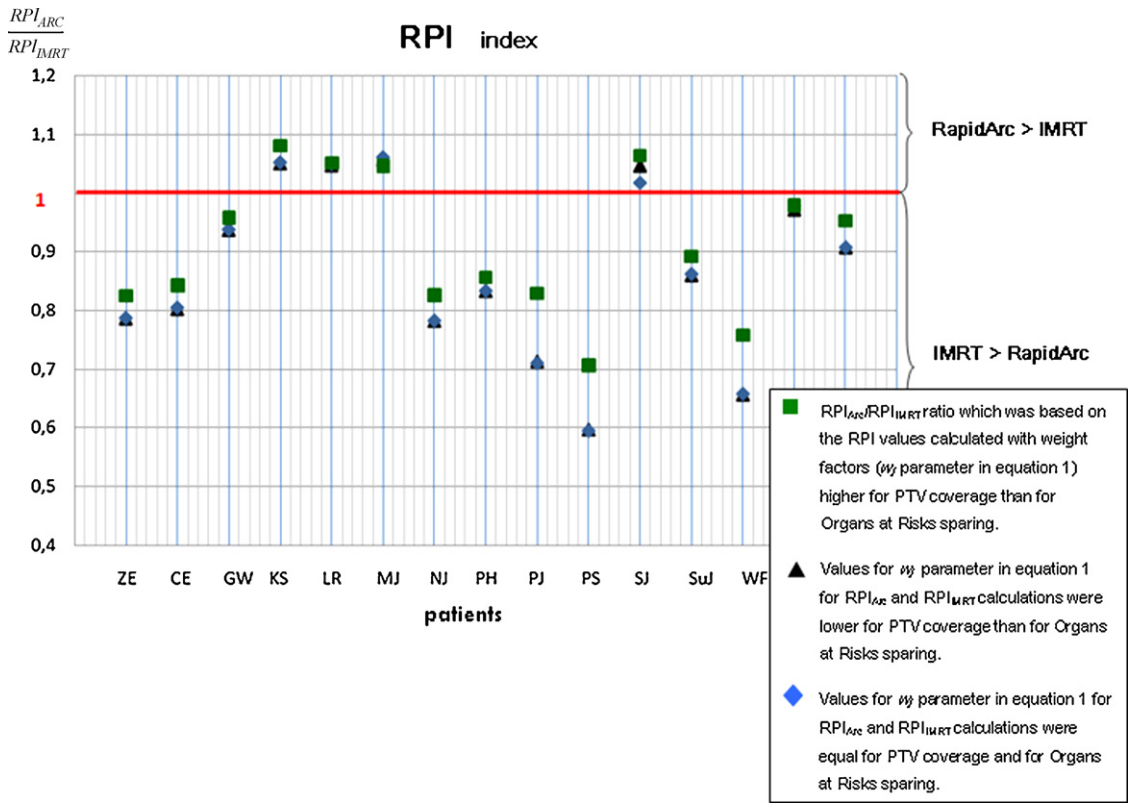

Fig. 1 – RPI$_{Arc}$/RPI$_{IMRT}$ ratio calculated for each patient and for the three groups of weight factors. Red line represents the RPI$_{Arc}$/RPI$_{IMRT}$ ratio equal to 1, when no difference between the plans is observed. IMRT provides better dose distribution than RapidArc in respect to RPI value for points located below the red line (RPI$_{Arc}$/RPI$_{IMRT}$ < 1). Points located above the red line represent values of the RPI$_{Arc}$/RPI$_{IMRT}$ ratio which are higher than 1. For these points RapidArc provides better dose distribution in respect to the RPI index.

5. Discussion

RPI calculations for the IMRT and RapidArc dose distributions were performed taking into account three different ratios of the weight factors for OaR and PTV structures. In each group, the comparison revealed superiority of the IMRT plans in respect to competitive RapidArc plans; however, the absolute differences between mean values of RPI$_{IMRT}$ and RPI$_{Arc}$ were marginal.

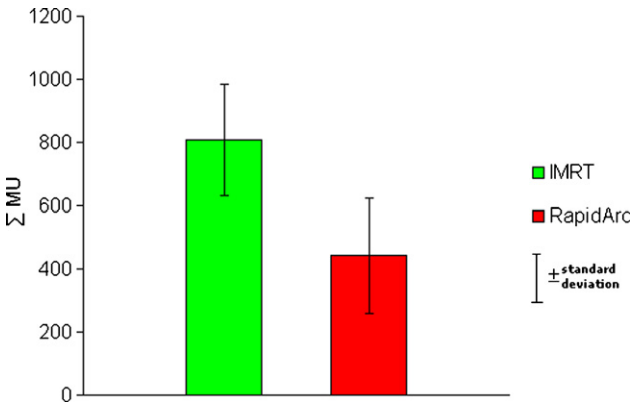

Fig. 2 – Mean values of total number of monitor units $\sum$MU and standard deviations in the group of plans calculated for the static field IMRT technique and rotational technique ($\sum$MU$_{IMRT}$ and $\sum$MU$_{Arc}$).

