

Differences Among IMRT and 3D-CRT Plans for Patients with Brain Cancer

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Abstract—IMRT is the primary development of 3D-CRT, because it represents a dose distribution to the tumor cell in superior way also sending of highly conformal radiation to irregularly and concave shaped target volume. The purpose of the present study is to compare the dosimetric analysis of two plans of radiotherapy (IMRT) and 3D-CRT, which include target volume and organ at risk for both plans. The present study selected eight patients, seven cases with different types of brain cancer and one case with chordoma cancer, all the cases previously irradiated in Zhianawa Cancer Center. All selected cases were re-planned by both techniques. IMRT planning provides reducing the dose of both right and left optic nerve mean dose for right optic nerve 23.52 Gy and left 22.51 Gy compared with the 3D-CRT plan (right optic nerve 28.06 Gy and left 25.71 Gy). IMRT plan reduces dose of both right and left eye compared to 3D-CRT plan, the mean dose for right eye 17.53 Gy and left 13.71 Gy compared with the 3D-CRT plan (right eye 18.4 Gy and left 16.97 Gy). IMRT plan provided better target cover (PTV95%) (97.33 ± 1.16) for (prescribed dose of 40Gy) than 3D-CRT (96.96 ± 1.83).

Keywords: 3D-CRT, IMRT, PTV, Radiotherapy, Reduce dose.

I. INTRODUCTION

Radiation therapy is vastly used for malignant and benign tumor cells to limit the risk of recurrence and also to improve tumor control (1). The main purpose of radiotherapy (RT) is to send the prescribed dose to the tumor cell and as much as possible protect the organs at risk (OAR). Radiation therapy currently, association with surgery and chemotherapy, is a way to treat different types of tumors (2).

Nowadays, cancer is the main cause of death worldwide (3) With the increase in life expectancy, cancer is expected to be one of the most factor mortality for the future. Nearly 50% of all cancer patients are nowadays treated with external beam radiotherapy using photons (4) (5).

There are more than hundred different types of brain and other central nervous system tumors according to the World Health Organization (6).

The brain tumors are classified primarily depends on their histopathological characteristics or location of the tumor. Initially, brain tumors generated from brain tissues but secondary brain tumors are those that metastasize to numerous positions throughout the brain. Hence, neuropsychiatric symptoms are more often combined with metastatic tumors (7) some patients who have intrinsic primary brain tumor cells might experience cognitive, neurological and psychiatric symptoms that vastly affect their daily life (8).

Metastases to the brain from systemic malignancies are the most common direct of the nervous system part by cancer. It is evaluated that in the United States as many as 200,000 cases of brain metastases (BMs) each year are diagnosed (9). Over the past 20 years, radiotherapy sending has developed from two-dimensional conventional external beam radiation therapy (2D-CRT) to three-dimensional conformal radiation therapy (3D-CRT). The further advance, intensity-modulated radiotherapy (IMRT) uses computed tomography-based planning and sending of radiation, aided by computerized optimization of the intensities of multiple beams. (10)(11). 3D-CRT is one of the techniques of radiotherapy treatment, which depended on three-dimensional (3D) anatomic information and use dose distributions that conform as much

as possible to the planning target volume (PTV) according appropriate dose to the target volume and decrease dose to the surrounding healthy normal tissue as much as possible. (12).

IMRT is the primary development of 3D-CRT, because it represents a dose distribution to the tumor cell in superior way also sending of highly conformal radiation to irregularly and concave shaped target volume (13). opposite to conventional radiotherapy, the intensity-modulated of the radiation beams are sent as a series of many small beams that are modulated by a multileaf collimator (MLC) in a dynamic sweeping manner (sliding window), by using advanced computerized optimization planning (inverse planning)(14).

The objective of the present study is to compare dosimetric analysis of two techniques of radiotherapy IMRT and 3D-CRT, including the volume of target and organ at risk for both techniques.

II. MATERIALS AND METHODS

A. Study design and settings

The data for both techniques IMRT and 3D-CRT was collected in Zhianawa Cancer Center in Sulaymaniyah, during the periods from Jun to August 2019.

B. Patient's selection

Present study selected eight patients, seven cases with different types of brain cancer and one case with chordoma cancer, all the cases previously irradiated in Zhianawa Cancer Center from November 2018 to July 2019. All selected cases were planned again by both techniques.

