Simultaneous Integrated Boost (SIB): RapidArc and Tomotherapy Plan Comparison for Unilateral and Bilateral Neck Irradiation

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Abstract. *Aim: The aim of the present study was to compare simultaneous integrated boost (SIB) plans using volumetric modulated arc therapy (RapidArc®; RA) or tomotherapy (TT) for bilateral (BL) and unilateral (UL) treatment in head-and-neck cancer (HNC) patients. Material and Methods: Seventeen computed tomography scans (CTs) of 16 patients with SIB were replanned using TT and RA. We defined three groups: All, UL and BL, compared the dose distributions, homogeneity, conformity to planning target volume (PTV), organs at risk (OAR) and healthy tissue (HT) sparing. We evaluated a therapeutic-width index (TWI) based on PTV coverage and parotid gland (PG) sparing. Results: PTV coverage for RA and TT was equivalent for all groups. UL irradiation resulted in similar doses to the HT for both techniques but TT achieved better sparing of spinal cord, larynx and contralateral PGs. TT provided better homogeneity. RA gave better conformity. Conclusion: Both methods achieved clinically acceptable results for UL and BL treatment, RA with better dose conformity to elective PTV, TT with better OAR sparing and homogeneity.*

Advances in radiotherapy technology (RT), such as intensity modulated radiotherapy (IMRT), or further developments, such as volumetric modulated arc therapy (VMAT), now allow treating multiple planning target volumes (PTVs) in a single plan (simultaneous integrated boost; SIB) (1) whilst enabling organ sparing even for complex shaped target volumes with head-and-neck cancer (HNC) patients (2). Sparing of the parotid glands to a mean dose (D_{mean}) of <26 Gy significantly reduced xerostomia when compared to conformal 3D RT without compromising tumor control in the phase III PARSPORT trail (3). IMRT for HNC patients using a SIB technique allows for more conformal dose distributions with better normal tissue sparing compared to IMRT with a sequential boost (4, 5). The effectiveness and safety of definitive SIB IMRT with or without concurrent chemotherapy and helical IMRT for HNC have been demonstrated in several studies (6-10). Early clinical outcome data for VMAT and SIB VMAT treatment for HNC is sparse (11, 12) but the potential benefits of VMAT have been illustrated (13). In the present work, we compared plan quality and organ at risk (OAR) sparing for the two rotational modalities VMAT RapidArc® (RA) and helical IMRT TomoTherapy® (TT) in the case of double SIB plans for the definitive treatment of advanced HNC patients in both the unilateral (UL) and bilateral (BL) situations.

Material and Methods

Sixteen patients with locally advanced HNC were randomly selected from a list of patients previously treated with definitive double SIB RT at our Department with either a RapidArc® (RA; Varian Medical Systems, Palo Alto, CA, USA) or a TomoTherapy® (TT; Tomotherapy Inc., Madison, WI, USA) plan. One patient with CUP (cancer of unknown primary) had a replanning computed tomography (CT) due to an excellent partial response (cN3 to cN2a) so that, in the end, 17 pairs of plans (11 BL, 6 UL) were compared. Patient and tumor characteristics are shown in Table I. All patients had three PTVs with corresponding dose levels. The high-risk volume consisted of the gross tumor volume (GTV) of the primary and the macroscopically involved lymph nodes (GTV1). This was set equal to the primary clinical target volume (CTV), CTV1 (14). The CTV2 consisted of the soft tissue within a 10-mm margin of the CTV1. The CTV3 consisted of elective nodal regions at risk

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Key Words: Head and neck cancer, unilateral neck, volumetric arc techniques, helical IMRT, dosimetric comparison.

Table I. *Patients and tumor characteristics*.

Characteristics	Total, n=17 (%)
Mean age, years	60.1 (range=47-81)
Sex	
Female	6 (35)
Male	11 (65)
Tumorsite	
ORO	11 (65)
OC	1 (6)
Parotid	2 (12)
CUP	3 (17)
T	
x	3 (17)
1	1 (6)
2	5 (30)
3	3 (17)
4	5 (30)
N	
0	3 (17)
1	1 (6)
2a	1 (6)
2b	6 (35)
2c	4 (24)
3	2 (12)
M	
0	17(100)
Neck irradiation	
BL	11 (65)
UL	6 (35)

ORO, Oropharynx carcinoma; OC, oral cavity carcinoma; CUP, cancer of unknown primary; T, tumor; N, lymph node; M, metastasis; BL, bilateral; UL, unilateral.

