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Conformity and Homogeneity Indices for Head and Neck Cancer Patients using 3DCRT

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Abstract: This study aims to demonstrate the conformity and homogeneity level achieved by 3D conformal radiation therapy for head and neck malignant tumors patients. Conformity and homogeneity indices are good quantitative tools for assessing and comparing the dose conformity and homogeneity of various treatment plans of one patient. In this study fifteen patients with advanced head and neck tumors have been selected. For each patient, five plans were promoted by using four planning techniques which were, Field-in-Field (FIF), Bellinzona, Conpas, Forward-Planned Multisegments (FPMS) with multiple energies denoted as FPMS (M) and another identical plan of FPMS but with using single energy denoted as FPMS (S). The CI_{RTOG} recorded values of 1.46 ± 0.16, 1.47 ± 0.16, 1.52 ± 0.18, 1.564 ± 0.20, 1.58 ± 0.21 for FPMS (M), FPMS (S), FIF, Conpas, and Bellinzona respectively. The HI recorded values of 0.187 ± 0.014, 0.193 ± 0.011, 0.196 ± 0.031, 0.202 ± 0.017, 0.219 ± 0.02 for FPMS (S), FPMS (M), FIF, Bellinzona, and Conpas respectively. It has been observed from the results that FPMS technique either using multiple energies or single has the highest conformity and homogeneity followed by FIF technique. For conformity, Conpas has the third rank followed by Bellinzona technique. For homogeneity, Bellinzona has the third rank followed by Conpas technique.

Keywords: Head and neck, Conformity index, Homogeneity index, 3DCRT.

1 Introduction

Radiation therapy or radiotherapy is the benefit of ionizing radiation to control or kill malignant tumor cells. In most of the time, radiotherapy is accomplished by a linear accelerator [1]. Radiotherapy (RT) is one of the three basics patterns of malignant disease treatment, the other two are surgery and chemotherapy [2]. During the radiation path to fight the tumor cells, it can cause harmful effects to the healthy tissue [3]. So the treatment goal is to focus the dose to the target as much as possible and to limit the exposure to the surrounding normal tissue as much as possible to reduce the adverse effects caused by radiotherapy treatment course. For head and neck tumors, radiotherapy is either radical treatment modality or adjuvant treatment after surgery [4].

It is a challenging task to design a plan which confirms the dose on the tumor while minimizes the surrounding normal tissue exposure for head and neck tumors, because this site of the human body distinguishes with its heterogeneity and also contains the spinal cord; the most vital organ at this site [5]. Head and neck radiotherapy treatment has been evolved from two dimensional (2D) to three dimensional conformal therapy (3DCRT) and intensity modulated radiation therapy (IMRT) [6]. Despite IMRT became the principle modality for treating head and neck tumors because of its ability to conform the dose on the tumor and to reduce the dose to the surrounding organs at risk (OAR) to high extent, also 3DCRT can do this task sufficiently through using some ”forward” iterative planning with 3-D conformal techniques. 3DCRT gives the opportunity to the target and the organs at risk to be delineated in three dimensional and with the utilization of Multi-Leaf Collimator (MLC), the desired dose coverage can be shaped around the target, simultaneously the irradiated healthy tissues can be minimized [7]. IMRT can be divided into two categories;

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Inverse Planning (IP-IMRT) in which the treatment plan can be accomplished by the IP treatment planning system and ”Forward” planning based on manual iterations by 3DCRT [8]. Many attempts were made to simulate IP-IMRT by forward planning 3DCRT especially for head and neck tumors to conform the dose on the target and hence the patient can enjoy with high quality of life. Between these attempts, Field-in-Field (FIF) technique [9], Forward Planned Multisegments (FPMS) technique [8], Bellinzona technique [10], Conpas technique [11] and Oblique Photon Fields Technique (OPFT)[12].

The conformity level of 3DCRT planning can be assessed by *the conformity index* (CI) which is proposed by the Radiation Therapy Oncology Group (RTOG) in 1993 [13] and described in the International Commission on Radiation Units and Measurements (ICRU) Report 62 [14].

Conformity index (CI_{RTOG}) takes into account the relation between the reference dose volume (V_{RI}) and the target volume (TV).

$$Conformity\ index(CI_{RTOG}) = \frac{V_{RI}}{TV} \quad (1)$$

If the conformity index is equal to 1, this means that, the conformation is ideal. If the conformity index is greater than 1, this means that the irradiated volume is greater than the target volume and health tissues are included. If the conformity index is less than 1, this means that, the target volume is partially irradiated.