C. Inclusion criteria:

The present study selected the patients that had one PTV. The prescribed dose was decided by radiation oncologists according to stage, size, position, and tumor type in the patients, the ten patients were divided into four groups according to their prescribed does as following: the prescribed dose of 3000cGy, 3900cGy, 4005cGy, , and chordoma cancer with 6000cGy.

D. Exclusion criteria:

All the other types of cancer were excluded from this study. All the cases with two PTV were also excluded. All the other prescribed doses were excluded.

E. Forward planning (Three-Dimension Conformal Radiotherapy)

The present study used Xio (release 5.00.02) three-dimensional radiotherapy treatment planning system (TPS). The energy used to produce a plan in 3D-CRT for all types of cancer was 6MV photons. Three to four beams were designed for treatment planning. To cover the PTV multileaf collimator was used.

F. Inverse planning (Intensity-Modulated Radiotherapy)

Distribution of dose is inversely determined in IMRT, which that means the treatment planner must decide the dose distribution for each organ at risk and after that, the computer will start to calculate a group of the beam that will be generated (15).

Dose constraints for organ at risk for both plans

Table 2.1: The tolerance doses for organs at risk for both parallel and serial organs.

OAR	Types	Tolerance of dose (Gy)
Eye	Parallel	Mean Dose <35 Gy
Cochlea	Parallel	Mean Dose ≤45 Gy
Lens	Serial	Maximum Dose 7 Gy
Optic Nerve	Serial	Maximum Dose <55 Gy
Brain Stem	Serial	Maximum Dose <54 Gy
Optic Chiasm	Serial	Maximum Dose <55 Gy

G. Evaluation of the treatment planning system:

The gross tumor volume (GTV), the clinical target volumes (CTVs), the planning target volume (PTV), and organs at risk OARs were contoured by the original treating radiation

oncologist, according to the principles of International Commission on Radiation Units and Measurements (ICRU) Report 83(16).

H. Dose-Volume-Histogram (DVH):

The dose-volume-histogram (DVH) is a tool to show the dose (maximum dose, minimum dose and mean dose) that is delivered to organs at risk and target volume (17). Dose-volume histograms are a useful tool used to assess many treatment plan dose distributions and presenting a complete summary of the entire 3-D dose matrix, and showing the amount of target volume or critical organs receiving more than the specified dose (18).

I. Conformity Index:

Conformity index (CI) defines as an attempt to measure exactly how well the distribution of dose follows the shape of target volume, and it is a ratio of the tissue volume which receiving at least 95% of the prescription dose divided by the volume of the planning target volume as shown in equation (1). CI is more conformal when its value closer to 1. (19).

$$CI = V_{95\%}/V_{PTV} \dots\dots\dots \text{Equation (1) (19).}$$

J. Homogeneity Index:

Homogeneity index (HI) is a common tool that uses to analyze dose homogeneity in the tumor volume as shown in equation (2). It is used to compare the dose distributions of many treatment plans (20)(21)(22).

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \dots\dots\dots \text{Equation (2) (23).}$$

Where D2% and D98% represent the doses of the PTV, respectively, D%98 means that at least 98% of the PTV receives this dose, and hence, D%2 means that at least 2% of the PTV receives this dose. D2% considered to be the maximum dose and D98% are considered to be the

minimum dose, lower HI values mean a more homogenous target dose (23).

K. Statistical methods:

Statistical analysis was done by using SPSS version 19 statistical software package. Data described by the mean \pm standard deviation. t-test used to compare the prescribed dose of both techniques, and p-value<0.05 was considered to be statistically significant.

III. RESULTS

Dosimetric analysis and OAR comparison between two techniques with a prescribed dose of 40Gy, which include four patients

As shown in table (2.2) HI and CI were similar for both plans with (p=0.5 and 0.2).

Table 2.2: HI, CI, D 98%, Mean dose and D 2% of 3D-CRT and IMRT for brain tumor patients for PTV of 40Gy.

Dosimetric parameters	Radiation dose by modality		P value
	3D- CRT	IMRT	
HI	0.13 \pm 0.02	0.14 \pm 0.02	0.5
CI	0.96 \pm 0.01	0.97 \pm 0.01	0.2
D 98% (Gy)	37.29 \pm 0.89	37.61 \pm 0.83	0.6
Mean dose (Gy)	40.42 \pm 0.32	40.96 \pm 0.62	0.2
D 2% (Gy)	42.85 \pm 1.12	43.7 \pm 0.83	0.26
PTV Cover	96.96 \pm 1.83	97.33 \pm 1.16	0.74

As shown in figure (2.2) IMRT planning provides reduces dose to both right and left eyes mean dose for (right was 17.53 Gy and left 13.71 Gy) compared with 3D-CRT (right was 18.4 Gy and left 16.97 Gy).