Statistical significance was evaluated in this experiment and revealed no significance between mean RPI values ($p > 0.05$) probably because of the small sample group. Further investigation with larger number of patients is then necessary.

The experiment showed the Radiation Planning Index to be a useful tool for treatment plan rating when a simple comparison of DVH curves for each structure provides ambiguous results. Dose distribution optimization meets the objectives of the plan which assumes delivery of the prescribed dose to the target and simultaneous sparing of normal tissue. Those tasks are rival and their simultaneous performance is sometimes impossible. Therefore, it is difficult to decide whether dose distribution with acceptable OaRs and unsatisfactory target coverage is more preferable than treatment plan with higher OaRs doses but appropriate target coverage. Moreover, the decision making process based only on selected dose constraints rejects the slope of the DVH curve at the lower dose ranges and does not take into account the dose homogeneity in the target.

RPI was designed for unambiguous analysis of the whole dose distribution, represented as a histogram. RPI formula combines the rival goals of the treatment planning procedure taking into account dose distribution in all target structures and all risk volumes. Moreover, RPIWin reads the shape of DVH

curve supplementing the RPI formula with information about dose distribution throughout the whole structure.

Additional analysis of the number of monitor units showed that RapidArc is a fast treatment delivery method in comparison to the IMRT. Difference between the number of MU was statistically significant with $p < 0.05$. In this paper, only pure time for dose delivery (expressed in the number of monitor units) was taken into account while comparing the two irradiation techniques. Non-coplanar fields in the IMRT technique prolonged the treatment session because of the table position that had to be changed by the staff between each treated fields. In our experiment in arc therapy with a single arc, no table rotation was used. Gantry movements in Rapid Arc are utilized for dose distribution optimization and dose delivery because the beam is on during gantry rotation. Consequently, the total time for delivery of the treatment plan is significantly reduced in comparison with the "classic" IMRT.

Presented experiment showed that IMRT has an advantage over RapidArc treatment delivery technique in respect to dose distribution. However, the differences are statistically insignificant and seem to be illusive. Moreover, relatively longer treatment time, in respect to the Rapid Arc technique, may worsen the precision of the treatment delivery. Longer patient immobilization and irradiation may increase the risk of the intrafraction movement.

RapidArc provides dose distributions at almost the same level of conformity and homogeneity as the IMRT technique, with treatment times shorter by about 45%. It confirms that RapidArc is a treatment modality that can compete with the IMRT technique in the field of plan dosimetry and treatment time delivery.

6. Conclusions

Spatial dose distributions in the IMRT and RapidArc techniques shows high level of complexity. Evaluation and comparison between competitive treatment plans basing on the spatial distribution of dose values and DVH curves remains, therefore, an ambiguous task for a physician. Large number of structures taken into account during planning, additionally hamper selection of the most favorable treatment plan. Competing goals of treatment planning procedure (target's prescription dose and simultaneously critical structure's maximal dose) achieved by the rival plans with different priority levels complicate the comparison between dose distributions calculated for the patient. Evaluations based on selected dosimetric or volumetric parameters lead to the reduction of the spatial dosimetrical information which may be crucial for treatment results. Factors and indices introduced by many authors aid the plan evaluation and comparisons. RPI index presented in this paper provided an unambiguous tool for comparison of the dosimetric quality of IMRT and RapidArc plans.

Both treatment modalities presented in this paper provided almost equivalent dosimetry according to the RPI analysis. However, MU analysis revealed that RapidArc plans can be delivered in a shorter time by about 45% in comparison to the IMRT plans. Risk of the patient movement during treatment delivery increases with the therapeutic time. This makes the arc therapy a reliable method for treating patients with prostate cancer.

Conflict of interest

There is no relationship with the authors (Wojciech Leszczyński, Krzysztof Ślosarek, Marta Szlag) of the manuscript entitled "Comparison of dose distribution in IMRT and RapidArc technique in prostate radiotherapy" and other people or organisations that may cause the conflict of interest with regard to a submitted manuscript.

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