Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE

DOI: 10.47750/jptcp.2023.1118

Role of Body Mass Index in Intensity Modulated Radiation Therapy for Head and Neck Cancer

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Submitted: 09 January 2023; Accepted: 08 February 2023; Published: 07 March 2023

ABSTRACT

Background: Radiation treatment 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 body mass index (BMI) on the quality of the 11-field intensity modulated radiation therapy plan for head and neck cancer patients. **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 was utilized to generate an 11F-IMRT plan and was carried out on an ELEKTAMLCi2 linear accelerator. The effect of body mass index 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 target volume was better covered as well as the dose was slightly homogeneous for overweight patients, whereas the conformity of dose distribution significantly improved in normal weight patients (P-value < 0.05). The majority of organs were better spared in the overweight group. For BMI 25 kg/m2, the dose was significantly reduced by 23.6 % and 65.2 % for the brainstem and contralateral optic nerve, respectively (P-value < 0.05). **Conclusion:** Increasing body mass index enhanced the overall plan quality except of conformity of dose distribution in target volume among entire techniques.

Keywords: body mass index; number of monitor units; head and neck cancer; intensity modulated radiation therapy; homogeneity index; conformity index.

INTRODUCTION

Radiotherapy is a treatment technique that utilizes radiation to decimate cancer cells [1]. 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 [2]. Head and neck cancers refer to a group of tumors emerging in the sinuses, nasal cavity, larynx, pharynx, oral cavity, or salivary glands [3]. Radiation treatment technology is rapidly evolving, with image-guided modalities, linear accelerators, and patient immobilization devices constantly being updated. These modern technological devices allow for the decrease of dose to normal tissue structures while permitting the dose to be raised in the tumor and improving the local control rate [4]. Compared to conventional radiation therapy, IMRT protects nearby essential organs more effectively and achieves more conformal dose coverage for the

target volume [5]. Due to the complicated structure of the head and neck anatomy and the closeness of the tumor to critical tissues, IMRT is commonly used [6].

There has been a paucity of research into how BMI affects the efficacy of radiation therapy for obesity in head and neck cancers. According to Yavas et al. (2014), using field-in-field (FIF) and three-dimensional conformal radiotherapy (3D-CRT) radiotherapy plans significantly increased dose homogeneity in target volume and improved OAR protection in obese patients [7]. Furthermore, Boyle et al. (2014) demonstrated that when using brachytherapy for vaginal cancer, some organs at risk, such as the bladder and small bowel, received a lower dose in those with a higher BMI compared to those with a lower BMI [8]. The data of Ishimaru et al. (2014) demonstrated that in prostate cancer, higher BMIs seem to lower doses to the rectum and incidence [9]. The purpose of this study was to determine the effect of body mass index on the 11F-IMRT technique in head and neck cancer treatment.

METHODS AND MATERIALS

Patient Characteristics and plans

The study used CT data sets from 13 patients who had head and neck cancer within the age range of 21 to 69 years at ZCC. Each patient was assigned a clinical identification number (ID) that contained a six-digit number and/or a letter. Table 1 lists the patient details for this study, indicating gender, weight, height, and body mass index (BMI). The average age, weight, height, and body mass index were 48.385±4.559 year, 70.308±5.871 Kg, 1.654±0.023 m, and 25.342±1.542 Kg/m2 respectively.

TABLE 1: Characteristics of the patients

Characteristics		**N (%)**	**Mean±SEM (min-max)**
Tumor location	Head and neck	13 (100)	
Gender	Male	5 (38.5)	
	Female	8 (61.5)	
Age (y)	>60	3 (23.1)	68.000±0.577 (67-69)
	<60	10 (76.9)	42.500±4.398 (21-58)
Weight (Kg)		13 (100)	70.308±5.871 (480-114)
Height (m)		13 (100)	1.654±0.023 (1.540-1.800)
BMI (Kg/m^2)		13 (100)	25.342±1.542 (18.750-35.185)
	> 25	6 (46.2)	30.248±1.587 (25.26-35.185)
	< 25	7 (53.8)	21.136±0.803 (18.75-24.034)

The Monaco TPS v5.51.10 is based on the inverse planning dose calculation and was used to generate all plans for each data set. A large bore Optima CT 580 RT scanner (General Electric Healthcare-USA) had previously acquired the CT data. 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 was 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. All patients were treated with 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 high-risk PTV alone. Table 2 shows the guidelines for PTV and OARs dose volume restrictions at ZCC.