(15). The expansion of the CTVs by an isotropic margin of 5 mm gave the corresponding PTV1-3, allowing for setup errors. The target volumes and OAR were contoured on axial slices in the Eclipse treatment planning system (TPS), version 11.0.42 (Varian Medical Systems, Palo Alto, CA, USA) before transferring to the respective TPS. The same dose objectives were used for the PTVs, parotid glands (PG), spinal cord (SC), larynx, oral cavity (OC) and submandibular glands (SMG) in the RA and TT planning (Table II). The dose prescription was identical for all datasets consisting of 32 daily single fractions of 2.2, 1.9 and 1.7 Gy to PTV1, PTV2 and PTV3, respectively, resulting in total doses (TD) of 70.4, 60.8 and 54.4 Gy. The plan normalization was performed as median dose to 100% of PTV1, respecting the prescription guidelines of the International Commission on Radiation Units and Measurements (ICRU) report 83 (http://jicru.oxfordjournals.org/content/10/1.toc). The goal was respecting the prescription to the PTVs while keeping the irradiated volumes of the SC, PGs, OC, SMGs, larynx and healthy tissue (HT) as low as reasonable achievable (ALARA). Extra structures consisting of ring margins 3-cm wide outside of the PTV3 and the OAR were used to enforce rapid dose falloffs in the optimization for both RA and TT plans.

RA planning. A total of seventeen plans were optimized with the TPS Eclipse v11.0.42. A detailed prescription of the single arc RapidArc® technique has been published earlier (16). Treatment

Table II. *Summary of dose volume constraints used in the plan optimization process*.

Target/ Organ at risk	Median dose	Planning goals
PTV1	70.4 Gy	V95% , D_{max} 107%
PTV2	60.8 Gy	V95% , D_{max} 107%
PTV3	54.4 Gy	V95% , D_{max} 107%
Spinal cord		D_{max} ≤50Gy
Healthy tissue		ALARA
Parotid gland, CL		D_{mean} ≤26Gy
Parotid gland, IL		ALARA
Submandibular gland		D_{mean} ≤39 Gy; or ALARA
Oral cavity		V_{50}<50%
Larnyx		D_{mean} ≤40-45Gy, V_{60} ALARA

PTV, Planning target volume; CL, contralateral; IL, ipsilateral; V95%, volume getting 95% of dose; D_{max}, maximum dose; ALARA, as low as reasonably achievable; D_{mean}, mean dose; V_{50}, 50 Gy volume in %; V_{60}, 60 Gy volume in %.

was with Varian Clinac DHX accelerators equipped with Millenium 120-leaves multileaf collimator (MLC), with a maximum dose rate of 600 MU/min. BL treatment plans used two 358" arcs running clockwise and counterclockwise between the gantry angles 181˚ and 179˚. The corresponding collimator angles lay between 10˚-30˚ and 350˚-330˚, depending on PTV length. When this technique resulted in inadequate OAR sparing, especially for the SC, we added a third arc with a collimator angle of 90˚, *i.e.* with the leaves in a longitudinal position. For the UL treatment we generally used two half arcs where the gantry angles depended on the treatment side. Collimator angles between 30˚ and 330˚ were generally used. The "normal tissue objective" feature of the RA technology was used to suppress hot spots outside of the PTVs. After optimization, the final dose distribution was calculated using the AAA algorithm with a grid size of 2.5 mm.

TomoHD planning. All CT datasets with structures and contours were transferred to the TT planning workstation. Treatment was with the Tomotherapy Hi-Art 5.0.2 (TomoTherapy Inc.) system and used the TT convolution/superposition C/S algorithm for the computations. We used a field width set at 2.5 cm, a pitch of 0.25 and a modulation factor of 3-4 with the dose calculation grid set to fine mode.

