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IMRT versus 3D-CRT for thyroid cancer

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A 3D-CRT involving a 4-field (5-field, 6-field, etc.) technique (photon and electron beams) and an alternative IMRT 7-field technique with 6 MV photon fields for thyroid cancer were compared. The IMRT allows reduction in the dose to the spinal cord of about 12 Gy and permits better coverage of the target volume with smaller standard deviation (average 4.65% for 3D-CRT as compared with 1.81% for IMRT). The time needed to prepare therapy (TPS, dosimetry, preparing boluses and electron aperture) and the session time are about the same for both techniques.

Key words: thyroid, IMRT, 3D-CRT, Target Conformity Index, comparison of treatment plans.

Introduction

At the Maria Sklodowska-Curie Memorial Cancer Centre in Warsaw, a 3D-CRT involving a 4-field (5-field, 6-field, etc.) technique (photon and electron beams) [1] is often used in the treatment of thyroid cancer. This results in a high dose to the spinal cord, which limits the total dose. An IMRT technique was investigated as an alternative for this tumour location.

Material

Radiotherapy plans for 10 patients were examined and compared. Physicians outlined PTV and boost volumes on CT slices. Patients received 3D-CRT treatment in two courses. In the first one, 2 Gy (50 Gy prescribed to PTV) was delivered in 25 fractions. Boost fields were designed to irradiate the boost volume of about 5 fractions with a 2 Gy fraction dose (prescribed to the boost volume). In order to compare the techniques, plans were analysed for the first course of treatment. It has to be mentioned that the dose to the spinal cord (which should be less than 45 Gy) often limits requirements for PTV (85% and 110% of prescribed dose are accepted as minimum and maximum doses in PTV). On the other hand, IMRT plans were examined according to ICRU 67 recommendations (minimum dose of 95% and maximum dose of 107% of the prescribed dose).

Methods

The 3D-CRT plans were generated on Helax TPS, and IMRT plans were prepared on Eclipse TPS (with a Helios optimization module). A sliding window technique for delivering IMRT plans was used. IMRT plans were made with the same geometry. A 7-field technique with 6 MV photon fields was used (beam geometry: 204°, 256°, 308°, 0°, 52°, 104°, 156° and collimator: 3°).

Plans were compared for selected CT slices. The following statistics were used: minimum and maximum doses, a standard deviation and DVH. A TCI_C^+ (Uncomplicated Target Conformity Index for Comparing Plans) methodology was also used [2–4] (see Equation 1).

$$TCI_C^+ = \prod_{i=1}^{N_T} TCI_i \prod_{i=1}^{M_{NT}} NTSI_{C_j} \tag{1}$$

where:

TCI_C^+ — Uncomplicated Target Conformity Index for Comparing Plans,

TCI — Target Conformity Index (calculated for minimum and maximum doses equal to 95% and 107% of the prescribed dose),

$NTSI_C$ — Normal Tissue Sparing Index for Comparing Plans (here scaled by percentage difference of DVH between compared plans),

N_T — Amount of target volumes,

M_{NT} — Amount of normal tissues.

A Normal Tissue Sparing Index for Comparing Plans, $NTSI_C$ (used in TCI_C^+), was calculated for test doses (the test volume was defined as a minimum volume receiving a test dose in plans compared) and was scaled by a percentage difference of DVH for normal tissues (the spinal cord and the whole patient body were considered). The time needed for plan preparation (including treatment planning and dosimetric verification) and the time for delivering the dose during one radiation session were also compared.

Results

The comparison of particular CT slices provides us with information about a better dose coverage of the target in IMRT plans. The dose distribution better fits the target volume, and the spinal cord is also better spared (Figure 1). On the other hand, the lower part of the target often receives a lower dose in the IMRT plan (the volume receiving a 100% of dose is smaller (Figure 2)).

The dose statistics for PTV are presented in Table 1. The minimum dose for PTV in IMRT plans is 87% on average, as compared with 81% for 3D-CRT. The maximum dose for PTV is smaller in IMRT (105% on average) than that in 3D-CRT (110% on average). Standard deviation of the dose delivered to PTV in 3D-CRT is, on average, 2.6 times higher than that in IMRT plans (Figure 3).

