A TREATMENT PLANNING COMPARISON OF TWO DIFFERENT 3D CONFORMAL TECHNIQUES FOR IRRADIATION OF HEAD AND NECK CANCER PATIENTS

Dushko Lukarski[1], Valentina Krstevska[1], Sonja Petkovska[1]

[1] University Clinic for Radiotherapy and Oncology, Vodnjanska 17, Skopje, R. Macedonia, duskol@yahoo.com, krstevskav@gmail.com, pet.sonja@gmail.com

***Abstract* – The purpose of this treatment planning study was to compare two different three dimensional conformal irradiation techniques for head and neck cancer patients.**

For 33 patients with head and neck carcinoma, irradiated according to the classical technique, we computed and evaluated a second irradiation technique in order to optimize the treatment planning protocol. The classical technique, termed "electron-photon fields", employed two lateral semi-fields (23 fractions) for irradiation of the upper part of the planning target volume that should receive 50 Gy (PTV_{50}) and an anterior and posterior field for the lower part. After the 23rd fraction the lateral fields were reduced from the dorsal side (2 fractions), in order to exclude the spinal cord from them. At the same time the dose to the shielded part of the target volume was delivered with matched electron fields. Finally, after the 25th fraction, the high risk volume was irradiated to the desired dose with plan where the spinal cord was completely shielded. In the new technique, termed "oblique photon fields", 4 oblique isocentric photon fields were used (25 fractions): two anterior fields that covered the entire target volume that should receive 50 Gy and two posterior fields that covered only half of the target volume in order to shield the spinal cord. Thus, the necessity for using electron fields is eliminated. We kept the plan for irradiation of the high risk planning target volume the same as in the classical technique. The prescribed dose per fraction in all plans was 2 Gy. In both techniques the plans were optimized to the same maximal point dose and the same dose to the spinal cord.

The oblique fields plan showed better coverage and homogeneity of the PTV_{50}, except for the patients with positive resection margins receiving postoperative radiotherapy (receiving 66 Gy), where the coverage did not differ significantly. The conformity in both techniques did not differ significantly. The mean dose to the parotid glands was significantly smaller with the oblique fields plan in case of patients with negative resection margins and when all the patients were treated as one group.

The preferred treatment technique is thus the oblique photon fields technique, not only because of the superior dosimetric parameters, but also because of the absence of the electron fields which complicate the entire treatment process from dosimetric as well as practical aspect.

***Keywords* – treatment planning, head and neck cancer, 3D conformal radiotherapy**

1. INTRODUCTION

The radiation treatment of the patients with head and neck cancer is considered one of the most challenging treatments in radiotherapy. One of the reasons for that is the anatomy of the body itself, where the volume that should be irradiated is located, ranging from the thick bony structures at the face, through the thin rounded contour of the upper neck, to the thick flatter surface of the supraclavicular areas. The other reason, which is the main reason, is that the volume that should be irradiated has a convex shape encompassing the spinal cord, which is the most critical organ at risk (OAR) at this site. The maximal dose tolerated by the spinal cord is considered to be between 45 Gy and 50 Gy. The presence of the other OAR like the oral cavity and the parotid glands, complicate the treatment further.

The classical approach in the treatment of this complex convex shape of the planning target volume (PTV) is to irradiate it up to the maximal allowable dose with two lateral photon fields (usually of 6 MV) and then to reduce the fields from the dorsal side in order to spare the spinal cord. The part of the PTV that remains outside of the reduced fields is then irradiated by electron fields of suitable energy (usually 9 MeV) that are matched to the photon fields. Such a protocol was adopted at our institution as well.

However such an approach has certain downsides. The first downside is of dosimetric nature. When an electron field is matched to a photon field a hot spot develops on the side of the photon field because of the outscattering of electrons from the electron field. This hotspot can be up to 125% of the prescribed dose. The second downside is of technical nature. Namely, for the electron fields one must mould the customized blocks that correspond precisely to the planned field. In practice, the accuracy of the molding can not be better than 1-2 mm. This can lead to additional hot or cold spots during the treatment. And finally, there is a practical aspect of increasing the workload of the department.