Plan evaluation. All plans were evaluated with the Eclipse TPS. The comparisons were performed both quantitatively with a dose-volume histogram (DVH) analysis and qualitatively by visually inspecting the isodose curves on axial CT slices. The mean volume of PTV1-3 and PGs, the D_{mean} (mean dose to the respective volumes), D_5 (dose to at most 5% of the PTV, representing the near maximal dose), D_{100} (minimum dose), D_{98} (dose to at most 98% of the PTV) and D95 (dose to at most 95% of the PTV) for the PTV1-3 were evaluated. For the OARs, we assessed the D_{mean} for the larynx, for the HT and for the IL and CL PG and SMG, the D_{max} of the SC, the V_{60} (in %) for the larynx and the V_{50} (%) for the OC (17). Additionally, we evaluated the SALT-coverage factor (CVF; CVF=TVRI/TV; TVRI: irradiated target volume encompassed by reference isodose, TV: target volume) for PTV coverage, the healthy tissue conformity index (Lomax, HTCI; HTCI=TVRI / VRI; VRI: irradiated volume encompassed by reference isodose), the conformity number (van´t

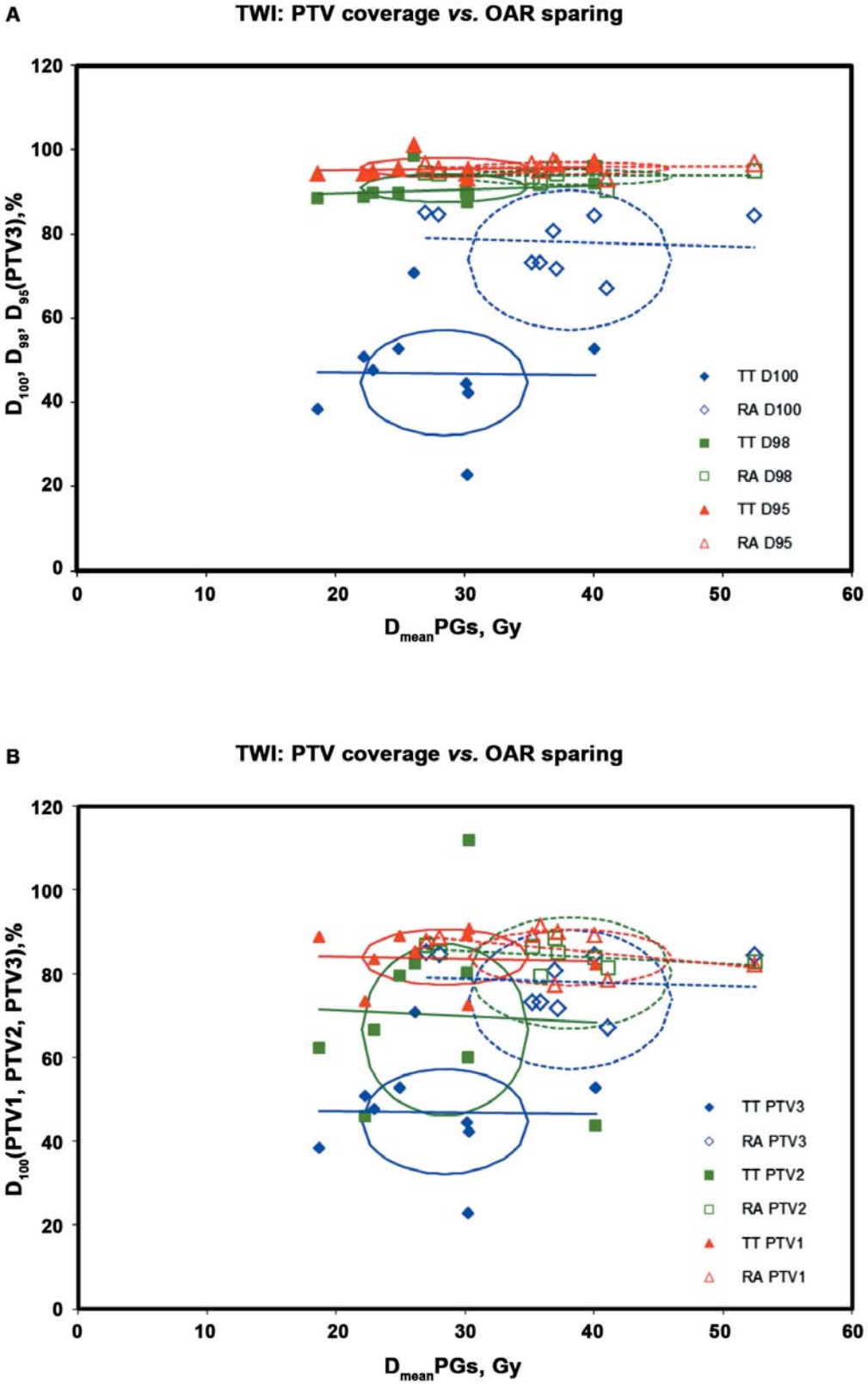

Figure 1. *Therapeutic width index (TWI) for both parotid glands (PGs) in the bilateral (BL) group. TT, TomoTherapy®; RA, RapidArc®; PTV, planning target volume; OAR, organs at risk; D_{mean}, mean dose; D_{100}, minimum dose; D_{98}, dose covering 98% of PTV; D_{95}, dose covering 95% of PTV.*

Table III. *Dose-volume histogram (DVH)-parameters and treatment efficiency for all seventeen patients and different treatment modalities (SD, standard deviation).*

Volume	Parameter		TT		RA		*p*-Value
