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Original article

Simultaneous integrated boost radiotherapy for thyroid cancer

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ABSTRACT

Aim: The purpose of this study was to examine the usefulness of using Simultaneous Integrated Boost (SIB) radiotherapy for thyroid cancer treatment.

Background: At our hospital a 3D Conformal RadioTherapy (3D-CRT) technique involving photon and electron beams for the treatment of thyroid cancer was often used.[1] High dose to the spinal canal was limiting the total dose of such a treatment. After investigation of Intensity Modulated Radiotherapy (IMRT) technique involving seven photon beams for first course of treatment[3] we decided to examine possibility of reducing treatment fractions by using SIB radiotherapy.

Material and methods: Plans for 10 patients were studied. For each patient, IMRT plan for the first course of treatment (50 Gy for PTV), two plans for the second course of treatment (10 Gy for BOOST) and a SIB plan (50 Gy for PTV, 56 Gy for BOOST) were prepared. For all plans, comparisons of dose statistics for the PTV, BOOST, PTV without BOOST (defined as PTV without BOOST with 1 cm margin), spinal canal and Patient Outline (Body) was done.

Results: Minimum dose for BOOST is higher in the SIB technique than in the two course treatment. PTV without BOOST receives the same average dose in SIB and the 1st course IMRT – 50.10 Gy and 49.84 Gy, respectively. In the SIB technique, higher reduction of dose delivered to the spinal canal is possible (27 Gy compared with 30 Gy).

Conclusion: SIB therapy for thyroid cancer with relation to typical two course treatment is a good proposal of reducing the number of fractions with the same dose for BOOST and PTV without BOOST. Additionally, better sparing of the spinal canal is achieved.

1. Introduction

The Maria Sklodowska-Curie Memorial Cancer Centre in Warsaw often used the 3D Conformal Radiotherapy (3D-CRT) technique, involving 4 and more photon and electron beams, for treatment of thyroid cancer.[1] High dose to the spinal canal limited the total dose of such a treatment. After implementation of the IMRT technique involving seven photon beams for first course of treatment[3] we decided to examine the possibility of reducing treatment fractions by using Simultaneous Integrated Boost (SIB) radiotherapy. This approach was presented by Mohan et al. in 2000.[4] SIB is the application of IMRT (known also as simultaneous modulated accelerated radiation therapy – SMART) in which high and low risk volumes are irradiated with different fraction dose in the same time. Normally,

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patients with head and neck cancers (especially with thyroid cancer) are irradiated with 2 Gy/fraction in the first phase of treatment and then high risk volume is irradiated to higher total dose with the some dose per fraction (2 Gy/fraction). According to the linear quadratic model, it is assumed that the same radiobiological effect (for tumor) can be achieved by irradiating with higher dose per fraction and with less number of fractions. Some clinical comparisons for classic and SIB irradiation have also been done.[5–8]

2. Material and methods

Plans for 10 patients irradiated with 3D-CRT were studied. The PTV (at least 3 mm under skin), BOOST, spinal canal and patient outline were drawn on CT scans. For each patient, an IMRT plan for the first phase of treatment (50 Gy for the PTV in 25 fractions) and two alternative plans, IMRT and 3D-CRT, for the second phase of treatment (10 Gy for BOOST in 5 fractions) were prepared. The SIB plan (50 Gy for PTV, 56 Gy for BOOST in 25 fractions) was compared with the technique consisting of two phases. All IMRT and SIB plans were performed with seven 6 MV fields, the same beam geometry: 204°, 256°, 308°, 0°, 52°, 104°, 156° and 3° rotation of collimator.