To overcome these difficulties we conducted a treatment planning study where we compared this classical approach to a new technique using 4 oblique photon fields, eliminating the need for electron fields [1-4] and their matching to the corresponding photon fields. In the comparison of the two protocols we name the classical approach as "electron – photon" technique (EPT) and the new one, which is under investigation, as "oblique photon fields" technique (OPFT).

2. MATERIALS AND METHODS

2.1. Patient population and contouring

A total of 33 patients were included in this study. The patient characteristics are given in Table 1 and the type of radiotherapy in Table 2.

Table 1. Patient characteristics (n=33)

Characteristics	Number of patients (%)
Gender	
Male	32 (97)
Female	1 (3)
Site of primary tumor	
Cavum oris	6 (18.2)
Oropharynx	3 (9.1)
Hypopharynx	8 (24.2)
Larynx	16 (48.5)
T stage	
T2	3 (9.1)
T3	12 (36.4)
T4	18 (54.5)
N stage	
N– vs. N+	
N–	25 (75.8)
N+	8 (24.2)
Stage	
II	1 (3)
III	11 (33.3)
IV	21 (63.6)

Table 2. Type of radiotherapy

Type of radiotherapy	Number of patients (%)	Prescribed dose (Gy)
Postoperative radiotherapy if negative resection margins and negative neck	10 (30.3)	60
Postoperative radiotherapy if close or positive resection margins and metastatic lymph nodes in the neck	10 (30.3)	66
Definitive radiotherapy	13 (39.4)	70

In patients who were planned for postoperative radiotherapy and there were no positive resection margins and nodal involvement (PRNR), the clinical target volume (CTV_{60}) encompassed the bed of the primary tumor. In patients who were planned for postoperative radiotherapy but there were close or positive margins of resection of the primary tumor as well as metastatic lymph nodes in the neck (PRPR), CTV_{66} represented an union of $CTVt_{66}$ that encompassed the bed of the primary tumor and $CTVn_{66}$ that encompassed the area of neck dissection. In patients who were candidates for definitive radiotherapy (DR), the gross tumor volume of the primary tumor ($GTVt_{70}$) and the metastatic lymph nodes ($GTVn_{70}$) were defined as any visible tumor and the gross nodal disease revealed on imaging studies and/or physical examination. $CTVt_{50}$ encompassed the $GTVt_{70}$ plus a margin of 1.0-2.0 cm for the potential microscopic extension of the disease. In all the patients with negative neck lymph nodes irrespectively of the type of planned radiotherapy, $CTVn_{50}$ included the nodal regions in the neck at I-III/IV for oral cavity cancers, II-IV for oropharyngeal and laryngeal cancers and I-IV for hypopharyngeal cancers [5, 6]. In surgically treated patients with positive lymph nodes, $CTVn_{50}$ included $CTVn_{66}$ and encompassed retropharyngeal lymph nodes and nodal regions at levels I-V. In patients with clinically involved neck lymph nodes who were not treated surgically, $CTVn_{50}$ included $GTVn_{70}$ with a margin of 0.5-1.0 cm and also encompassed retropharyngeal lymph nodes and nodal regions at levels I-V. Level VI was included in $CTVn_{50}$ in all the cases when primary tumor invaded subgllotis or esophagus. The planning target volumes were PTV_{50}, PTV_{60}, PTV_{66} and PTV_{70}. The PTV_{50}, PTV_{60}, and PTV_{66} provided a margin of 0.5 cm around CTV_{50}, CTV_{60} and CTV_{66}, respectively. In patients planned for definitive radiotherapy, when there were no positive lymph nodes in the neck, the PTV_{70} encompassed the $GTVt_{70}$ plus a 0.5 cm margin. In patients with nodal disease, the GTV_{70} was union of $GTVt_{70}$ and $GTVn_{70}$, and by adding a margin of 0.5 cm around it, we obtained PTV_{70}.