			All n=17				
			Mean±SD	%	Mean±SD	%	
PTV1	D_{mean}	Gy	69.9±0.3	99.3	70.4±0.1	100	0.00
	D_{100}	Gy	60.2±4.0	85.5	58.2±5.5	82.7	n.s.
	D_{98}	Gy	66.0±0.4	93.8	65.0±2.3	92.4	n.s.
	D_{95}	Gy	66.8±0.5	94.8	66.3±1.1	94.2	n.s.
	D_5	Gy	72.2±0.9	102.6	73.0±0.8	103.7	0.04
	SALT CVF		0.93±0.05		0.92±0.04		n.s.
	HTCI		0.91±0.05		0.93±0.05		n.s.
	CN		0.85±0.06		0.86±0.07		n.s.
	HI		1.08±0.02		1.12±0.05		0.01
PTV2	D_{mean}	Gy	62.3±0.8	102.5	61.9±0.6	101.8	n.s.
	D_{100}	Gy	41.8±11.1	68.7	48.2±7.1	79.4	0.05
	D_{98}	Gy	55.6±2.1	91.4	56.2±2.6	92.5	n.s.
	D_{95}	Gy	58.2±1.0	95.8	57.7±1.6	94.8	n.s.
	D_5	Gy	66.5±0.8	109.4	66.4±1.0	109.2	n.s.
	SALT CVF		0.98±0.01		0.97±0.03		n.s.
	HTCI		0.77±0.11		0.84±0.07		0.04
	CN		0.76±0.11		0.81±0.07		n.s.
	HI		1.14±0.02		1.18±0.07		0.03
PTV3	D_{mean}	Gy	55.2±1.1	101.5	55.2±0.6	101.5	n.s.
	D_{100}	Gy	27.4±8.8	50.4	40.2±7.9	73.9	0.00
	D_{98}	Gy	49.7±1.9	91.3	50.4±1.6	92.7	n.s.
	D_{95}	Gy	52.1±1.3	95.8	51.9±0.8	95.4	n.s.
	D_5	Gy	58.6±2.2	107.7	58.9±2.2	108.4	n.s.
	SALT CVF		0.96±0.04		0.97±0.02		n.s.
	HTCI		0.74±0.07		0.81±0.05		0.001
	CN		0.71±0.08		0.79±0.06		0.001
	HI		1.13±0.04		1.14±0.05		n.s.
OAR							
PG	D_{mean} CL	Gy	17.5±10.6		23.1±13.5		0.01
	D_{mean} IL	Gy	30.9±11.3		40.3± 13.7		0.001
	COINPTV3		0.73±0.12		0.65±0.17		0.02
	TWI		3.25±3.6		2.04±1.09		n.s.
SMG	D_{mean} CL	Gy	36.3±19.8		43.1±18.1		0.01
	D_{mean} IL	Gy	61.7±4.8		61.7±5.4		n.s.
SC	D_{max}	Gy	37.2±6.4		45.8±4.9		0.00
Larynx	V_{60}	%	7.7±9.6		3.7±7.9		n.s.
	D_{mean}	Gy	25.7±10.7		43.1±8.7		0.00
OC	V_{50}	%	34.8±25.5		40.6±33.3		n.s.
HT	D_{mean}	Gy	31.6±4.4		33.7±5.9		n.s.