In order to compare plans, dose statistics (minimum, maximum and mean dose, standard deviation) for the PTV, BOOST, PTV without BOOST (defined as the PTV without BOOST with 1 cm margin), spinal canal and Patient Outline (BODY) were analyzed. For the SIB technique, dose statistics and Dose Volume Histograms (DVH) for doses higher than 50 Gy were converted to 2 Gy fraction. Parameter $\alpha/\beta = 2$ was applied. The TCI_C^+ (Uncomplicated Target Conformity Index for Comparing Plans) methodology for comparing DVH was used[2,3,9,10] (see Eq. (1)). A Normal Tissue Sparing Index for Comparing Plans, $NTSI_C$ (used in TCI_C^+), was calculated for test doses connected with the test volume defined as a minimum volume receiving a test dose in compared plans. $NTSI_C$ was scaled by a percentage difference of DVH for normal tissues. In order to compare two phase treatment versus SIB, the BOOST, PTV without BOOST and spinal canal volume were considered. The BOOST, spinal canal and whole patient body were used in comparison of IMRT and 3D-CRT second phase of treatment.

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

where, TCI_C^+ is the Uncomplicated Target Conformity Index for Comparing Plans; TCI is the Target Conformity Index (calculated for minimum and maximum doses equal to 95% and 107% of the prescribed dose respectively); $NTSI_C$ is the Normal Tissue Sparing Index for Comparing Plans (here scaled by percentage difference of DVH between compared plans); N_T is the amount of target volumes; M_{NT} is the amount of normal tissues.

3. Results

The plans were accepted with regard to the PTV/BOOST coverage while 99% of target volume received at least 90% or 95% of prescribed dose for the 3D-CRT and IMRT plans, respectively. In all types of plans at most 1% of target volume (PTV or BOOST) received dose higher than 107%. The comparison of 3D-CRT and IMRT as a 2nd phase of treatment was done first. TCI was better for the IMRT boost (average 1 compared to 0.88). Higher conformity of the IMRT plan requires delivery of higher doses for normal tissues. That is why, $NTSI_C$ for the body is on average 0.98 for 3D-CRT and 0.86 for IMRT. Also for the spinal canal, $NTSI_C$ is better for the 3D-CRT boost (on average 0.86 for 3D-CRT and 0.78 for IMRT). This result was caused by the use of a smaller number of fields in the 3D-CRT technique, usually outside the spinal canal. In fact, sparing of the spinal canal in 3D-CRT is mostly connected with underdosage in the BOOST volume. TCI_C^+ is 0.74 on average for 3D-CRT and 0.67 for IMRT (see Figs. 1 and 2; Table 1).

While comparing SIB with a standard two phase treatment, the dose distribution in the PTV without BOOST was investigated (see Figs. 3–6; Table 2), especially mean dose which can be higher with regard to dose gradient. The SIB technique gives the same dose as in the 1st phase of IMRT treatment. When

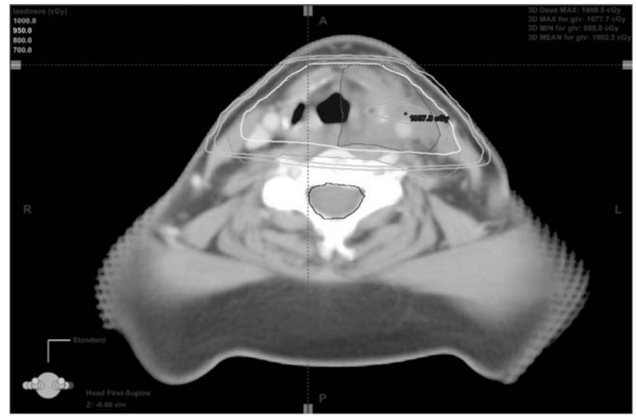

Fig. 1 – Dose distribution for 3D-CRT boost for one representative patient included in the study. Isodoses are shown as thick lines, while PTV, BOOST, spinal canal and patient outline are shown as thin lines.