The parotid glands, as organs at risk, were delineated separately. The spinal cord was delineated with

diameter of 1.4 cm and a margin of 0.3 cm was added to create Planning Organ at Risk Volume (PRV_spinal).

2.2. Description of the treatment techniques

Each of the 30 patients included in this treatment planning study was irradiated according to the EPT technique, which was the standing protocol at our institution. For each of them a second plan was computed and evaluated according to the OPFT technique. The treatment planning was conducted using the Eclipse Version 7.3.10, a commercial 3-D treatment planning system manufactured by Varian Medical Systems. In both techniques, the planned dose per fraction in all the treatment plans was 2 Gy.

2.2.1. Electron – photon technique

The EPT consists of three stages. In the first stage (23 fractions), we used 4 photon semi fields: two opposing lateral semi-fields of equal weights with beam qualities of 6 MV for the upper neck, and anterior and posterior semi-fields for the lower neck. For the anterior field we used 6 MV photons and for the posterior 15 MV photons, with weights approximately 3:1 in favor of the anterior field. In the second stage (2 fractions), the lateral fields were reduced from the dorsal side in order to exclude the spinal cord from the fields. The dose to the shielded dorsal part of the PTV_{50} was delivered by two lateral electron fields, which were matched to the photon fields. Depending on the patient anatomy, the electron fields were of energies 9 MeV and rarely 12 MeV. In the third stage of the treatment plan (5, 8 or 10 fractions), depending on the position and the volume of the PTV_{60}, PTV_{66} or PTV_{70}, we used arrangements with 2 to 4 photon fields in lateral or oblique directions with occasional use of electron fields. In this stage the spinal cord was completely out of field.

2.2.2. Oblique photon fields technique

The OPFT consists of two stages. In the first stage (25 fractions) we used 4 oblique isocentric photon fields of beam qualities 6 MV. Two of the fields, the anterior ones, were positioned at gantry angles 300˚ and 60˚ and covered the whole PTV_{50}. The posterior oblique fields were at gantry angles between 210˚ and 220˚ from the right side of the patient, and between 135˚ and 145˚ from the left side. The spinal cord was shielded in these fields, so they covered only part of the PTV_{50}. The weight of the posterior fields was approximately 4 times smaller than the weight of the anterior ones. The second stage was identical to the third stage of the first technique.

2.3. Plan evaluation and comparison

The first criterion in the optimization of the treatment plans was the maximal dose to the spinal cord. In both techniques the maximal dose to the PRV_Spinal was equal and it was less then 50 Gy.

The second criterion was the global dose maximum – in both techniques the global dose maxima in the corresponding plans was equal.

The dose volume histogram (DVH) analysis was applied to both PTVs and OARs for each patient. The PTVs were analyzed in terms of coverage, conformity and homogeneity. Since the treatment plan for irradiation of the high risk volume (stage three in EPT and stage two in OPFT) was the same in both techniques, the analysis was performed only on the part of the treatment plans delivering 50 Gy. The conformity and homogeneity was evaluated only for PTV_{50}.

The analysis was performed for each of the three types of radiotherapy separately (Table 2) and also for all the patients as one sample. In the last case the PTV_{60}, PTV_{66} and PTV_{70} are all termed as PTV_{boost}. For evaluation of the coverage of the target volumes PTV_{50}, PTV_{60}, PTV_{66}, PTV_{70} and PTV_{boost}, we used the volumes receiving 47.5 Gy, 50 Gy and 52.5 Gy (i.e. 95%, 100% and 105% of the prescribed dose). The notation that we use for the volume receiving X Gy is V_X. We also compared the mean doses of the PTVs in both techniques.