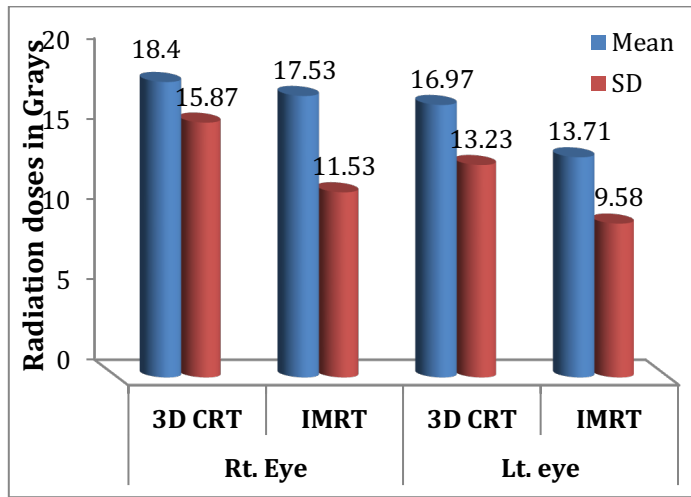


Figure 2.2: Mean and standard deviation of maximum dose for both right and left eyes in IMRT versus 3D-CRT for four patients with brain tumor 40Gy.

In figure (2.3) IMRT planning provides reduces dose to both right and left cochlea mean dose for (right was 9.52 Gy and left 10.57 Gy) compared with 3D-CRT (right was 15.85 Gy and left 16.1 Gy).

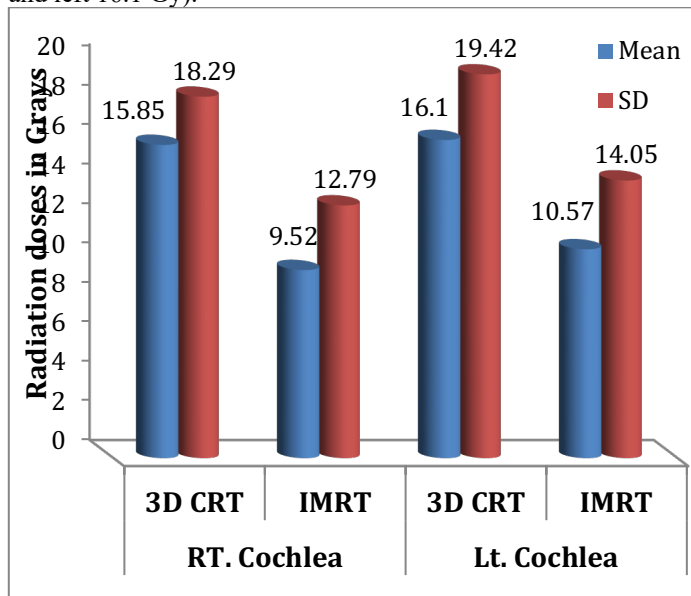


Figure 2.3: Mean and standard deviation of maximum dose for both right and left cochlea in IMRT versus 3D-CRT.

In figure (2.4) 3D-CRT provide reduces of maximum dose for both right and left lens than the IMRT plan.

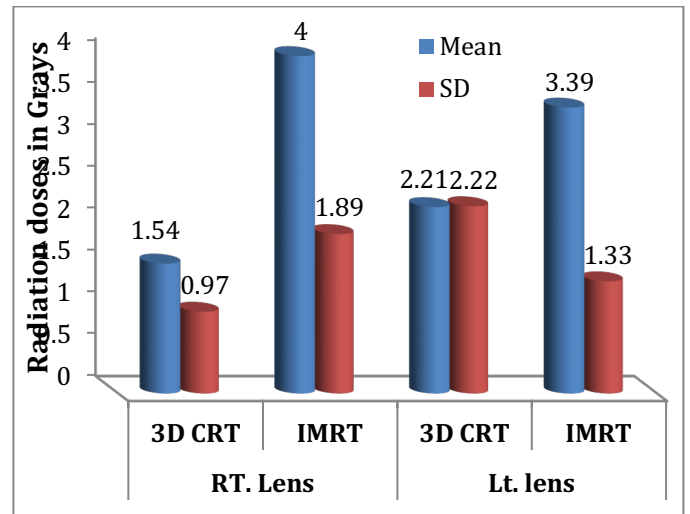


Figure 2.4: Mean and standard deviation of maximum dose for both right and left lenses in IMRT versus 3D-CRT.

