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The effect of field number on intensity modulated radiation therapy plan quality in head and neck cancer

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***Abstract*---**Background: Radiotherapy of head and neck cancer is a difficult process because of the complex anatomy and close proximity of various organs at risk (OARs). This study aimed to assess the impact of field number of intensity modulated radiation therapy (IMRT) technique on the quality of the treatment of the head and neck cancer patient.. Methods and materials: The CT scans of thirteen head and neck cancer patients were selected at the Zhianawa Cancer Center (ZCC). The Monaco treatment planning system (TPS) V5.51.10 with the Monte Carlo (XVMC) algorithm V1.6 were utilized to generate nine and eleven field IMRT plans, all plans were carried out on an ELEKTAMLCi2 linear accelerator. The effect of field number was assessed by planning target volume (PTV) coverage, homogeneity index (HI), conformity index (CI), OARs dose, the monitor units (MUs), and delivery time. Results: The 11F-IMRT had improved tumor coverage and better spared ipsilateral and contralateral optic nerves, on the contrary the doses to the were above acceptance limit value. The CI of 11F-IMRT was better than 9F-IMRT, while the HI was similar. The 9F-IMRT had a reduced treatment time by 37.7 %, although increased MUs by 12.8%. Conclusion: The 9F and 11F of IMRT although have nearly similar target coverage, while increasing the beam field caused to exceeded the dose constraints in ipsilateral parotid and ipsilateral eye lens. The 11F-IMRT plan was time-consuming and with lower monitor units (MUs).

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***Keywords*---**number monitor units, intensity modulated radiation therapy, head and neck cancer, homogeneity index, conformity index.

Introduction

Head and neck cancer refer to group of tumors emerging in the sinuses, nasal cavity, larynx, pharynx, oral cavity, or salivary glands [1]. Radiotherapy is a treatment technique that utilizes radiation to decimate cancer cells. [2]. Radiation may be used as a primary treatment or as an adjuvant treatment in combination with chemotherapy or surgery, depending on a patient's pathological health conditions [3]. Radiation treatment technology is rapidly evolving, with image-guided modalities, linear accelerator, and patient immobilization devices are constantly being updated. These modern technological devices allow for the decrease of dosage to normal tissue structures while permitting the dose to be raised in the tumor and improving the local control rate [4].

The Radiology Institute was the first radiotherapy services in Iraq that installed in Baghdad city 1920s and deep X-ray therapy unit was established in Mosul in 1959 [5]. The number of clinical radiation oncologist and megavoltage machine are insufficient and under international standard in Iraq, it has been recorded that 168 radiation oncologists [6] about 25 radiotherapy centers with 23 megavoltage machines are available including Kurdistan Region [7]. According to Iraqi Cancer Registry (ICR) cancer is the second factor of mortality in the society, 35864 new cases of cancer were diagnosed in the year 2019, head and neck cancer takes a sixth rank by 5.02% [8].The total number of deaths by cancer in Iraq was 10957; the rate of death by head and neck cancer was only (1.14%) [9].

Due to the complicated structure of the head and neck anatomy and closeness tumor to critical tissues, intensity-modulated radiation therapy is commonly used [10]. A multitude of different-intensity beamlets confine the radiation beam, IMRT optimization is used inverse planning used which is a computer algorithm that adjusts the beam weighting and blocking to achieve an optimal plan and dose constrain [11]. Compared to conventional radiation therapy, intensity modulated radiotherapy (IMRT) protects nearby essential organs more effectively and achieves more conformal dose coverage for the target volume [12]. The steep and shoot IMRT provides radiation doses by using many defined multiple fixed beam angles. As a consequence, the period of therapy might be shortened [13].