For the conformity analysis we used two criteria – the conformity index (CI_{RTOG}) as defined by the RTOG [7] and the conformity number (CN) as introduced by van't Riet [8, 9]. The CI_{RTOG} was calculated as the ratio of the volume receiving 95% of 50 Gy i.e. 47.5 Gy and the volume of the PTV_{50}. Because the CI_{RTOG} fails in cases of insufficient coverage, we used the CN, which is a product of the coverage factor and the healthy tissue conformity index. The coverage factor is defined as the ratio of the volume of the part of the PTV_{50} receiving 47.5 Gy and the whole volume of the PTV_{50}. The healthy tissue conformity index is defined as the ratio of the volume of PTV_{50} receiving 47.5 Gy and the total volume of the body receiving 47.5 Gy.

For the homogeneity analysis we also used two indices. The homogeneity index (HI) is defined as the ratio of the dose received by the 95% of the PTV_{50} ($D_{95\%}$) to the minimum dose received by the "hottest" 5% of the PTV_{50} ($D_{5\%}$). The homogeneity index HI_{Wu} as defined by Wu et al. [10] is used in intensity modulated radiotherapy studies for head and neck. It is defined as:

$$HI_{Wu} = \frac{(D_{2\%} - D_{98\%})}{D_{prescripti\ on}} \quad (1)$$

Where $D_{2\%}$ is the minimum dose received by the "hottest" 2% of the PTV_{50}, $D_{98\%}$ is the dose received by the 98% of the PTV_{50} and $D_{prescription}$ is the prescribed dose (50 Gy).

From the OAR we compared the mean dose to the parotids.

In the analysis we compared the respective physical quantities by the non-parametric Wilcoxon exact signed rank test. Statistical significance was assumed at the level of $p \leq 0.05$.

3. RESULTS AND DISCUSSION

The mean volumes of the PTVs and of the parotids are given in Table 3.

Table 3. Mean volumes and standard deviations

Mean ± SD	PRNR	PRPR	DR	All
PTV_{50} (cm^3)	417.5 ± 64.1	493.1 ± 97.3	600.9 ± 137.5	512.7 ± 130.5
PTV_{60} (cm^3)	104.1 ± 20.0	—	—	—
PTV_{66} (cm^3)	—	183.1 ± 84.7	—	—
PTV_{70} (cm^3)	—	—	160.8 ± 81.0	—
PTV_{boost} (cm^3)	—	—	—	150.4 ± 75.1
$V_{left\ parotid}$ (cm^3)	14.6 ± 4.3	12.3 ± 5.4	9.5 ± 4.4	11.9 ± 5.0
$V_{right\ parotid}$ (cm^3)	17.2 ± 2.6	13.7 ± 6.1	10.9 ± 3.1	13.6 ± 4.8

In Table 4 the mean values of the physical quantities defined above and the p value for the corresponding mean comparison for the patients with PRNR are given. The parameters referring to PTV_{50} were significantly greater in the OPFT, with the exception of V_{50}. This means that keeping the same global maximum and the same dose to the spinal cord, we can irradiate the PTV_{50} to greater dose with this technique. Even though the mean values for PTV_{60} were greater in EPT, the differences were not significant. The only exception here was again the V_{50}. There was no significant difference in the conformity, but the homogeneity was better with OPFT. The parotid glands were also spared more with OPFT.