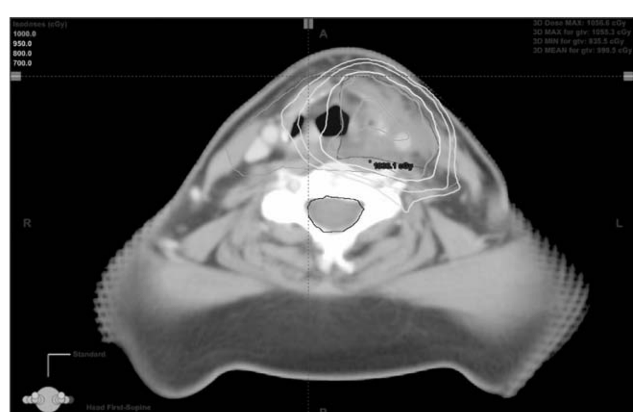

Fig. 2 – Dose distribution for IMRT boost for one representative patient included in the study. Isodoses are shown as thick lines, while PTV, BOOST, spinal canal and patient outline are shown as thin lines.

Table 1 – Comparison of TCI, $NTSI_C$ and TCI_C^+ for 3D-CRT and IMRT as the 2nd phase of treatment.

Patient no.	TCI_BOOST		$NTSI_C$_SPINAL_CANAL		$NTSI_C$_BODY		TCI_C^+	
	3D	IMRT	3D	IMRT	3D	IMRT	3D	IMRT
1	0.86	1.00	0.94	0.80	0.98	0.87	0.80	0.70
2	0.90	1.00	0.83	0.84	0.99	0.88	0.74	0.74
3	0.89	1.00	0.99	0.88	0.99	0.89	0.87	0.79
4	0.95	1.00	1.00	0.74	0.99	0.93	0.95	0.69
5	0.87	1.00	1.00	0.64	0.98	0.87	0.86	0.56
6	0.88	1.00	1.00	0.54	0.98	0.80	0.87	0.43
7	0.84	1.00	0.85	0.78	0.98	0.83	0.70	0.64
8	0.84	1.00	0.60	0.94	0.97	0.85	0.49	0.79
9	0.91	1.00	0.39	1.00	0.95	0.82	0.34	0.82
10	0.85	1.00	1.00	0.61	0.98	0.85	0.83	0.51
Average	0.88	1.00	0.86	0.78	0.98	0.86	0.74	0.67

Table 2 – Comparison of dose statistics for PTV without BOOST taking into account: minimum dose (min), maximum dose (max), mean dose (mean), and dose standard deviation (std). Statistics for SIB were calculated by dividing absolute dose by prescribed dose in first phase of IMRT treatment.

Patient no.	PTV without BOOST min [%]		PTV without BOOST max [%]		PTV without BOOST mean [%]		PTV without BOOST std [%]		mean IMRT/SIB [1]
	IMRT	SIB	IMRT	SIB	IMRT	SIB	IMRT	SIB	
1	89.1	84.1	106.3	110.1	99.4	99.6	2.0	2.2	1.00
2	83.2	83.9	106.6	107.6	99.7	100.4	2.0	2.1	0.99
3	90.0	92.2	106.1	110.3	99.9	100.6	1.4	1.8	0.99
4	92.9	92.6	104.9	107.1	100.4	101.7	1.5	2.0	0.99
5	89.6	91.8	106.4	105.9	98.7	98.2	1.6	1.6	1.01
6	88.5	91.8	106.4	108.5	100.0	100.2	2.1	2.2	1.00
7	86.4	86.4	105.7	107.5	99.7	99.9	1.9	2.1	1.00
8	84.4	90.3	105.8	110.8	99.8	100.4	2.1	2.4	0.99
9	86.0	85.5	106.5	108.8	99.9	100.9	1.8	2.2	0.99
10	86.5	85.8	105.8	108.2	99.2	100.1	1.5	1.7	0.99
Average	89.0	88.9	106.1	108.2	99.6	100.1	1.7	1.9	1.0

the total dose to the PTV without BOOST was considered, it was lower and more uniform in the SIB technique than in two phase treatment. Dose statistics for the BOOST are presented in Table 3. The minimum dose for the BOOST in two phase therapy is 96–97% on average compared with 93% for 3D-CRT. The maximum dose for the BOOST is almost the same. TCI for the BOOST equals 1 for two phase treatment and 0.99 for the SIB technique. $NTSI_C$ for the spinal canal is better for SIB: 0.96 compared to 0.83–0.86 for two phase treatment. $NTSI_C$ for the body is comparable for SIB and two phase treatment, and because of that it does not have influence on the TCI_C^+ parameter (see Tables 4 and 5). The spinal canal receives higher doses in two phase treatment – on average 30 Gy compared to 27 Gy