Although only the first course of treatment was taken into consideration we also compared dose distributions in the boost volume (Table 2). The minimum dose in boost is, on average, higher for IMRT plans (93% compared with 88%). The maximum dose in boost is, on average, smaller for IMRT plans (104% as compared with 107%). The standard deviation of the dose distribution in the boost volume in 3D-CRT is, on average, 3 times higher than that in IMRT plans (Figure 4).

The spinal cord receives 1.4 times higher dose in 3D-CRT plans. This corresponds to the difference of about 1160 cGy on average (Table 3 and Figure 5).

TCI-PN for IMRT is equal to 0.99 on average, and only 0.39 for 3D-CRT (Table 4). It means that the dose distribution in IMRT plans is definitely better adjusted to the target volume than that in 3D-CRT plans. $NTSI_C$ provides better spinal cord sparing through the IMRT technique. Unfortunately, by the IMRT technique a higher percentage of the whole body receives relatively small doses. What is still under investigation is whether small doses cause induced malignancies. The calculated value of $TCI^+{}_C$ is, on average, 0.82 for IMRT as compared with 0.05 for 3D-CRT.

Table 1. Comparison of dose statistics for PTV taking into account: minimum dose (min), maximum dose (max), mean dose (mean), and dose standard deviation (std)

patient no.	PTV min [%]		PTV max [%]		PTV mean [%]		PTV std [%]		std 3D/ IMRT [1]
	3D	IMRT	3D	IMRT	3D	IMRT	3D	IMRT	
1	80.46	88.05	111.44	104.17	100.17	100.04	5.76	1.863	3.09
2	80.69	88.89	112.44	104.85	100.05	100.02	4.17	1.824	2.29
3	82.79	85.03	109.88	104.34	100.06	99.99	4.21	1.586	2.66
4	81.85	91.13	110.25	103.89	99.42	100.08	4.50	1.829	2.46
5	80.82	87.69	109.70	104.17	100.22	100.04	4.19	1.943	2.16
6	80.92	82.92	107.55	106.34	94.61	100.04	4.88	2.104	2.32
7	80.03	88.66	111.93	105.21	98.39	100.01	4.63	1.777	2.61
8	79.77	86.91	110.91	105.49	99.76	100.00	5.21	1.761	2.96
9	83.25	88.32	110.36	105.23	100.07	100.01	4.25	1.675	2.54
10	80.28	86.19	109.50	105.65	95.18	100.01	4.69	1.697	2.76

Table 2. Comparison of dose statistics for BOOST taking into account: minimum dose (min), maximum dose (max), mean dose (mean), and dose standard deviation (std)

patient no.	BOOST min [%]		BOOST max [%]		BOOST mean [%]		BOOST std [%]		std 3D/ IMRT [1]
	3D	IMRT	3D	IMRT	3D	IMRT	3D	IMRT	
1	83.39	96.51	109.34	104.17	101.02	101.37	5.51	1.034	5.32
2	94.70	96.12	107.60	104.85	102.65	101.67	2.36	1.408	1.67
3	92.59	94.30	106.07	103.48	101.81	100.94	2.40	1.171	2.05
4	95.36	94.75	102.11	102.83	100.16	100.97	1.07	0.937	1.14
5	89.14	96.99	107.22	103.63	101.47	101.45	3.39	1.263	2.68
6	85.74	96.91	107.15	105.37	97.46	101.72	3.97	1.323	3.00
7	83.01	93.43	109.26	104.67	99.05	100.92	4.79	0.967	4.95
8	86.78	81.17	107.85	105.39	101.36	100.93	3.67	1.227	2.99
9	86.92	90.26	110.39	104.16	101.48	100.67	4.10	1.298	3.16
10	81.52	86.93	105.16	105.65	94.72	101.06	4.75	1.461	3.25