At present, many studies have investigated the dosimetric differences between various field beam of IMRT plan for different types of cancer tumors, and the results consistently show that the effect of increasing the field number is more effective on the dose of organ at risk however the treatment time is increased. According to the research Ibrahim et al. [14] increasing the beam field of IMRT had significant effect on plan quality, while Shanei et al. [15] shows that increasing the field numbers caused improve of PTV coverage . Although according to Jeong et al. [16] there is not significantly enhance treatment outcomes by using more field beam. The purpose of this study was to determine the effect of field number on IMRT plan in head and neck cancer treatment. A comparison of tumor coverage, HI, CI, dose to OARs, MUs, and delivery time was used to evaluate either 9F-IMRT or 11F-IMRT plan is better for clinical application.

Methods and Materials

Cases and plans

Both 9F-IMRT and 11F-IMRT plans were created for each data set. The Monaco TPS v5.51.10 is based on the inverse planning dose calculation was used to generate whole plans. The thirteen computed tomography (CT) of head and neck cancer patients at Zhianawa Cancer Center (ZCC) have been taken. The CT data were previously acquired by a large bore Optima CT 580 RT scanner (General Electric Healthcare-USA). The slice thickness of the CT images was 2 mm with the DICOM format, starting from above the head and ending under the shoulders, which were used to aid tumor delineation.

Contouring

The CT scans were transferred to the Monaco TPS to contour OARs and PTVs. Clinical target volume (CTV) and OARs (eye lens, spinal cord, brainstem, parotids, optic nerves, optic chiasm, eye, mandible, and cochlea) were delineated by radiation oncologists. Planning target volume (PTV) included CTV plus 3 mm margins. Seven patients had two PTVs, five patients had three PTVs, and only one case had four PTVs. All patients previously were treated by prescribed doses of 70 to 54 Gy depending on the case. . The idea of PTV2 is provided in accordance with local practice and is used primarily as a tool to restrict exposure to organs at risk. The results of dose comparison will be provided for PTV1 alone. Table 1 shows the guidelines for PTV and OARs dose volume restrictions at ZCC.

Table 1: PTV and OARs dose volume constraints for IMRT plan according to ZCC guidelines

Volume/OAR	Dose constraint		
PTV1	$D_{98\%} > 95\%\ D_p$	and	$D_{2\%} \leq 110\%\ D_p$
spinal cord	$D_{max} < 45$ Gy	or	1cc ≤ 50 Gy
Brainstem	$D_{max} < 54$ Gy	or	1cc ≤ 60 Gy
Parotid	$D_{mean} < 26$ Gy	or	≤ 50% > 30 Gy
Eye lens	$D_{max} < 10$ Gy		
Cochlea	$D_{mean} < 40$ Gy		
Optic chiasm	$D_{max} < 54$ Gy	or	1cc ≤ 60 Gy
Optic nerve	$D_{max} < 54$ Gy		

Plan designing

For the 9F-IMRT technique, the angles of the gantry are fixed at 0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, and 320°, while the beam angle for 11F-IMRT plan were set up at 32.5°, 65°, 97.5°, 130°, 162.5°, 195°, 227.5°, 260°, 292.5°, 325°, and 357.5°, while he collimator was not rotated for both plans. The XVMC algorithm V1.6 was used to calculate dosimetry with a 3.8 mm calculation grid. All plans were produced by utilizing Elekta Synergy Linac 6 MV photon beams, which have 40-pair leaf tungsten with a 1 cm thickness and a variable dose rate of 600 MU/s. The Monaco TPS v5.51.10 was used to generate all plans.

Plan comparison

Plans were deemed acceptable only if PTV coverage and OAR dose complied with ZCC guidelines dose constraints. The effectiveness of both plans was determined by comparing CI, HI, delivery time per fraction, and MUs. The CI was calculated by (Eq. 1)

$$\mathrm{CI} = \frac{V_{95\%}}{V_{PTV}} \quad \ldots\ldots\ldots. \; (1)$$

$V_{95\%}$ = volume covered by 95% of prescribed dose
V_{PTV} = PTV volume
The HI was found by using (Eq. 2):

$$\mathrm{HI} = \frac{D_{2\%} - D_{98\%}}{D_P} \quad \ldots\ldots\ldots\ldots \; (2)$$

$D_{2\%}$ = maximum dose delivered to 2% of the PTV
$D_{98\%}$ = minimum dose calculated for 98% of the PTV
D_p = prescribed dose for the PTV

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 26.0 software program (IBM Corporation, Armonk, NY, USA). Independent samples t-test was used to assess the statistical significance of the differences between means. The mean and standard error of mean were taken, probability values of $p < 0.05$ were considered to be statistically significant.