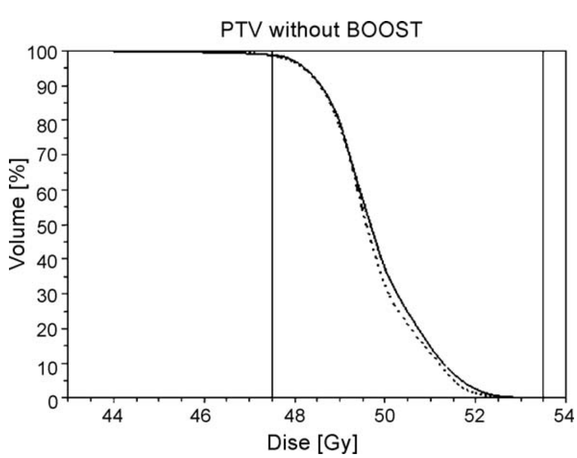

Fig. 3 – DVH for PTV without BOOST volume for one representative patient included in the study. 1st course IMRT (dotted) compared to SIB (solid). Vertical lines show 95% and 107% of prescribed dose (50 Gy).

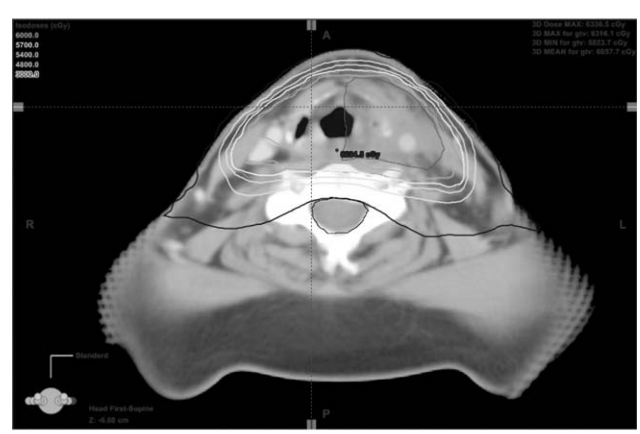

Fig. 4 – Dose distribution for IMRT + 3D-CRT boost for one representative patient included in the study. Isodoses are shown as thick lines, while PTV, BOOST, spinal canal and patient outline are shown as thin lines.

Table 3 – Comparison of dose statistics for BOOST taking into account: minimum dose (min), maximum dose (max), mean dose (mean), and dose standard deviation (std). Statistics for SIB were calculated by dividing absolute dose by prescribed dose in two phases of treatment.

Patient no.	BOOST min [%]			BOOST max [%]		
	IMRT + 3D	IMRT + IMRT	SIB	IMRT + 3D	IMRT + IMRT	SIB
1	95.4	97.2	93.0	105.3	106.1	104.7
2	96.6	97.2	94.2	104.7	105.3	103.9
3	96.6	96.8	93.9	105.4	106.1	105.9
4	95.5	95.0	93.6	101.3	101.4	101.6
5	96.5	97.3	91.7	104.9	105.5	104.3
6	93.9	94.2	91.8	103.8	103.9	104.0
7	89.8	90.9	88.3	105.2	105.2	104.6
8	96.3	96.1	92.4	105.0	106.2	104.2
9	88.0	88.5	86.9	104.6	105.6	106.0
10	93.6	94.4	91.7	106.3	107.8	104.3
Average	96.1	96.7	93.3	104.3	104.9	104.0