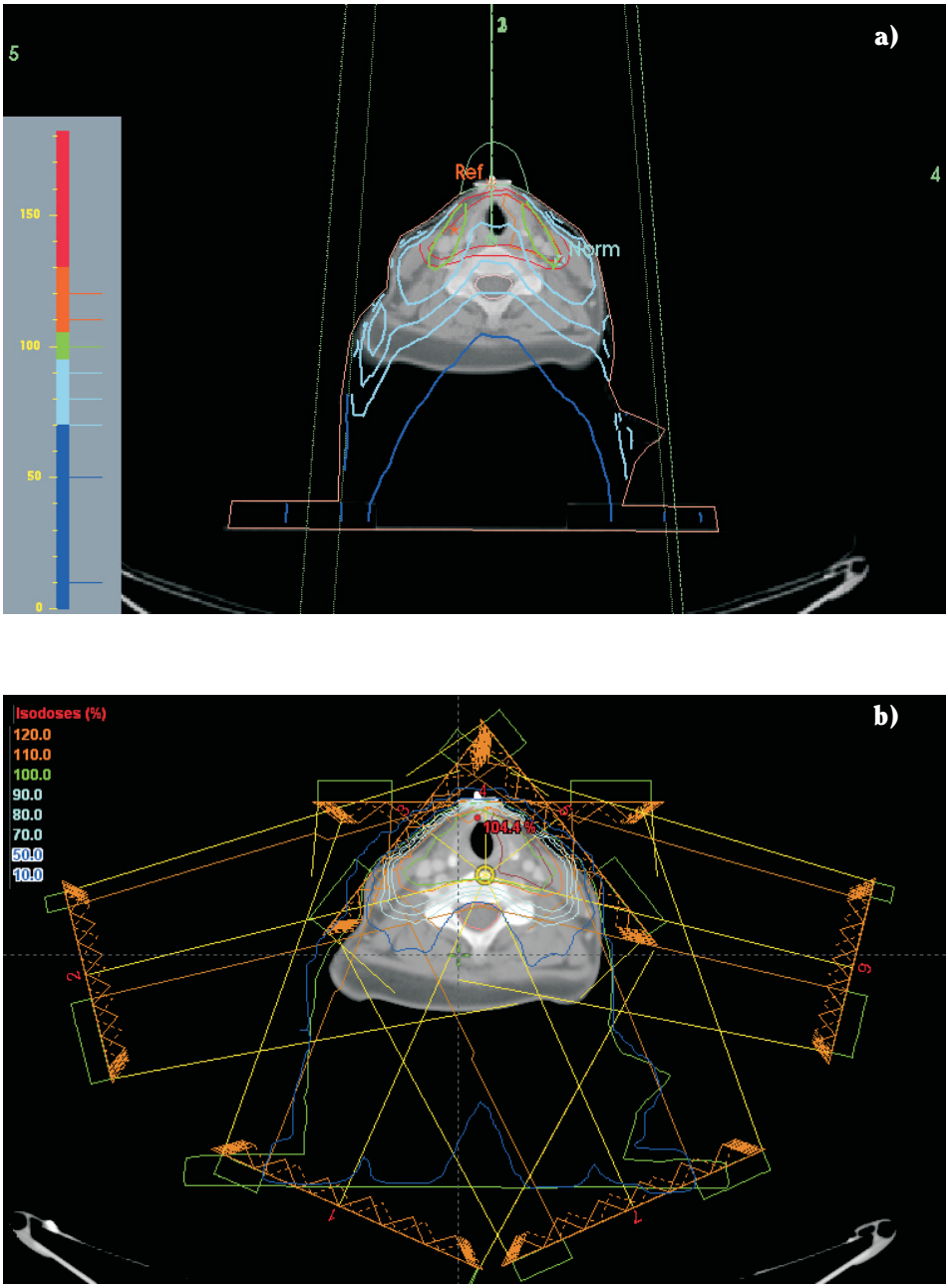

Figure 1. Comparison of dose distribution in upper region of PTV: a) 3D-CRT, b) IMRT