Results

Planning target volume coverage

After considerable attempts, 9F-IMRT and 11F-IMRT plans were generated according to the planning guidelines. The general quality of the designs created was comparable, but statistical discrepancies were found between the two methods. The PTV dose coverage is a part of the plan quality, presented in Table 2. Adequate PTV coverage was obtained in both plans. The P-values for $D_{2\%}$, $D_{98\%}$, and $V_{95\%}$ were 0.256, 0.118, and 0.383, respectively. The average $V_{95\%}$ was 98.30±0.27 and 97.81±0.48 respectively in the 9F-IMRT and 11F-IMRT with (P-value =0.383). No significant differences in target coverage were noticed between the two techniques.

Table 2: PTV70 Coverage for both 9F-IMRT and 11F-IMRT plan

Dose (Gy)	9F-IMRT	11F-IMRT	P-value
$D_{2\%}$	76.82±0.27	76.36±0.29	0.256
$D_{98\%}$	66.66±0.19	65.93±0.4	0.118
$V_{95\%}$ (%)	98.30±0.27	97.81±0.48	0.383

Conformity index (CI) and homogeneity index (HI)

A qualitative assessment of each plan was determined by the comparison of the dose volume histogram (DVH), HI, and CI. Table 3, shows average CI for both plans, the 11F-IMRT provides better conformity. The average CI of 9F-IMRT was 1.74±0.09, while it was 1.66±0.10 of 11F-IMRT, the P-value was 0.533, with no statistically noticeable difference between the two plans. The HI for both techniques is identical and equal to 0.14±0.01 with P-value 0.977 as shown in Table 3, there is an insignificant difference between both techniques.,

Monitor units (MU) and delivery time

The 11F-IMRT plan required lower MUs than the 9F-IMRT plan the average MUs of 9F-IMRT and 11F-IMRT were 1006.48±71.60 and 892.11±51.54, respectively (with P-value 0.207). Table 3 shows the average number of MUs for the 9F-IMRT and 11F-IMRT plans. The delivery time required for one treatment fraction for both the 9F-IMRT and 11F-IMRT plans is illustrated in Table 3. The 11F-IMRT plan was required more time than the 9F-IMRT plan. The average delivery time of 9F-IMRT was 480.69±28.27 s, while it was 772.54±23.52 s for 11F-IMRT, P-value < 0.05. Overall delivery times were reduced by 37.7 %.

Table 3: CI, HI, MUs, and delivery time in both 9F-IMRT and 11F-IMRT plans

Parameters	9F-IMRT	11F-IMRT	P-values
CI	1.74±0.09	1.66±0.10	0.533
HI	0.14±0.01	0.14±0.01	0.977
MU	1006.48±71.60	892.11±51.54	0.207
Time (s)	480.69±28.27	772.54±23.52	< 0.05

Doses to organs at risk

The doses to the organ at risks were illustrated in Table 4. The mean dose was calculated for parallel organs, while for serial organs the maximum dose was measured. The 11F-IMRT plan slightly better spared for the spinal cord, cochleae, and optic chiasm, while more superior for both optic nerves. Ipsilateral and contralateral optic nerves were received 24.51±6.42 Gy and 31.12±7.45 Gy respectively by 11F-IMRT, these values were raised to 38.18±4.95 Gy and 38.76±8.04 Gy, respectively in 9F-IMRT without significant differences. On the other hand, increasing the beam field had a negative effect on protecting the ipsilateral parotid and ipsilateral eye lens, the radiation dose to these organs were above the threshold value. In the 9F-IMRT, the doses to the brainstem, parotids, and eye lenses were slightly lower than in the 11F-IMRT with (P-values > 0.05)