According to the RTOG guidelines, ranges of conformity index values have been defined to determine the quality of conformation. If the conformity index is situated between 1 and 2, the treatment is comply with the treatment plan; an index between 2 and 2.5, or 0.9 and 1, is considered to be a minor violation, and when the index value is less than 0.9 or exceed 2.5, the protocol violation is considered to be a major, but may nevertheless be considered to be acceptable.

Another index for evaluating the plan is the Homogeneity Index (HI), which takes into the homogeneity of the dose distribution within the target. There are many formulas, the following is one of them;

$$HI = (D_1 - D_{99})/D_{mean} \quad (2)$$

Where, D_{99} and D_1 are the doses to 99% and 1% of the target volume respectively. Mean dose or D_{mean} is the mean dose of the target volume.

The aim of this paper is to compare between FIF technique, FPMS technique, Bellinzona technique and Conpas technique by using conformity and homogeneity indices for head and neck tumors.

2 Research Procedure

(a) Linear Accelerator and Treatment Planning System
The linear accelerator which has been utilized for treatment delivery is Linac, DMX fabricated by Varian Medical Systems with 40 pair multileaf collimator, having a width of 1 cm projected at the isocenter. It is able to deliver electron beams with energies 6 Mev, 9 Mev, 12 Mev and 15 Mev and photon beams 6 MV and 15 MV. Only photon beams have been utilized in our study. All treatment plans were calculated and optimized using the Eclipse treatment planning system version 8.14 (Varian Medical Systems) with Anisotropic Analytical Algorithm (AAA) for photon dose calculation.

(b) Patients Characteristic and preparation
In this comparative planning study, fifteen patients of head & neck cancer with different advanced tumors (5 larynx, 6 hypopharynx, 4 oropharynx) were included. All patients have been immobilized in supine position with thermoplastic head and shoulders mask with five fixation points attached to a carbon fibre plate support. 3mm Computed Tomography (CT) axial slices in treatment position were acquired for each patient. For each patient, on the CT images, slice per slice for each of the following structures was drawn by the oncologist; 1-Primary Gross Tumor Volume (GTV) defined as the gross tumor extension, 2-Clinical Target Volume (CTV) including the GTV, all potential direct routes of microscopic spread and all node levels at risk (depending on the site and stage), 3-Planning Target Volume (PTV) including the CTV with a uniform margin of 5mm, thus taking into account any organ motion and setup errors , 4-Spinal Cord was

delineated as the spinal canal and 5-both parotid glands were delineated separately.

(c) Dose Prescription
The prescribed dose was 54 Gy to the PTV with the conventional fractionation scheme (2 Gy per fraction, five fractions per week) as a phase one followed by a boost including high risk volume (or the tumor bed) irradiation by shrinking fields. In this study the first phase has been manipulated.

(d) Treatment planning techniques description
Fifteen patients were included in this study, For each patient five plans were promoted using Bellinzona technique, FIF technique, Conpas technique, FPMS (using 6 MV and 15 MV) and another identical FPMS (using 6 MV only), So a total of 75 plans were executed. Some modifications have been made on both Conpas and FPMS techniques .In the following a demonstration of the used techniques:

(i) Bellinzona technique:
This technique described in details in 1999 by Fogliata et al., [10] and had been revised to make use of MLC instead of blocks as originally proposed by herrassi, [15] naming it Revised Bellinzona (R.Bellinzona). Bellinzona or Revised Bellinzona technique in general is consisted of five fields (also known as five field technique) as the following; Posterior field (G180-T0; i.e., gantry angle 180, couch angle zero), two long lateral fields ($G270*285, T5*15$ and $G90*75, T5*15$) covering all of the PTV; gantry and couch angles optimization is to reach a better dose distribution and Lastly, two symmetrical posterior-oblique fields (G140 $*$ 150, T0, from the left side) and ($G210*220, T0$, from the right side) all shielding the spinal cord completely. The posterior field can be split into two separated fields (half- beam block field) in the case where the spinal cord can't be completely shielded due to the MLC leaves travel distant constrains (Figure.1(a)).

(ii) Field-in-Field technique (FIF):
The original technique described in details by Portaturi et al., [9] consists mainly of 11 fields and the unique isocenter point placed behind the first cervical vertebral body. The fields arrangements were performed by using six angles (0, 280, 80, 180, 135, and 220), with a mean of two fields per angle, each field configuration was done by a multileaf collimator (leaf thickness 5mm). 6-MV photon beams were used in this treatment planning technique. The original study contained a number of cases between of them 17 larynx cases and 12 oropharynx and dose normalization was made at the PTV isocenter (Figure.1(b)).