Patient no.	BOOST mean [%]			BOOST std [%]		
	IMRT + 3D	IMRT + IMRT	SIB	IMRT + 3D	IMRT + IMRT	SIB
1	100.9	100.9	99.6	1.6	1.8	1.8
2	101.0	101.0	99.6	1.3	1.2	1.5
3	100.5	100.5	99.6	1.5	1.6	1.5
4	99.4	99.4	99.6	0.7	0.7	1.3
5	101.0	101.0	99.6	1.4	1.6	1.8
6	100.3	100.3	99.6	1.6	1.5	1.6
7	100.8	100.8	99.6	1.7	1.4	1.7
8	100.9	100.9	99.6	1.6	1.5	1.6
9	100.1	100.1	99.6	1.6	1.6	1.8
10	101.0	101.0	99.8	1.8	1.9	1.8
Average	100.5	100.6	99.6	1.3	1.4	1.6

Table 4 – Comparison of TCI, $NTSI_C$ and TCI_C^+ for IMRT + 3D and SIB.

Patient no.	TCI_BOOST		$NTSI_C$_SPINAL_CANAL		TCI_C^+	
	IMRT + 3D	SIB	IMRT + 3D	SIB	IMRT + 3D	SIB
1	1.00	0.99	0.79	0.99	0.79	0.99
2	1.00	1.00	0.87	1.00	0.87	1.00
3	1.00	1.00	0.83	0.87	0.83	0.86
4	1.00	1.00	0.86	1.00	0.86	1.00
5	1.00	0.99	0.83	1.00	0.83	0.99
6	1.00	0.96	0.87	0.86	0.87	0.83
7	1.00	0.99	0.85	1.00	0.85	0.99
8	1.00	0.99	0.77	0.90	0.77	0.89
9	0.99	0.96	0.76	1.00	0.76	0.96
10	1.00	1.00	0.87	0.98	0.87	0.97
Average	1.00	0.99	0.83	0.96	0.83	0.95

Table 5 – Comparison of TCI, $NTSI_C$ and TCI_C^+ for IMRT + IMRT and SIB.

Patient no.	TCI_BOOST		$NTSI_C$_SPINAL_CANAL		TCI_C^+	
	IMRT+IMRT	SIB	IMRT+IMRT	SIB	IMRT+IMRT	SIB
1	1.00	0.99	1.00	1.00	1.00	0.99
2	1.00	1.00	0.87	0.98	0.87	0.98
3	1.00	1.00	0.82	0.87	0.82	0.86
4	1.00	1.00	0.83	1.00	0.83	1.00
5	1.00	0.99	0.81	1.00	0.81	0.99
6	1.00	0.96	0.86	0.86	0.86	0.83
7	1.00	0.99	0.86	1.00	0.86	0.99
8	1.00	0.99	0.85	0.90	0.85	0.89
9	0.99	0.96	0.85	1.00	0.84	0.96
10	1.00	1.00	0.83	1.00	0.83	1.00
Average	1.00	0.99	0.86	0.96	0.85	0.95

Table 6 – Comparison of maximum dose for spinal canal.

Patient no.	Max dose for spinal canal [Gy]		
	IMRT + 3D	IMRT + IMRT	SIB
1	32.91	33.25	29.09
2	33.18	31.29	31.26
3	26.58	26.98	26.60
4	28.80	29.86	25.11
5	38.62	39.50	29.01
6	28.44	30.26	28.75
7	28.21	26.98	24.60
8	28.80	28.25	26.73
9	31.97	30.36	27.17
10	24.85	27.14	25.37
Average	30.42	30.39	27.37