TT, TomoTherapy®; RA, RapidArc®; PTV, planning target volume; PG, parotid gland; SMG, submandibular gland; SC, spinal cord; CL, contralateral; IL, ipsilateral; OC, oral cavity; HT, healthy tissue; OAR, organs at risk; n.s., non-significant; D_{mean}, mean dose; D_{100}, minimum dose; D_{98}, dose covering 98% of PTV; D_{95}, dose covering 95% of PTV; D_5, dose to at most 5% of the PTV, representing the near maximal dose; V_{60}, 60 Gy volume; V_{50}, 50 Gy volume; SALT CVF, SALT-coverage factor; HTCI, healthy tissue conformity index ; CN, conformity number; HI, homogeneity index; COINPTV3, conformity index planning target volume 3; TWI, therapeutic width index.

Riet, CN; CN=CVF×HTCI) and the conformity Index (Baltas, COIN; COIN=CN*(1-VRI(OAR)/(OAR)) for the measurement of conformity of dose distribution in the PTVs. A higher CN indicates a higher dose conformity in the PTVs. We also calculated the homogeneity index (HI; HI=D_5/D_{95}) for the PTVs, with a higher HI corresponding to worse dose homogeneity. In addition, we introduced and evaluated a "therapeutic width index" (TWI, TWI=ratio of PTV coverage dose and D_{mean} of PGs) for the PGs. A higher TWI should correlate with a better BL PG sparing.

Statistical analysis. The Microsoft Excel 2007 and IBM SPSS Version 20 were used to calculate the data and to obtain descriptive statistics of the patients. Student's two-sided paired *t*-tests used a significance level of 0.05.

Results

The mean volume of PTV1 was 119±90 cm^3 (standard deviation, SD) (range=20-371), 145±82 cm^3 for PTV2 (range=38-326) and 447±200 cm^3 to PTV3 (range=119-826). The mean PG volume was 24.5±12.9 cm^3 (range=9-54). A detailed summary of the results for the PTVs and selected OARs for all three groups is shown in Tables III, IV and V.

PTV dose conformity and homogeneity. As seen in Table IV, no significant differences were found for PTV1-3 for the UL plans in terms of D_{mean}, D_{100}, D_{98}, D_{95}, D_5, coverage (CVF) and HI. RA significantly improved conformity to PTV3 as measured by HTCI and CN. For the BL plans (Table V), no significant differences were found in D_{95} and D_5 for all three PTVs. TT plans achieved a better homogeneity (p=0.03) but a significantly lower D_{mean} (p=0.00) in PTV1, as well as a lower D_{100} (p=0.00) and D_{98} (p=0.05) for PTV3. RA had a significantly better conformity for PTV2 and PTV3 as measured by the HTCI and CN. For the group of all patients (Table III), the RA plans gave a significantly better dose conformity and higher D_{100} for PTV2 and PTV3 (D_{100} mean 12.8 Gy higher for PTV3 and 6.4 Gy higher for PTV2) and an enhanced D_{mean} for PTV1 (in %±SD: RA 100±0.2 *vs*. TT 99.3±0.4). TT achieved a better dose homogeneity in PTV1 and PTV2, and a lower D_5 (TT: 102.6 % *vs*. RA 103.7%). The D_{mean} lay at 101.5%, 102.5% and 99.3% for TT and 101.5%, 101.8% and 100% for RA for PTV3, PTV2 and PTV1, respectively.

OAR sparing and healthy tissue. For a detailed summary of the results see Tables III-V. The constraints for the maximal dose to the SC and V_{60} for the larynx were achieved with both techniques irrespective of group, although TT resulted in a significantly lower dose to the SC. In the BL group and the group of all patients, TT achieved a significantly lower D_{mean} for the CL SMG, IL PG and the larynx. In the group of all patients, TT also gave a lower D_{mean} to the CL PG (p=0.01) and a higher PTV3 COIN index for the PGs (p=0.02). For the BL group, TT resulted in a significantly

better TWI for the PGs (p=0.002) (Figure 1A and B), better HT sparing (p=0.04) and a lower dose to the OC (p=0.02). In the UL group, no significant differences were found regarding the PGs, SMGs, OC and HT.