In figure (2.5) the IMRT plan delivers a lower dose for both right and left optic nerve than 3D-CRT plan, for the right optic nerve 23.52Gy versus 28.06Gy in 3D-CRT and for left optic nerve 22.51Gy in IMRT versus 25.71Gy in 3D-CRT.

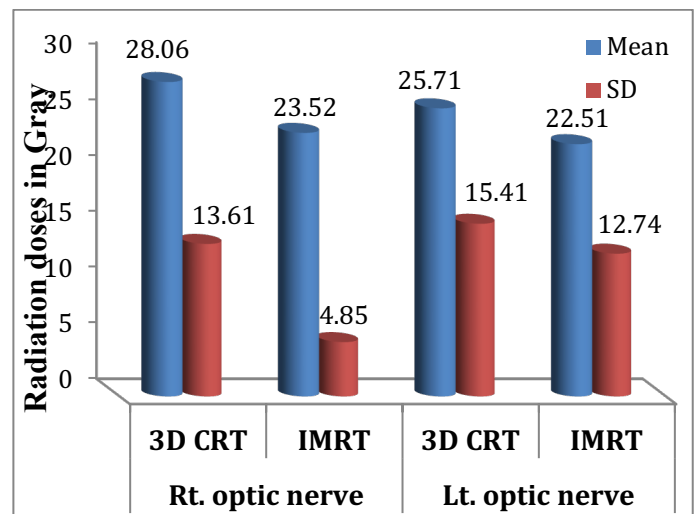


Figure 2.5: Mean and standard deviation of maximum dose for both right and left optic nerve in IMRT versus 3D-CRT.

Dosimetric analysis and OAR comparison between two techniques with prescribed dose of 30Gy, which include two patients

As shown in Table (2.3) homogeneity index and conformity index for both plan was not statistically significant $p=0.1$ and $p=0.77$ respectively.

Table 2.3: HI, CI, D 98%, Mean dose and D 2% of 3D-CRT and IMRT for brain tumor patients for PTV of 30Gy.

Dosimetric parameters	Radiation modality Mean± SD		P value
	3D- CRT	IMRT	
HI	0.1± 0.001	0.14± 0.02	0.1
CI	0.99 ± 0.003	0.96± 0.13	0.77
D 98% (Gy)	28.6± 0.16	27.9± 0.52	0.21
Mean dose (Gy)	30.44 ± 0.08	30.6± 0.14	0.3
D 2% (Gy)	31.68± 0.1	32.32 ± 0.4	0.16
PTV Cover	98.87± 0.32	96.08± 1.35	0.1

As shown in figure 2.6: IMRT plan was better to reduce the dose for the left eye (13.74Gy) than 3D-CRT (16.29Gy).

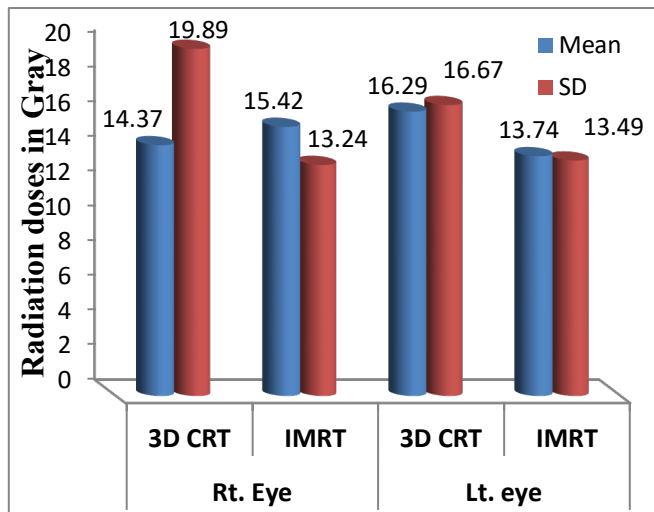


Figure 2.6: Mean and standard deviation for both right and left eyes in 3D-CRT versus IMRT in patients with 30 Gy.