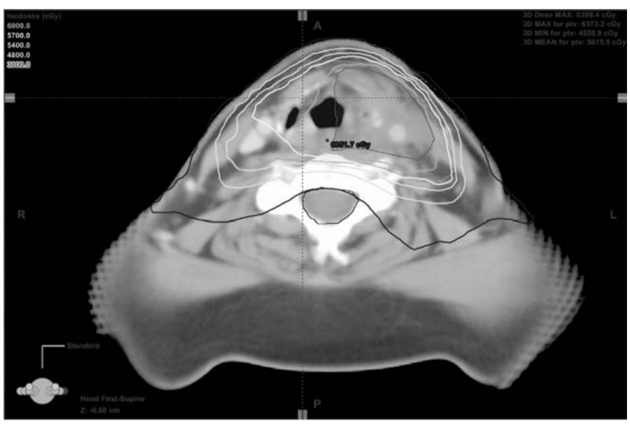

Fig. 5 – Dose distribution for IMRT + IMRT boost for one representative patient included in the study. Isodoses are shown as thick lines, while PTV, BOOST, spinal canal and patient outline are shown as thin lines.

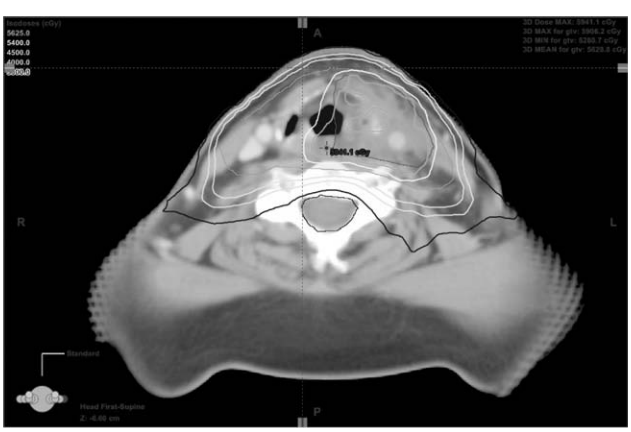

Fig. 6 – Dose distribution for SIB for one representative patient included in the study. Isodoses are shown as thick lines, while PTV, BOOST, spinal canal and patient outline are shown as thin lines.

in SIB (see Table 6). But the dose for spinal canal in both techniques is still far below the tolerance dose.

4. Discussion

IMRT is known as a technique with higher dose conformity for thyroid cancer patients and better sparing of the spinal cord.[3,11] The SIB technique gives a chance of comparable conformity with better sparing of organ at risk. It is also less time consuming than two phase treatment – both for planning (preparation of only one plan is needed) and treatment (smaller number of fractions). In the SIB technique, the BOOST has insignificantly lower minimum dose and TCI. The spinal canal has 3 Gy lower maximum dose than in two phase treatment. In fact, for some plans maximum spinal canal dose was almost the same. Dogan et al.[7] reported no reduction of spinal cord dose with SIB–IMRT compared to sequential (two phases) IMRT. The same effect was observed by Fogliata et al.[6]

Comparing dose in the whole body is rather difficult because of unknown radiobiological effect of different fractionation doses in normal tissues. Dogan et al.[7] received up to 70% lower volume of nontarget tissues receiving doses higher than 15 Gy for SIB–IMRT. In our study dose distributions seem to be comparable for whole body irradiation. The same effect is observed while we consider the volume of nontarget tissues receiving doses >15 Gy (mean difference was below 1%). The PTV without BOOST volume in SIB therapy has almost the same dose distribution as for the first course of IMRT treatment. That means that in the SIB technique, the PTV without BOOST would not receive, from 2nd course of therapy, unnecessary dose leading to the raising of mean dose.

5. Conclusion

SIB therapy for thyroid cancer allowed us to accomplish our goals: a reduction of the number of fractions with the same BOOST and PTV without BOOST dose and better sparing of the spinal canal. The PTV without BOOST volume does not receive additional dose as in the case of the 2nd course in the non-SIB technique. Before implementing the SIB technique for thyroid cancer therapy, further discussion of total and fraction dose should be carried out. It is possible that from clinical point of view applying a higher prescribed dose may be beneficial.

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