(iii) Forward Planning Multisegments technique (FPMS):
FPMS technique, described in details by N. Lee [8] designed to treat the primary tumor and the upper neck nodes of H&N cancers (matched with lower anterior neck and supraclavicular field) with 7 gantry angles represented in an anterior, 2 lateral (G90 for left side, G270 for right side), 2 symmetrical anterior oblique (G60 for Left Anterior Oblique (LAO), G300 for Right Anterior Oblique (RAO)) and 2 symmetrical posterior oblique, For a total of 13 MLC-shaped segments. Four of the 7 beam angles contain multiple segments. Depending on the case, up to 3 segments at a given angle can be designed and tailored to maximize the coverage of the target while minimizing the normal tissue exposure. The treatment planning is based on a careful design of each segment and optimization of the associated weights. 6MV and 18MV photon beams were used as well as wedges (Figure.1(c)). Our difference with the original FPMS can be considered as the following: 1- 6MV and 15MV beams have been used instead of 6MV and 18MV beams, 2- all fields (or segments) were designed to contain all PTV (containing the lower neck and the supraclavicular nodes as well as the upper neck nodes) so eliminating the need for an anterior lower neck field matching, 3- the two lateral field angles were not fixed at gantry of 90 and 270 as well as the two symmetrical anterior oblique. All of them could be kicked out in which turning the gantry versus the anterior position by about 5-10 to reach a better dose distribution. Finally the two symmetrical posterior beam angles were set to be 140 (from left) and 220 (from right) and only these fields in which 15 MV beams have been used, and all other fields (or segments) were optimized with 6MV. In addition to our multiple energy modified FPMS (denoted as FPMS (M)) technique, an identical plan has been made from this technique for each patient, using 6 MV beams only (denoted as FPMS (S)) to assess the beam energy effect.

(iv) ConPas technique: Conpas technique described in detail by wigyenraad et al., [11] consists of 6-7 isocentric fields including two pairs of full-length parallel opposed oblique half-beams and a large AP (Anterior Posterior) beam with a separate supraclavicular segment. The planning procedure begins by placing the isocenter in the anterior part of the vertebral body halfway between the upper and lower limits of the PTV. After that, both oblique posterior beams are setup and turned into half beams by closing the collimators on the spinal cord side. These two half beams are the most important component in conpas with respect to parotid sparing. Initially, the two posterior oblique angles are set to be 140 and 220, then these angles can be modified in the beam's eye view mode so that the parotid glands maximal blocking