TABLE 2: 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	$1cc \leq 50$ Gy
Brainstem	$D_{max} < 54$ Gy	or	$1cc \leq 60$ Gy
Parotid	$D_{mean} < 26$ Gy	or	$\leq 50\% > 30$ 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: IMRT plans were performed using 11 equally spacing coplanar beams with equal spaces around the target. To prevent conflicting fields, treatment fields with odd numbers were selected, the IMRT plan was to set the beam arrangement. To find the equal angle of beam field, one completed cycle was divided by the number of fields. The beam angle were set up at 32.5°, 65°, 97.5°, 130°, 162.5°, 195°, 227.5°, 260°, 292.5°, 325°, and 357.5°, without collimator rotation. The isocenter of the plan that is defined as the point of beam intersection was positioned at the center of the primary PTV. This was recommended as the ICRU reference point. 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 for dose constraints. The effectiveness of both groups was determined by comparing CI, HI, delivery time per fraction, and MUs. The CI was calculated by (Eq. 1)

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

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

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

$D_{2\%}$ = 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
To screen the weight classification, the body mass index (BMI) was determined based on the weight and height of the patient. The equation (3) was used to determine the BMI [10]:

$$BMI = \frac{Weight}{Height^2} \quad \ldots\ldots\ldots \quad (3)$$

weight and height were measured by Kg and m respectively.
Statistical analysis was carried out by using the Statistical Package for the Social Sciences (SPSS) version 26.0 software program (IBM) Corporation, Armonk, NY, USA. An independent samples t-test was used to assess the statistical significance of the differences between the 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: Following considerable attempts, entire plans were generated according to the planning guidelines. Tumor coverage is a part of the plan quality; adequate PTV coverage was obtained in all plans as presented in Table 3. The average V95% was 97.450±0.568% and 98.238±0.827% respectively, for the normal and overweight group with a P-value > 0.05. The target coverage was slightly better in overweight patients, whereas no significant difference was noticed between the two groups.

TABLE 3. The tumor coverage, CI, HI, MU, and delivery time for normal weight patients and overweight patients

Parameters	Normal weight	Overweight and obese	P-value
$V_{95\%}$ (%)	97.450±0.568	98.238±0.827	0.452
CI	1.453±0.058	1.896±0.161	0.040
HI	0.145±0.010	0.135±0.011	0.481
MUs	973.093±59.210	797.628±74.758	0.096
Time (s)	804.714±30.106	735.000±32.915	0.147

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 the mean conformity index with a standard error of mean for normal weight and overweight patients in the IMRT technique for head and neck cancer. The value of CI was 1.453±0.058 and 1.896±0.161 for normal and overweight patients, respectively. The data indicated that the conformity of dose distribution is superior for patients with normal weight as compared to high BMI patients. The difference was statistically significant between both groups (P-value =0.040). The data showed that the conformity index was improved by reducing the BMI of the patients. The dose distribution for the overweight group was slightly homogenous as compared to normal patients, while the P-values were greater than 0.05. The value of HI was 0.145±0.010 and 0.135±0.011 for normal weight and overweight, respectively. The differences were statistically insignificant with a P-value > 0.05.

3.3 Monitor units (MU) and delivery time

Table 3 shows the average number of MUs and delivery time for the normal weight and overweight patients. The patients with a BMI ≤ 25 Kg/m2 required higher monitor units as compared to the overweight patients. The average MUs was raised by 22% (with a P-value of 0.096). The radiation delivery time was faster for the overweight group. The average delivery time of normal weight was 804.714±30.106 s, while it was 735.000±32.915 s for the overweight group, P-value < 0.05.

3.4 Doses to organs at risk

The radiation doses to nearby OARs were represented in Table 4 for both groups. Dose limits were considered to exclude the dose to parotids and contralateral lens for the normal weight group as well as the ipsilateral eye lens for the healthy group. Increasing body mass index has an important role in reducing the radiation dose to surrounding OARs. The majority of organs were better spared in the overweight group.

The doses to the spinal cord were equal to 42.118±1.762 Gy and 38.496±4.920 Gy for the healthy and overweight groups, respectively (P-value > 0.05). According to the statistical analysis, there was a significant difference between radiation doses to the brainstem organ for both groups; the P-value was equal to 0.048. The dose to both parotids exceeded the tolerance limit in the normal weight group. However, parotids were better preserved in the overweight groups, although the differences were statistically insignificant. The ipsilateral eye lens was more spared in the normal weight group. Conversely, the dose to the contralateral lens was greater in this group as compared to the overweight groups.

The radiation dose to the ipsilateral and contralateral for normal body mass index were (6.664±0.885 Gy and 10.403±3.829 Gy), while these values in the overweight group were (16.524±11.705 Gy and 8.239±1.417 Gy) without statistical significance. In the normal weight group, the doses to the ipsilateral cochlea, contralateral cochlea, ipsilateral optic nerve, and contralateral optic nerve were reduced by 4.1%, 26.7%, 34.7%, and 65.2%, respectively, as compared to overweight patients. The differences only for the contralateral optic nerve were statistically significant (P < 0.05).The calculated dose to optic chiasm was higher in the overweight group as compared to the normal groups, while there was no statistically significant difference between the results due to the high standard error of the mean in normal weight groups and missing data in overweight patients.