Table 4: Average OARs dose for 9F-IMRT and 11F-IMRTwith P-value

Organs at risk (OAR)	Dose (Gy)		P-value
	9F-IMRT	11F-IMRT	
Spinal cord D_{max}	42.18±2.48	40.45±2.40	0.620
Brainstem D_{max}	42.70±3.31	44.47±2.67	0.683
Ipsilateral parotid D_{mean}	25.82±1.60	26.37±1.57	0.807
Contralateral parotid D_{mean}	22.60±1.76	24.78±1.99	0.421
Ipsilateral lens D_{max}	9.05±1.74	10.61±4.45	0.752
Contralateral lens D_{max}	8.51±1.58	9.68±2.49	0.699
Ipsilateral cochlea D_{mean}	25.93±5.13	23.65±4.69	0.748
Contralateral cochlea D_{mean}	20.41±4.33	17.58±2.56	0.583
Optic Chiasm D_{max}	37.74±7.59	36.23±8.82	0.900
Ipsilateral optic nerve D_{max}	38.18±4.95	24.51±6.42	0.130
Contralateral optic nerve D_{max}	38.76±8.04	31.12±7.45	0.502

Discussion

In this study, the effect of treatment field number of IMRT was evaluated for head and neck cancer. The quality of the entire plans was clinically acceptable for covering tumors and protecting OARs. The 11F-IMRT was better for $D_{2\%}$ and inferior for $D_{98\%}$ as compared to 9F-IMRT plan. Generally, in the 9F-IMRT the percentage volume of the tumor which received 95% of the prescribed dose was greater than this value in 11F-IMRT. Due to the high standard errors there is no observable statistical difference in tumor coverage between both plans.

The radiotherapy treatment plan was evaluated statistically using the conformity index (CI), which is an essential parameter that indicates the relationship between isodose distribution and the target volume, according to the radiation therapy and oncology group (RTOG) guidelines for ideal tumor coverage CI = 1 [17]. The average CI in 11F-IMRT was slightly better than in 9F-IMRT by 4.9%, it indicates that the conformity dose distribution was enhanced the by increasing the field number. In order to evaluate the regularity of dose distribution in the PTV, the HI can be used. A lower HI means that a more homogeneous and superior dose distribution may be achieved in the target volume [18]. The dose homogeneity was identical between both plans. In the current study it is found that the homogeneity of dose was not improved by increasing the number of fields, which is critical when the target is located near an organ at risk, restricting the PTV coverage to a reasonable level. The conformity of the dose is another parameter to assess the plan quality; in most of cases the 11F-IMRT provided better conformity than 9F-IMRT. The average CI in 11F-IMRT was improved by 4.9%.

Kai et al. [19] assessed the quality of the plan for 5F and 9F-IMRT coplanar treatment plans for scalp angiosarcoma. The results showed that the target coverage, CI, and HI were improved by adding more field number. Jeong et al. [16] compared dosimetric parameters between different beam fields in non-coplanar IMRT plans for nasal cavity and paranasal sinus cancer. According to the results, the plan quality was not improved by increasing the field number; HI and CI remain approximately same value in all different beam fields. Data from Jeong et al. [16] contradicts our findings in terms of CI, while being in line with Kai et al. [19].

Distribution of the doses that satisfied the guidelines was possible in this study. In both techniques, the dose of OARs was maintained below the threshold for tolerability except of radiation dose to ipsilateral parotid and ipsilateral eye lens in 11F-IMRT. The therapeutic ratio of radiation therapy is based on dose constraint of the organ at risks. Ipsilateral and contralateral optic nerves were better spared in the 11F-IMRT technique. The P-value of the optic chiasm was the highest among all OARs, equal to 0.900, indicating that the average dose distribution among all patients was approximately same value in both techniques. According to the statistical analysis there was no statistically significant difference between both field numbers in term of OARs protection.