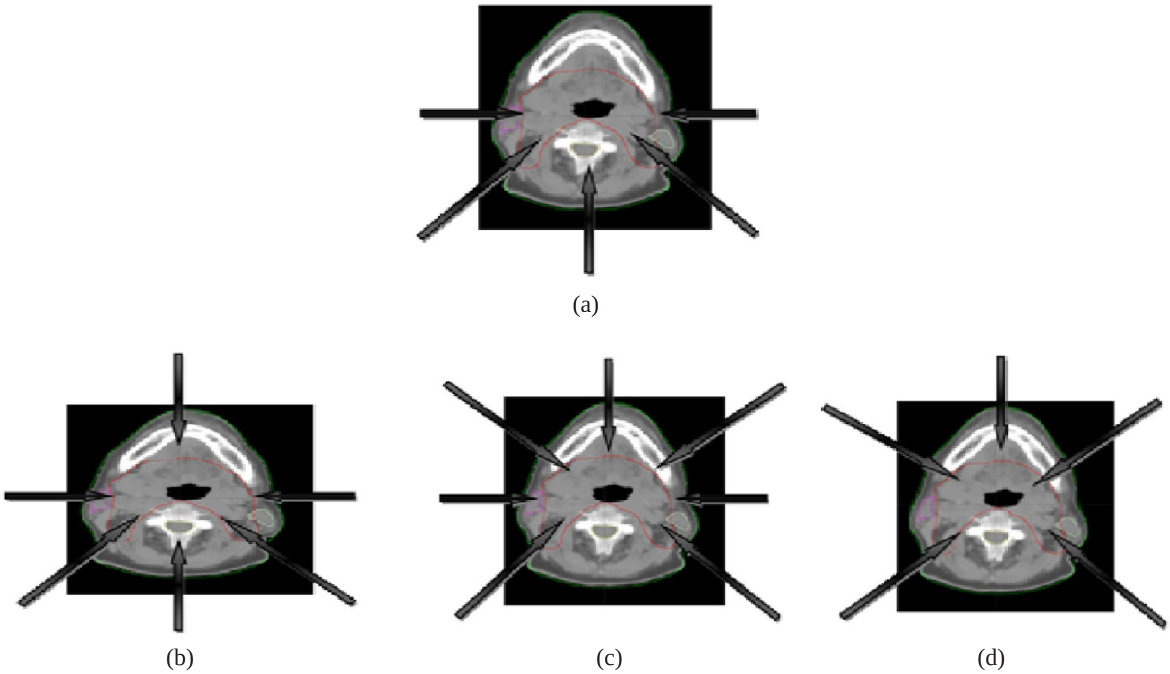

Fig. 1: Schematic layout of the different beam arrangements for each technique. (a) R.Bellinzona; (b) FIF; (c) FPMS; (d) Conpas

is possible, then the two anterior oblique beams are setup and turned into half-beams by closing the collimators that are off the side of the spinal cord, by this they are exactly opposing the two respective posterior beams. Beam weights and wedges are optimized in each beam (Fig.1(d)). The study manipulated larynx and hypopharynx cases. In our Conpas trial a deviation has been done to some extent from the original conpas design with respect to the two anterior oblique fields, they were let to cover the all PTV. The oblique posterior fields have not been half-beam fields, but just get enough with excluding the cord out of these fields with the conservation of the separate supraclavicular segment. Our trial of conpas technique modification resembles to some extent the oblique photon fields (OPFT) proposed by Lukarski[12].

3 Data Analysis

For evaluating statistical significance between the different techniques, two tailed t-test were used. $P(\leq 0.05)$ values were considered statistically significant.

(i) Conformity index values: Table 1. displays the conformity index values. The CI_{RTOG} recorded values of 1.46 ± 0.16, 1.47 ± 0.16, 1.52 ± 0.18, 1.564 ± 0.20, 1.58 ± 0.21 for FPMS (M), FPMS (S), FIF, Conpas, Bellinzona respectively. According to CI_{RTOG}, the FPMS demonstrated the highest conformity, the next was FIF, followed by Conpas and lastly Bellinzona. For Pairwise comparison, the differences were significant ($P = 0.0278$) for FIF vs. FPMS(M). ($P = 0.0052$) for FIF vs. Bellinzona. The difference was not statistically significant for both FPMS (M) vs. FPMS (S); $P = 0.3762$ and FIF vs. Conpas, $P = 0.111$. (ii) Homogeneity index values: The goal of treatment plan is to make the target dose homogeneous as possible. The lower the HI value (close to zero), the better homogeneity of the target dose. Table 2. displays the homogeneity index values. As shown from the demonstrated data, the highest homogeneity was achieved by FPMS (S) $= 0.187 \pm 0.01$, then FPMS (M) $= 0.193 \pm 0.01$, FIF was the next $= 0.196 \pm 0.03$, followed by Bellinzona $= 0.202 \pm 0.01$ and lastly Conpas $= 0.219 \pm 0.02$, the statistical difference was found for FPMS(M) vs. FPMS(S), $P = 0.011$ and for FIF vs. Conpas, $P = 0.0156$, while there was no significant difference between FIF vs. Bellinzona, $P = 0.3967$ and FIF vs. FPMS(M), $P = 0.7636$. Tables 3,4,5. summarize PTV mean dose, PTV near minimum doses, expressed by, D99 , and PTV maximum doses, expressed by D1.

Table 1: Summary of Conformity index mean values vs. the used techniques

Conformity Index (RTOG)					
	FIF	FPMS (M)	FPMS (S)	Bellinzona	Conpas
Max	1.99	1.73	1.71	2.04	1.95
Min	1.22	1.2	1.23	1.27	1.25
Mean ± SD	1.52 ± 0.18	1.46 ± 0.16	1.47 ± 0.16	1.58 ± 0.21	1.56 ± 0.20
P value for pairwise comparison between the used techniques					
FIF vs. FPMS (M)		0.0278	FIF vs. Bellinzona		0.0052
FPMS(M) vs. FPMS(S)		0.3762	FIF vs. Conpas		0.1111