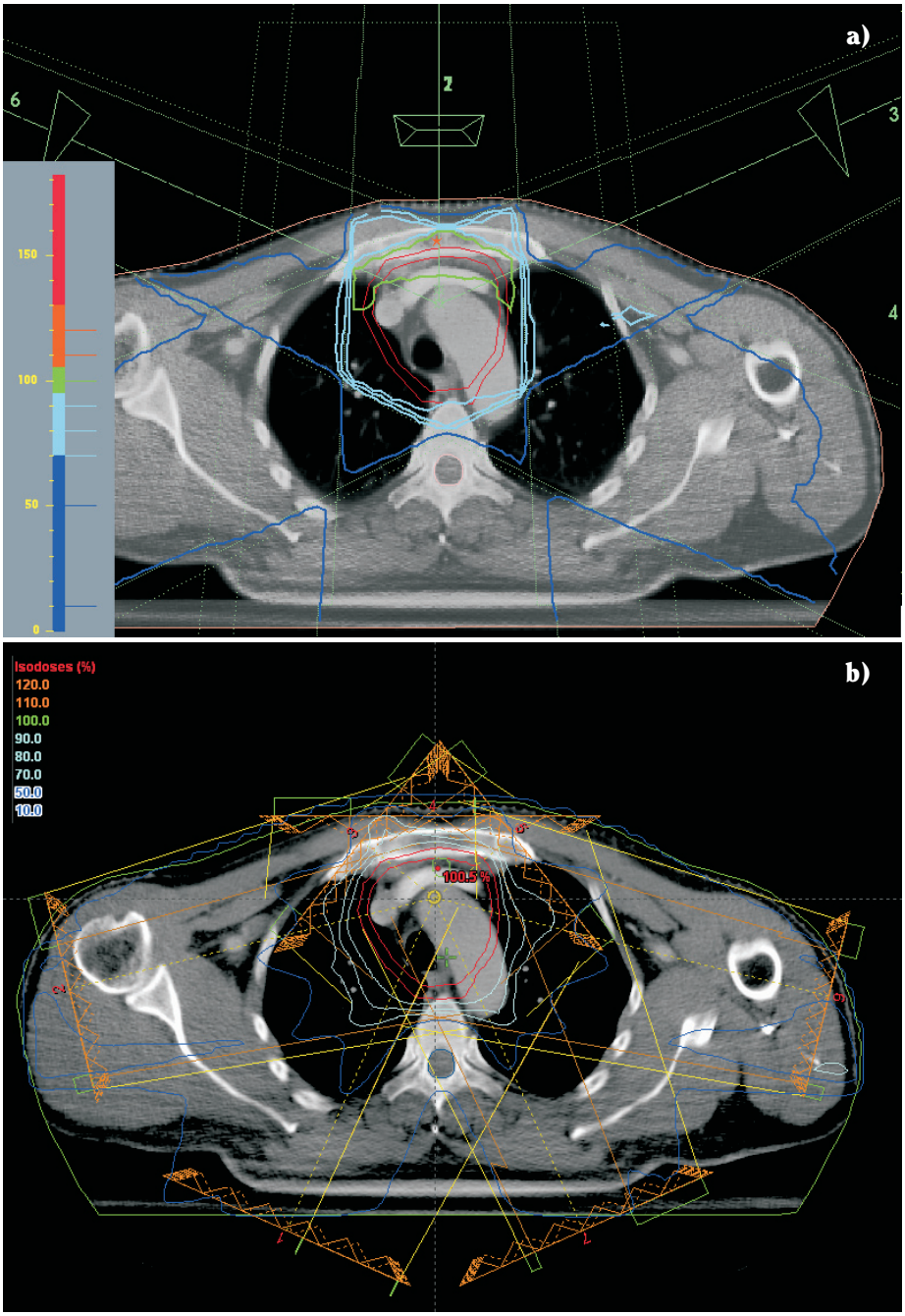

Figure 2. Comparison of dose distribution in lower region of PTV: a) 3D-CRT, b) IMRT