Table 4. Dosimetric comparison of the techniques for patients with PRNR

Mean values ± SD	OPFT	EPT	p
PTV_{50}			
$V_{47.5}$ (%)	92.1 ± 4.8	89.5 ± 4.6	0.005
V_{50} (%)	65.9 ± 10.7	63.7 ± 8.6	0.508
$V_{52.5}$ (%)	16.5 ± 4.5	11.5 ± 4.1	0.047
D_{mean} (Gy)	50.5 ± 0.6	50.2 ± 0.5	0.042
PTV_{60}			
$V_{47.5}$ (%)	96.2 ± 3.1	97.2 ± 2.2	0.114
V_{50} (%)	84.8 ± 6.2	89.2 ± 6.1	0.037
$V_{52.5}$ (%)	40.1 ± 13.0	36.5 ± 10.0	0.332
D_{mean} (Gy)	51.7 ± 0.6	51.8 ± 0.4	0.779
CI_{RTOG}	1.92 ± 0.18	1.81 ± 0.15	0.114
CN	0.45 ± 0.05	0.45 ± 0.06	0.767
HI	0.87 ± 0.03	0.86 ± 0.03	0.012
HI_{Wu}	0.19 ± 0.04	0.22 ± 0.04	0.005
Parotids			
D^{left}_{mean} (Gy)	35.7 ± 6.9	39.3 ± 6.2	0.009
D^{right}_{mean} (Gy)	37.0 ± 6.0	39.6 ± 6.1	0.009

In Table 5 the same parameters are given, but for patients with PRPR. No significant difference in any of the dosimetric parameters could be seen, except for the homogeneity, where the OPFT shows superiority.

Table 5. Dosimetric comparison of the techniques for patients with PRPR

Mean values ± SD	OPFT	EPT	p
PTV_{50}			
$V_{47.5}$ (%)	88.7 ± 4.8	87.1 ± 1.5	0.332
V_{50} (%)	58.0 ± 13.2	58.5 ± 7.1	0.721
$V_{52.5}$ (%)	12.5 ± 8.7	9.7 ± 5.8	0.262
D_{mean} (Gy)	50.1 ± 0.6	50.1 ± 0.6	0.919
PTV_{66}			
$V_{47.5}$ (%)	95.9 ± 3.0	96.3 ± 2.4	0.203
V_{50} (%)	75.3 ± 15.5	79.6 ± 7.9	0.575
$V_{52.5}$ (%)	27.2 ± 19.5	20.6 ± 8.2	0.114
D_{mean} (Gy)	51.1 ± 0.8	51.1 ± 0.4	0.767
CI_{RTOG}	1.81 ± 0.28	1.81 ± 0.26	0.878
CN	0.44 ± 0.06	0.43 ± 0.05	0.093
HI	0.86 ± 0.02	0.84 ± 0.02	0.030
HI_{Wu}	0.21 ± 0.02	0.22 ± 0.02	0.028
Parotids			
D^{left}_{mean} (Gy)	42.2 ± 8.2	44.3 ± 5.9	0.086
D^{right}_{mean} (Gy)	40.9 ± 6.6	42.4 ± 5.4	0.214

The same parameters for the patients receiving DR are given in Table 6. All the parameters referring to PTV_{50} were significantly greater in the OPFT. In this patient category, by using OPFT we can also irradiate the PTV_{50} to greater dose keeping the global dose maximum and the dose to spinal cord the same.

Table 6. Dosimetric comparison of the techniques for patients receiving DR

Mean values ± SD	OPFT	EPT	p
PTV_{50}			
$V_{47.5}$ (%)	90.8 ± 3.5	86.0 ± 4.0	0.002
V_{50} (%)	62.1 ± 8.5	53.1 ± 5.9	0.009
$V_{52.5}$ (%)	12.7 ± 5.4	8.6 ± 3.4	0.016
D_{mean} (Gy)	50.2 ± 0.4	49.7 ± 0.3	0.002
PTV_{70}			
$V_{47.5}$ (%)	97.8 ± 2.2	97.8 ± 2.4	1
V_{50} (%)	68.2 ± 9.7	75.5 ± 15.0	0.064
$V_{52.5}$ (%)	19.1 ± 11.2	18.2 ± 11.3	0.753
D_{mean} (Gy)	50.9 ± 0.5	51.1 ± 0.7	0.625
CI_{RTOG}	1.69 ± 0.19	1.59 ± 0.16	0.021
CN	0.48 ± 0.05	0.47 ± 0.05	0.255
HI	0.86 ± 0.03	0.84 ± 0.03	0.006
HI_{Wu}	0.20 ± 0.04	0.23 ± 0.03	0.002
Parotids			
D^{left}_{mean} (Gy)	46.6 ± 9.4	48.4 ± 8.3	0.184
D^{right}_{mean} (Gy)	48.2 ± 9.9	49.5 ± 8.2	0.345