The findings of our investigation were different from the data was achieved by Jeong et al. [16] and demonstrated that adding more beam fields in IMRT plan was an effective way for preserving most of the OARs while at the same time achieving adequate PTV coverage with more uniformity. On the other hand our result, were similar to Shanei et al. [15] that showed that change in the beam numbers in the IMRT technique could result in small improvements ($P=0.036$) of received dose by organs at risk except maximum dose of spinal cord was reduced by 9.61% was observed between the IMRT-9F technique and IMRT-5F.

Calculation of time began with the first beam and finished with the last MUs being received. The treatment time includes the time it takes to switch the gantry orientations between field angles. Treatment time was increased by adding more field number. The average time to deliver the single fraction of 9F-IMRT and 11F-IMRT was 480.69 ± 28.27 s and 772.54 ± 23.52 s, respectively, the time reduced by 37.7 %. The average MUs in 9F-IMRT was 1006.48 ± 71.60, while this value in 11F-IMRT was 892.11 ± 51.54 and reduced by 11.3% with P-value 0.207.The result showed that dose leakage from the linear accelerator and the total body irradiation was reduced by increasing field number.

According to the result of Jeong et al. [16] The MUs was proportional to the field number, the average value of MUs for each of 7F, 11F, and 15F beam were 2224 ± 423, 2350 ± 451, and 2475 ± 384, respectively. Treatment delivery time was increased by adding more field beams, 15F was required more time than 11F and 7F the value were 19.58 ± 0.64 min, 15.65 ± 0.75 min, and 11.72 ± 0.71 min, respectively. Ibrahim et al. [14] compared dosimetric parameters between 3D-CRT, 7F-IMRT, and 9F-IMRT of different stages for nasopharyngeal carcinoma treatment. Compared to the 9F-IMRT the average MUs and delivery time was reduced by 10% and 18% in 7F-IMRT, respectively. Our finding similar to the studies Jeong et al. [16] and Ibrahim et al. [14] in term of delivery time, although contrast in term of MUs.

The number of beam field in IMRT treatment plan was directly proportional with treatment time and inversely proportional with the MUs. As a result, in 9F-IMRT errors associated with target shift or organ movement was minimized, however the body was exposed to more radiation by machine leakage and scattered dose.

According to Sakthivel et al. [20], the possibility of a second cancer was reduced with lower dose exposure to healthy organs.

Conclusion

The study concludes that The number of treatment fields had affects the IMRT plan quality. The 11F-IMRT technique pronounced sparing of nearby OARs, while dose distribution to PTV1 approximately same compared to 11F-IMRT for head and neck cancer patients. On the other hand, for OARs which were at a distance from PTV1 and nearby skin, 9F-IMRT was superior to 11F-IMRT. All dose data obtained by both techniques for PTV1 and OARs agreed with ZCC guidelines and therefore are practically applicable. Increasing the field number of IMRT plans causes a long treatment times and reduce patient comfort, however probability of recurrent cancer was reduced by minimizing MUs. Technique selection is not solely determined by dose volume histogram (DVH) and physical characteristics; a clinical decision should be made as well, when two competitor techniques that similar in PTV coverage and OAR sparing. Therefore, in this research, the number of patients is small. It is essential to increase the sample number to confirm the findings. It is concluded that 11F-IMRT has better achieved the aims of this study, which was to produce an acceptable plan compared to IMRT for head and neck patients.

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The authors have no conflicts of interest.

Author contributions

Formal analysis: Salar Qader Hasan.
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Review and editing: Edrees Muhammad Tahir Nury and Suha Nafea Aloosi

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author.

Ethic approval

This study was approved by the Ethics Committee of the Hawler Medical University.

Clinical trials registry

For all patient treatment plans, Ethical Committee Approval was taken from Medical Ethics Committee, Hawler Medical University (Reg.No. 7/13 , 2022), and clinical trial registry was obtained from Thai Clinical Trials Registry (Reg.No. TCTR ID : TCTR20220527004, https://www.thaiclinicaltrials.org/show/TCTR20220527004).

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