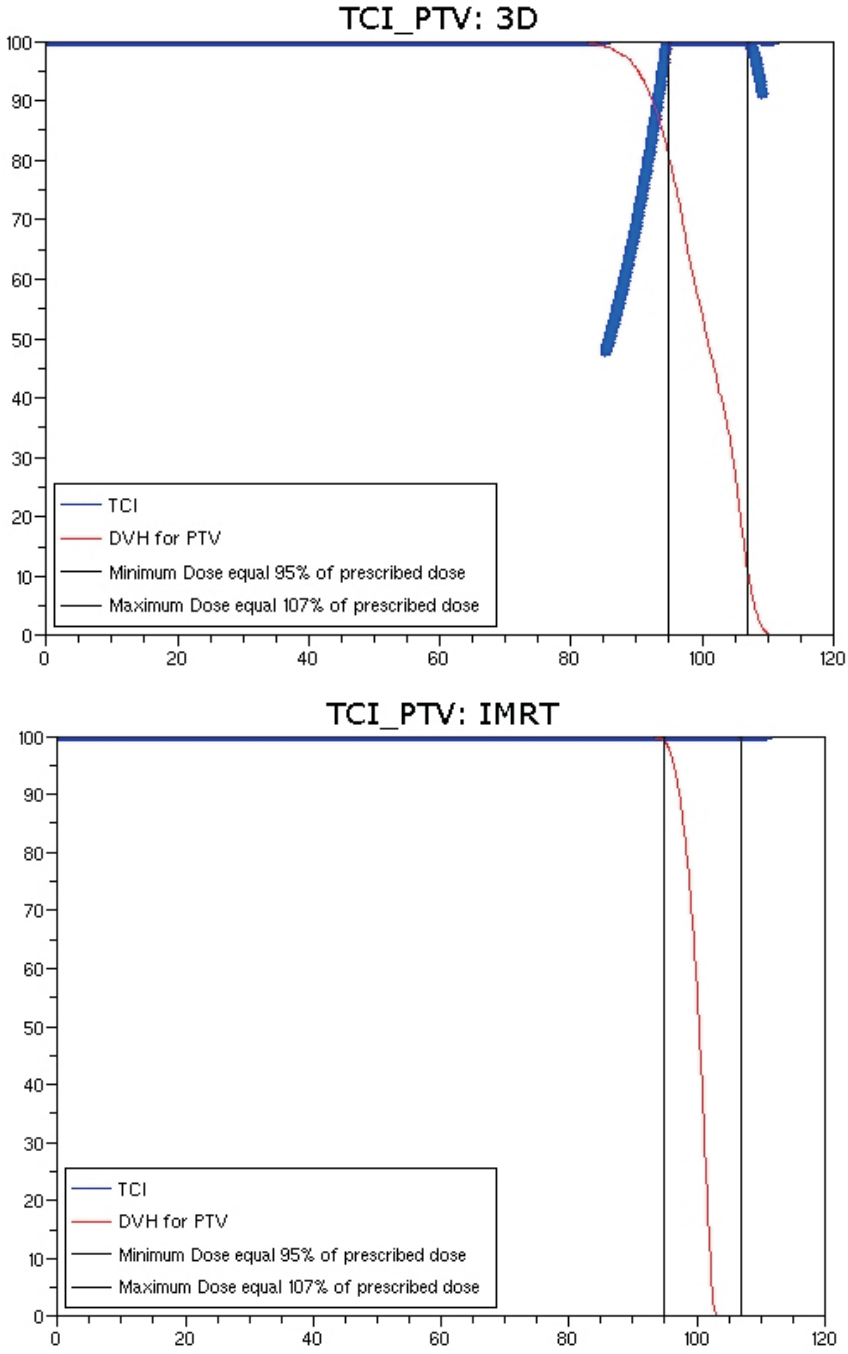

Figure 3. DVH and TCI for PTV: a) 3D-CRT, b) IMRT

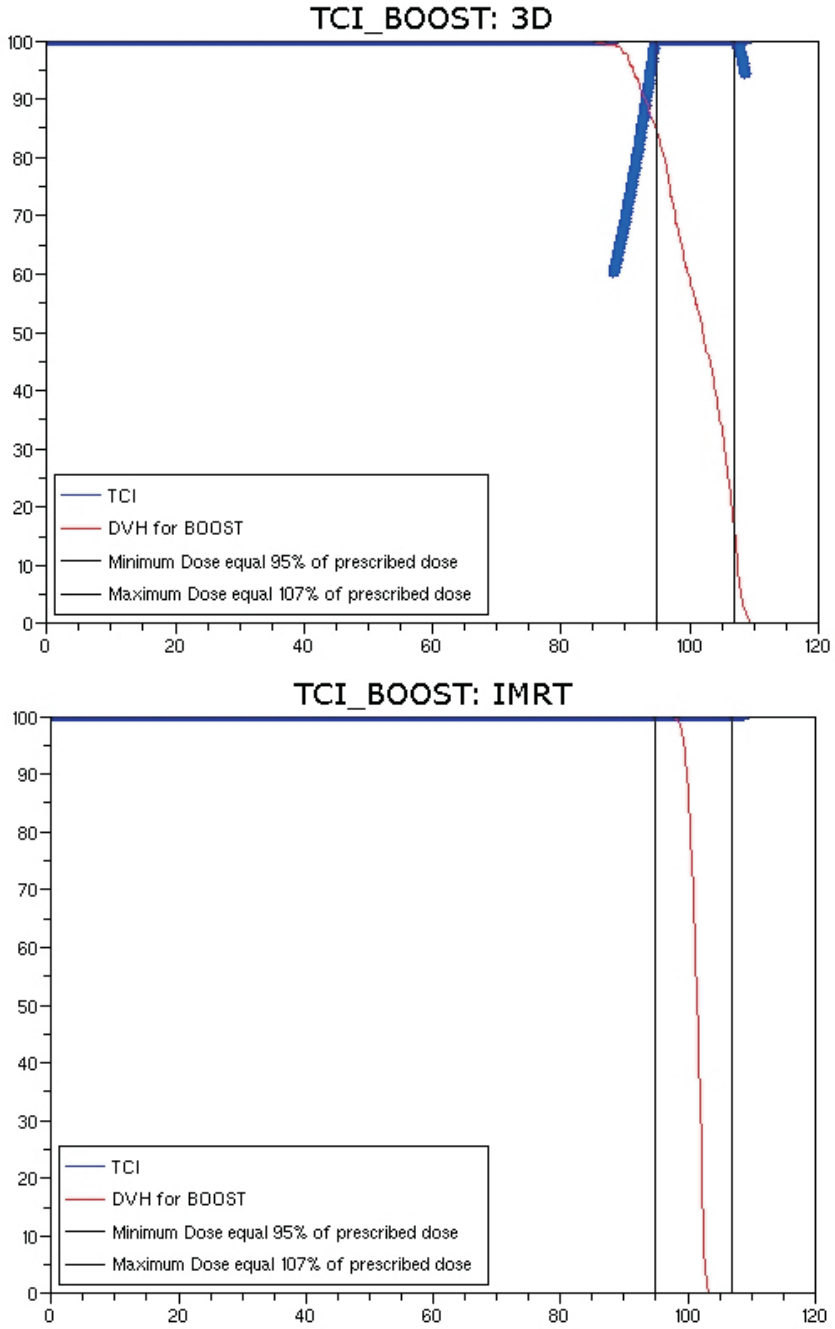

Figure 4. DVH and TCI for BOOST: a) 3D-CRT, b) IMRT

Table 3. Comparison of maximum dose for SPINAL CORD

patient no.	SPINAL CORD max [cGy]		3D/IMRT [1]	3D − IMRT [cGy]
	3D	IMRT		
1	4141	2778	1.49	1363
2	4301	3138	1.37	1164
3	4366	2470	1.77	1897
4	3804	2729	1.39	1076
5	3964	3560	1.11	404
6	3904	2835	1.38	1069
7	4000	2825	1.42	1175
8	4278	3414	1.25	864
9	4151	2657	1.56	1494
10	3527	2433	1.45	1094

Table 4. Comparison of TCI, $NTSI_c$ and TCI_c^+ for 3D-CRT and IMRT