Table 2: Summary of Homogeneity index mean values vs. the used technique

Homogeneity Index $= (D_1 - D_{99}) /$ mean dose					
	FIF	FPMS (M)	FPMS (S)	Bellinzonz	Conpas
Max	0.273	0.214	0.213	0.239	0.263
Min	0.158	0.172	0.159	0.182	0.181
Mean ± SD	0.196 ± 0.03	0.193 ± 0.01	0.187 ± 0.01	0.202 ± 0.01	0.219 ± 0.02
P values for pairwise comparison between the used techniques					
FIF vs. FPMS (M)		0.763	FIF vs. Bellinzona		0.396
FPMS (M) vs. FPMS(S)		0.011	FIF vs. Conpas		0.015

Table 3: Summary of PTV mean dose (D_{mean}%) vs. the used technique

Dmean %					
	FIF	FPMS (M)	FPMS (S)	Bellinzonz	Conpas
Max	104.5	104.2	103.9	105.0	103.0
Min	102.5	101.9	101.4	102.6	100.7
Mean ± SD	103.7 ± 0.65	102.9 ± 0.62	102.7 ± 0.67	103.3 ± 0.71	102.1 ± 0.57

Table 4: Summary of PTV near minimum doses, D_{99}%vs. the used technique

D_{99}%					
	FIF	FPMS (M)	FPMS (S)	Bellinzonz	Conpas
Max	93.2	91.9	92.7	90.8	91.4
Min	82	87.8	87.6	85.5	82.6
Mean ± SD	89.5 ± 3.16	90.2 ± 1.19	90.3 ± 1.55	89.1 ± 1.6	87.4 ± 2.2

Table 5: Summary of PTV near maximum doses,D_1% vs. the used technique

D_1%					
	FIF	FPMS (M)	FPMS (S)	Bellinzonz	Conpas
Max	110.3	110.6	110.1	110.5	110.5
Min	108.7	109.4	108.9	109.5	108.2
Mean ± SD	109.8 ± 0.42	110.1 ± 0.30	109.6 ± 0.40	110.0 ± 0.28	109.8 ± 0.60

4 Discussion

If the conformity index is equal to 1, this means that, the conformation is ideal. If the conformity index is greater than 1, this means that the irradiated volume is greater than the target volume and health tissues are included. If the conformity index is less than 1, this means that, the target volume is partially irradiated. According to the RTOG guidelines, ranges of conformity index values have been defined to determine the quality of conformation. If the conformity index is situated between 1 and 2, the treatment is comply with the treatment plan; an index between 2 and 2.5, or 0.9 and 1, is considered to be a minor violation, and when the index value is less than 0.9 or exceed 2.5, the protocol violation is considered to be a major, but may nevertheless be considered to be acceptable.

L.Cozzi et al., performed a comparative study of 3D conformal, IMRT, and proton therapy for treatment of advanced head and neck tumors. The applied 3DCRT technique was the five field (5F) technique or Bellinzona technique. The conformity index mean values were 1.91, 1.68, 1.60, 1.62, 1.23 for 3DCRT (5F), Intensity Modulated with 5 fields (IM5F), Intensity Modulated with 9 fields (IM9F), the Passive Scattering Proton technique (PTMS), and the Spot Scanned Proton technique (PPSI) respectively [16].

Our results of CI_{RTOG} mean were superior to those obtained by Lukarski et al., who compared between two different three dimensional conformal irradiation techniques for head and neck cancer; the classical technique, termed ”Electron-Photon fields”, ”EPT” and the new technique, termed ”oblique photon fields”, ”OPFT”, the results where all patients were considered as one group were equal to 1.79 $\pm$ 0.23, 1.72 $\pm$ 0.22 respectively for CI_{RTOG}[12].

In another study, A. Caraman et al., compared between 3D conformal, IMRT and VMAT techniques for head and neck cancer of 5 patients, the plans were created using the same 6MV photon beams commissioned for Varian clinac ix equipped with a 120 leaf millennium MLC and using the TPS (Treatment Planning System) Eclipse (version 11) and Analitical Anisotropic Algorithm. They assessed the conformity index according to RTOG formula. The mean values of CI_{RTOG} for 3DCRT, VMAT, and IMRT were, 1.20, 1.06, and 1.14, respectively. The use of millennium MLC, may be the cause of the inferiority of our results when compared by these results [17].

5 Conclusion

Conformity and homogeneity indices are good tools to evaluate the quality of the treatment plan besides the other available evaluation tools. The comparative study of the four used techniques demonstrated that the forward planned multisegments (FPMS) technique either using multiple or single energy exhibited the highest conformity and homogeneity for the treatment plans followed by FIF technique. With respect to the other two techniques, conpas has the third rank, followed by Bellinzona technique for conformity index. For homogeneity index the matter was different, the Bellinzona technique has the third rank followed by Conpas technique.

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