TABLE 4. The radiation dose to the OARs for normal weight patients and overweight patients

Organs at risk (OAR)	Average dose (Gy)		P-value
	Normal weight	Overweight and obese	
Spinal cord	42.118±1.762	38.496±4.920	0.513
Brainstem	49.676±1.316	37.963±3.821	0.048
Ipsilateral parotid	28.852±1.605	23.481±2.484	0.104
Contralateral parotid	27.578±1.997	21.509±3.308	0.153
Ipsilateral lens	6.664±0.885	16.524±11.705	0.554
Contralateral lens	10.403±3.829	8.239±1.417	0.626

J Popul Ther Clin Pharmacol Vol 30(2): e350–e356; 07 March 2023.

Ipsilateral cochlea	24.024±3.684	23.037±12.626	0.946
Contralateral cochlea	19.540±2.108	14.318±6.137	0.491
Optic Chiasm	32.602±10.380	50.740±13.054	0.492
Ipsilateral optic nerve	28.455±7.958	18.593±12.787	0.587
Contralateral optic nerve	39.758±8.008	13.846±0.012	0.048

DISCUSSION

In this research, the impact of body mass index on 1F-IMRT was investigated for head and neck cancer. The quality of the entire plan was clinically acceptable for covering tumors and protecting OARs except for the eye lens. Typically, the target volume in the overweight group was better covered by at least 95% of the recommended dose as compared to normal weight patients without statistically significant. The data appears to suggest that the target volume was enhanced by raising the BMI. 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 [11]. The average CI in normal groups was significantly better than that of overweight patients by 23.4%. According to the finding, there was a reversed relationship between the conformity of dose distribution and BMI. The homogeneity index (HI) was used to indicate the homogeneity of the radiation dose in target coverage. With a lower HI, it is possible to obtain a more homogenous and improved dose distribution in tumor [12].

Our findings show that the HI in the target volume was slightly improved in overweight patients as compared to those in the normal weight group. Our outcome was consistent with Yavas et al. (2014) that evaluated the influence of body mass index on field-in-field (FIF) and three-dimensional conformal radiotherapy (3D-CRT) radiotherapy plans for early stage endometrial cancer. The results demonstrated that in obese patients, the dose homogeneity in target volume was significantly increased as well as the OARs were better protected. Distribution of the doses that satisfied the guidelines was possible in this study. In both groups, the dose of OARs was maintained below the dose constraints except of radiation dose to parotid and eye lens. The therapeutic ratio of radiation therapy is based on dose constraint of the organ at risks and target coverage. Protecting the nearby organ at risk while improving target volume coverage was one of the most important aspects of radiotherapy. Increasing body mass index has an important role in reducing the radiation dose to surrounding OARs. The majority of organs were better spared in the overweight group. Boyle et al. (2014) evaluated the influence of BMI on organs at risk protection during brachytherapy for vaginal cancer. They showed that some organ at risks such as bladder and small bowel were received the lower dose in higher BMI as compared to those with a lower BMI, three-dimensional dose evaluation should be considered in patients with low BMI, particularly when combined with external beam radiation. The effect of BMI on gastrointestinal (GI) and genitourinary (GU) toxicity was investigated by Ishimaru et al. (2014) for prostate cancer. In conclusion, higher BMIs seem to lower doses to the rectum and the incidence of GI toxicity while increasing the incidence of GU toxicity in prostate cancer patients who receive radiation therapy. Our finding was in line with previous mentioned studies in terms of sparing the nearby organs at risk.

Calculation of time started 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. Our results demonstrated that the mean value of treatment time and monitor units were reduced with increasing the BMI. The data showed that dose leakage from the linear accelerator and the total body irradiation were reduced by decreasing body mass index of the patients. As a result, the errors associated with target shift in the overweight group was minimized. The body was exposed to low radiation by machine leakage and scattered dose, the possibility of a second cancer was reduced with lower dose exposure to healthy organs [13].

CONCLUSION

The study concluded that the body mass index had affected the IMRT plan quality. Increasing body mass index improved the overall radiotherapy plan except the conformity of dose distribution. There was insufficient research investigating the relationship between body mass index and radiation treatment quality. The current study is the first research that evaluated the influence of BMI on the efficacy of radiotherapy plan in Iraq. In contrast, this research had several shortcomings. First, the small sample size constrained our ability to use multivariable logistic regression models. Second, this was a single-center research, multicenter and large-scale studies are warranted. Occasionally, radiosensitive organs such as the eye lens must be sacrificed in order to preserve the priority organs (brainstem and spinal cord). Lens opacity (cataracts) was one of the radiation-induced effects if the received radiation dose greater than tolerance limit, this drawback can be treated surgically after radiation therapy.

ACKNOWLEDGMENT

The authors are very thankful to the Department of Physics at the Zhianawa Cancer Center (ZCC), Sulaimanyah, Iraq, for their continued support in completing this research work.

Financial disclosure: None declared.

Prior presentations: None

Conflict of interest: The authors have no conflicts of interest.

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Availability of data and materials: On request, the corresponding author will provide access to the data supporting the conclusions of this research.

Ethic approval: This research was authorized by the Ethics Committee of the Hawler Medical University.

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J Popul Ther Clin Pharmacol Vol 30(2): e350–e356; 07 March 2023.