patient no.	TCI_PTV		TCI_BOOST		$NTSI_c$ _SPINAL_CORD		$NTSI_c$ _BODY		TCI_c^+	
	3D	IMRT	3D	IMRT	3D	IMRT	3D	IMRT	3D	IMRT
1	0.38	0.99	0.50	1.00	0.19	1.00	0.90	0.90	0.03	0.89
2	0.48	0.99	1.00	1.00	0.21	0.99	0.91	0.76	0.09	0.74
3	0.48	0.99	0.90	1.00	0.10	1.00	0.87	0.87	0.04	0.86
4	0.41	1.00	1.00	1.00	0.30	0.86	0.94	0.85	0.11	0.73
5	0.46	0.99	0.73	1.00	0.39	1.00	0.92	0.88	0.12	0.87
6	0.18	0.99	0.42	1.00	0.26	1.00	0.88	0.82	0.02	0.82
7	0.36	0.99	0.38	1.00	0.15	1.00	0.89	0.82	0.02	0.81
8	0.39	0.99	0.63	1.00	0.13	1.00	0.92	0.78	0.03	0.78
9	0.51	1.00	0.60	1.00	0.18	1.00	0.90	0.84	0.05	0.83
10	0.22	0.99	0.22	1.00	0.28	1.00	0.92	0.86	0.01	0.85