For the PTV_{70} and for the parotids, there was no significant difference between the techniques. The

homogeneity was better with the OPFT, but the conformity depended on the index employed. When we used the RTOG index, the conformity was better with the OPFT, and when we used the conformation number, the difference was not significant.

In Table 7 the parameters for all 33 patients are given. Here as well, the parameters referring to PTV_{50} were significantly greater in the OPFT. Concerning the PTV_{boost} the differences were not significant, with the exception of V_{50}. Again like in the DR case, the two indices describing the conformity showed different significance – the RTOG index was significantly better with OPFT, but the conformation number was not. The homogeneity was better with the OPFT, and the mean doses to the parotids were significantly smaller.

Table 7. Dosimetric comparison of the techniques for all patients

Mean values ± SD	OPFT	EPT	p
PTV_{50}			
$V_{47.5}$ (%)	90.6 ± 4.4	87.4 ± 3.8	<0.001
V_{50} (%)	62.0 ± 10.9	58.0 ± 8.2	0.025
$V_{52.5}$ (%)	13.8 ± 6.4	9.8 ± 4.5	0.002
D_{mean} (Gy)	50.3 ± 0.6	50.0 ± 0.5	0.002
PTV_{boost}			
$V_{47.5}$ (%)	96.7 ± 2.8	97.2 ± 2.4	0.094
V_{50} (%)	75.4 ± 12.7	80.9 ± 12.1	0.010
$V_{52.5}$ (%)	27.9 ± 16.7	24.5 ± 12.7	0.118
D_{mean} (Gy)	51.2 ± 0.7	51.3 ± 0.6	0.802
CI_{RTOG}	1.79 ± 0.23	1.72 ± 0.22	0.017
CN	0.46 ± 0.05	0.45 ± 0.06	0.150
HI	0.86 ± 0.02	0.85 ± 0.03	<0.001
HI_{Wu}	0.20 ± 0.04	0.22 ± 0.03	<0.001
Parotids			
D^{left}_{mean} (Gy)	42.0 ± 9.2	44.4 ± 7.8	<0.001
D^{right}_{mean} (Gy)	42.6 ± 9.1	44.3 ± 7.9	0.004

4. CONCLUSION

As we can see from the presented results, for the patients with PRNR, DR and when all the patients are considered as one group, the OPFT showed better coverage of PTV_{50}. For the patients with PRPR the techniques were similar.

With exception of the V_{50} for the patients with PRNR and the entire group of patients, the coverage of the high risk volume did not differ significantly.

The conformity depended on the index used. When the RTOG index was used, the conformity of the OPFT was superior for the patients receiving DR and the entire group of patients. But when conformation number was used, the difference was not significant in any of the groups.

The OPFT was superior in regard to homogeneity in all 4 groups of patients.

As for the parotids, they were irradiated less in OPFT for the patients with PRNR and for the entire group of patients. In the other two groups, the doses to the parotids did not differ significantly.

So, we conclude that the OPFT gave somewhat better dosimetric results for patients with PRNR and DR and for the entire group of patients. For patients with PRPR the techniques were similar.

Bearing in mind that OPFT eliminates certain dosimetric and practical problems that are present in the EPT, like the field matching and the process of molding the individual blocks for the electron fields, we believe that these results justify going to the next step in introducing the OPFT as standard protocol at our institution - a clinical study evaluating both techniques from a clinical point of view.

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