Discussion

So far, two studies comparing SIB plans with TT, RA, VMAT (Elekta) and static beam IMRT (sbIMRT) for HNC have been reported in the literature (18-20). Some studies investigated TT, VMAT, sbIMRT (21-24), while others looked at sbIMRT and VMAT plans (25, 26). These studies used a SIB with two (18-20, 22, 25) or, as we did, three (21, 23) or a mixture of 2 and 3 (26) dose levels with a TD of 52.8-58.1 Gy in the lowest dose PTV3. None of the publications reported on the UL treatment situation. Based on a study (19) reporting that the differences in the calculation algorithms lead to smaller PTV and OAR volumes with TT as compared with RA, we decided to evaluate all plans in Eclipse to avoid this issue. Of special interest to us were the results concerning the dose to the CL OARs in the UL situation. We found here that both methods gave a D_{mean} of 5-10 Gy to the CL PG and 14.5-20 Gy to the CL SMG, respectively. Both methods gave consistently low doses to the OC and larynx, and even the IL PG could almost be sufficiently spared. Our analysis showed that TT plans generally result in better sparing of the SC and larynx for all three groups with a higher degree of dose homogeneity in the PTV1 for the group of all patients. Significantly lower dose values to various OARs with TT *vs*. RA have also been found by others (18-20). Van Gestel *et al*. (19) examined the supraglottic (SGL) and glottic (GL) larynx separately. They found no difference between TT and RA for the SGL, while VMAT was significantly worse than both other techniques. The GL was better spared with TT than with RA or VMAT. Lu and colleagues (23) reported on a significantly lower D_{mean} to the larynx with VMAT (37.8 Gy) *vs*. TT and IMRT in nasopharyngeal cancer patients. Others did not look at the larynx (20) or found better sparing with TT (18). We defined two planning parameters for the larynx: a D_{mean} ≤40-45 Gy and an ALARA restriction on the V_{60} according to the quantitative analysis of normal tissue effects in the clinic (QUANTEC) recommendations (17). We found that both constraints were met irrespective of the method used. However, TT gave a significantly lower D_{mean} than RA for all three groups. Better sparing of the CL PG with TT *vs*. RA has been described in the literature (18-20). We found the same for our group of all patients but not for the separate UL and BL groups. For the BL patients, the TWI for both PGs was significantly better with TT suggesting that better BL PG sparing can be achieved with TT (Figure 1A and 1B). TT spared the CL SMG better in our group of all patients, as well as in the BL group. The

Table IV. *DVH Parameters and treatment efficiency for unilateral neck treatment and different treatment modalities (SD, standard deviation).*