Table 5. Comparison of MU for 3D and IMRT plans

patient no.	3D	IMRT	MU_IMRT /MU_3D [1]
1	490	735	1.5
2	611	853	1.4
3	613	760	1.24
4	295	556	1.88
5	379	784	2.07
6	447	742	1.66
7	505	818	1.62
8	614	826	1.35
9	609	778	1.28
10	569	876	1.54

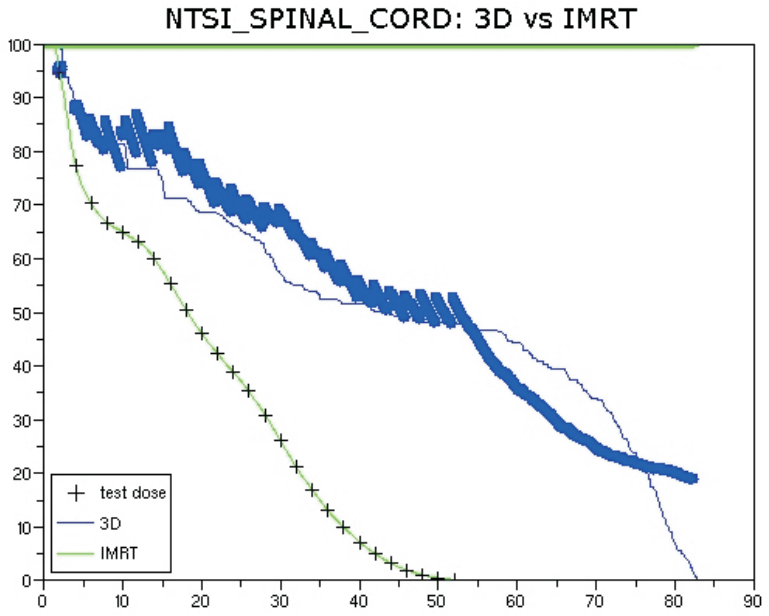

Figure 5. DVH and for SPINAL CORD

The average time needed to prepare a plan is 5 hours for 3D-CRT and 1.5 hour for IMRT. The whole time for preparing therapy also includes dosimetry verification for IMRT and creating individual bolus for 3D-CRT. During therapy sessions, IMRT needs 1.55 times more MU (Table 5). This is due to the longer time of treatment. In fact, during therapy with the 3D-CRT plan technicians have to change wedges, set electron aperture and change the technique from isocentric to SSD, when the electron field is irradiated. All this requires additional time and as such is time consuming. That is why we can say that session time is almost the same for both techniques.

Discussion

The IMRT allows reduction of the dose to the spinal cord and better coverage of the target volume. It fulfils the ICRU 67 recommendations, which is not the case for 3D-CRT plans. On the other hand, during IMRT treatment small doses are delivered to a substantially larger volume of the whole body.

Creating a 3D-CRT plan is quite time-consuming (for each patient, the planner has to define specific gantry angles and design an individual bolus for electrons). For the IMRT technique, template gantry angles can be used. IMRT requires more complex dosimetric verification, but 3D-CRT requires individual bolus to be made. IMRT is an isocentric technique which requires more MUs. 3D-CRT is a combination of isocentric photon beams with a fixed SSD electron beam technique. During 3D-CRT, technicians often have to change wedges. Therefore, the session time is about the same for both techniques.

Additionally, IMRT gives the opportunity to use a simultaneous integrated boost (SIB) radiotherapy, which would reduce the number of sessions.

Conclusions

IMRT seems to provide the opportunity to deliver a more uniform dose into the target volume over a smaller number of sessions. Also in the IMRT treatment, the spinal cord receives a smaller maximum dose. The IMRT technique's apparent superiority to 3D-CRT encourages its further development.

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