Volume	Parameter		TT	RA	p-Value
			UL n=6		
			Mean±SD	Mean±SD	
PTV1	D_{mean}	Gy	69.9±0.3	70.3±0.2	n.s.
	D_{100}	Gy	62.2±1.1	56.8±6.9	n.s.
	D_{98}	Gy	65.7±0.5	63.9±3.2	n.s.
	D_{95}	Gy	66.4±0.6	65.9±1.4	n.s.
	D_5	Gy	72.3±1.1	73.3±1.0	n.s.
	SALT CVF		0.91±0.05	0.91±0.05	n.s.
	HTCI		0.91±0.07	0.93±0.05	n.s.
	CN		0.84±0.09	0.84±0.07	n.s.
	HI		1.09±0.02	1.15± 0.07	n.s.
PTV2	D_{mean}	Gy	62.5± 0.8	61.9±0.8	n.s.
	D_{100}	Gy	44.2±8.5	47.4±5.6	n.s.
	D_{98}	Gy	56.0±1.7	55.2±2.8	n.s.
	D_{95}	Gy	58.3±1.1	57.0±2.0	n.s.
	D_5	Gy	66.7±1.0	66.6±0.9	n.s.
	SALT CVF		0.98±0.01	0.96±0.03	n.s.
	HTCI		0.78±0.17	0.85±0.07	n.s.
	CN		0.77±0.16	0.81±0.06	n.s.
	HI		1.14±0.02	1.21±0.07	n.s.
PTV3	D_{mean}	Gy	55.2±1.0	54.8±0.5	n.s.
	D_{100}	Gy	33.1±9.8	40.2±6.0	n.s.
	D_{98}	Gy	50.1±2.2	49.6±2.2	n.s.
	D_{95}	Gy	52.2±1.5	51.7±0.9	n.s.
	D_5	Gy	57.7±1.4	57.9±1.6	n.s.
	SALT CVF		0.97±0.02	0.97±0.02	n.s.
	HTCI		0.77±0.06	0.86±0.04	0.01
	CN		0.75±0.05	0.83±0.03	0.01
	HI		1.11±0.04	1.12±0.05	n.s.
OAR					
PG	D_{mean} CL	Gy	5.4±1.9	10.0±7.4	n.s.
	D_{mean} IL	Gy	26.7±15.2	27.9±14.7	n.s.
	COINPTV3		0.81±0.10	0.69±0.19	n.s.
	TWI		5.7±5.5	3.2±1.1	n.s.
SMG	D_{mean} CL	Gy	14.5±4.4	20.0±2.9	n.s.
	D_{mean} IL	Gy	59.8±6.1	59.1±7.1	n.s.
SC	D_{max}	Gy	36.6±7.5	42.3±5.7	0.03
Larynx	V_{60}	%	0.0	0.0	n.s.
	D_{mean}	Gy	15.8±9.6	32.5±3.6	0.02
OC	V_{50}	%	6.5±10.2	3.8±7.5	n.s.
HT	D_{mean}	Gy	30.5±3.9	29.9±4.1	n.s.

TT, TomoTherapy®; RA, RapidArc®; UL, unilateral; PTV, planning target volume; PG, parotid gland; SMG, submandibular gland; SC, spinal cord; CL, contralateral; IL, ipsilateral; OC, oral cavity; HT, healthy tissue; OAR, organs at risk; n.s., non-significant; D_{mean}, mean dose; D_{100}, minimum dose; D_{98}, dose covering 98% of PTV; D_{95}, dose covering 95% of PTV; D_5, dose to at most 5% of the PTV, representing the near maximal dose; V_{60}, 60 Gy volume; V_{50}, 50 Gy volume; SALT CVF, SALT-coverage factor; HTCI, healthy tissue conformity index ; CN, conformity number; HI, homogeneity index; COINPTV3, conformity index planning target volume 3; TWI, therapeutic width index.

Table V. *DVH Parameters and treatment efficiency for bilateral neck treatment and different treatment modalities (SD, standard deviation).*

Volume	Parameter		TT	RA	*p*-Value
			BL n=11 mean±SD		
PTV1	D_{mean}	Gy	69.9±0.3	70.4±0.1	0.00
	D_{100}	Gy	59.1±4.6	59.0±4.7	n.s.
	D_{98}	Gy	66.2±0.3	65.6±1.5	n.s.
	D_{95}	Gy	66.9±0.3	66.5±0.8	n.s.
	D_5	Gy	72.2±0.9	72.9±0.7	n.s.
	SALT CVF		0.95±0.05	0.93±0.03	n.s.
	HTCI		0.91±0.04	0.93±0.06	n.s.
	CN		0.86±0.05	0.87±0.07	n.s.
	HI		1.08±0.02	1.11±0.03	0.03
PTV2	D_{mean}	Gy	62.2±0.8	61.9±0.6	n.s.
	D_{100}	Gy	40.5±12.5	48.8±8.1	n.s.
	D_{98}	Gy	55.3±2.4	56.8±2.4	n.s.
	D_{95}	Gy	58.2±1.0	58.1±1.3	n.s.
	D_5	Gy	66.4±0.7	66.3±1.1	n.s.
	SALT CVF		0.98± 0.01	0.98±0.03	n.s.
	HTCI		0.77±0.08	0.83±0.08	0.05
	CN		0.75±0.07	0.81±0.08	0.04
	HI		1.14±0.02	1.17±0.07	n.s.
PTV3	D_{mean}	Gy	55.3±1.2	55.4±0.5	n.s.
	D_{100}	Gy	24.4± 6.8	40.2±9.0	0.00
	D_{98}	Gy	49.5±1.8	50.9±1.0	0.05
	D_{95}	Gy	52.1±1.2	52.0±0.8	n.s.
	D_5	Gy	59.1±2.4	59.4±2.4	n.s.
	SALT CVF		0.95±0.04	0.97±0.03	n.s.
	HTCI		0.73±0.07	0.79±0.05	0.003
	CN		0.69±0.09	0.77±0.06	0.03
	HI		1.14±0.03	1.14±0.05	n.s.
OAR					
PG	D_{mean} CL	Gy	24.1±6.5	30.3±10.3	n.s.
	D_{mean} IL	Gy	32.9±9.3	45.9±9.1	0.00
	COINPTV3		0.69±0.11	0.63±0.17	n.s.
	TWI		1.9±0.4	1.4±0.3	0.002
SMG	D_{mean} CL	Gy	48.4±13.0	55.9±3.8	0.05
	D_{mean} IL	Gy	62.8±3.9	63.1± 3.9	n.s.
SC	D_{max}	Gy	37.5±6.1	47.7±3.3	0.00
Larynx	V_{60}	%	10.5±9.9	5.1±9.0	n.s.
	D_{mean}	Gy	29.3±8.9	47.0±6.5	0.00
OC	V_{50}	%	46.2±20.2	55.3±27.3	0.02
HT	D_{mean}	Gy	32.2±4.7	35.8±5.9	0.04

TT, TomoTherapy®; RA, RapidArc®; BL, bilateral; PTV, planning target volume; PG, parotid gland; SMG, submandibular gland; SC, spinal cord; CL, contralateral; IL, ipsilateral; OC, oral cavity; HT, healthy tissue; OAR, organs at risk; n.s., non-significant; D_{mean}, mean dose; D_{100}, minimum dose; D_{98}, dose covering 98% of PTV; D_{95}, dose covering 95% of PTV; D_5, dose to at most 5% of the PTV, representing the near maximal dose; V_{60}, 60 Gy volume; V_{50}, 50 Gy volume; SALT CVF, SALT-coverage factor; HTCI, healthy tissue conformity index ; CN, conformity number; HI, homogeneity index; COINPTV3, conformity index planning target volume 3; TWI, therapeutic width index.

QUANTEC recommendation (2) for this organ, a D_{mean} of <35 Gy, was slightly surpassed by our D_{mean} of 36-37.5 Gy, which we assume to be probably clinically negligible. In terms of PTV coverage, no significant differences emerged between TT and RA in any group, as demonstrated by an average SALT CVF of ≥0.91. TT results in a significantly improved dose homogeneity to the PTV1 compared to RA. These findings are consistent with other published data (18-20). Interestingly, in our study, the dose conformity to the low-dose PTV3 in the UL neck was significantly better with RA. In accordance to our data, Van Gestel *et al.* (19) described a better CI for the RA technique *vs.* TT, while Wiezorek *et al.* (20) demonstrated a better CI for the TT plans. Broggi and colleagues did not consider target volume conformity (18). With one exception (n=38) (26), all published studies, including our own, suffer from the limited number of 5-10 (19-22, 24, 25), 18 (18) and 20 patients (23). Therefore, all these data need to be interpreted with caution.

RT has come a long way from a simple 2D approach to a sophisticated IMRT treatment where an OAR sparing with preservation of function has become possible. Treatment time and "time under the mask" has become an issue as 2D and 3D RT could be accomplished in just a few minutes, whereas a typical 7-9 field HNC IMRT requires dramatically increased treatment times (21-23, 25). However, arc volumetric techniques (VMAT, RA) can result in short treatment times of around 2-6 min (18, 19, 21, 22, 24). Furthermore, the SIB approach reduces the overall treatment duration. For both UL and BL HNC patients, TT resulted in significantly better OAR sparing and dose homogeneity but RA achieved better dose conformity to the elective target volume. Both rotational methods investigated in this study were able to achieve clinically acceptable results. Future research should investigate on how differences in dose distribution correlate, if at all, with those in clinical outcome.

Conflicts of Interest

The Authors declare to have no conflicts of interest.

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