As shown in figure 2.7: both right and left cochlea received a lower dose in 3D-CRT compared with IMRT.

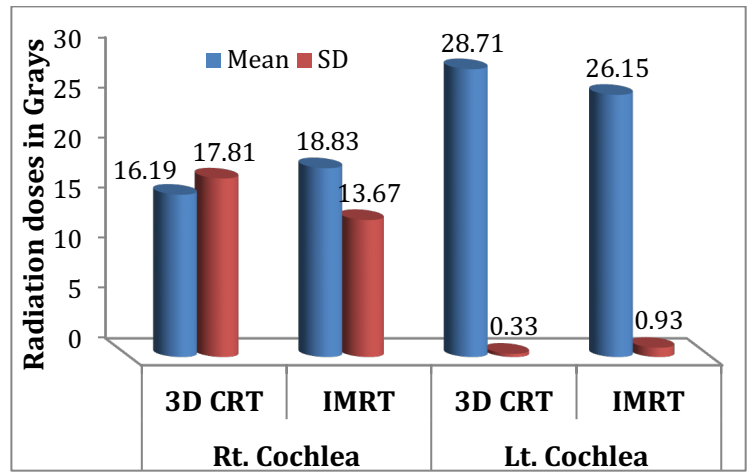


Figure 2.7: Mean and standard deviation for both right and left cochlea in 3D-CRT versus IMRT.

As shown in figure (2.8) both right and left lenses receive a fewer dose in 3D-CRT compared with IMRT.

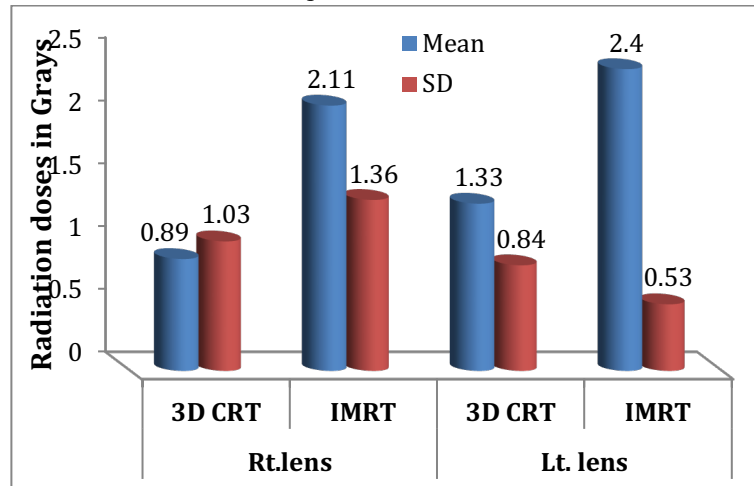


Figure 2.8: Mean and standard deviation for both right and left lenses in 3D-CRT versus IMRT.

As shown in figure (2.9) both right and left optic nerve receives a fewer dose in 3D-CRT compared with IMRT.

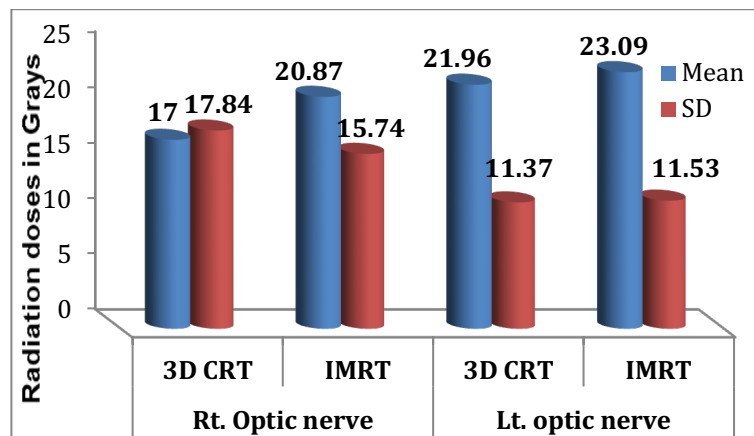


Figure 2.9: Mean and standard deviation for both right and left optic nerve in 3D-CRT versus IMRT.

Dosimetric analysis and OAR comparison between two techniques with the prescribed dose of 39Gy, which include one patient

As shown in table (2.4) the conformity index was superior in the IMRT plan than 3D-CRT. However, coverage of PTV in IMRT (99.86%) was better than 3D-CRT (98.32%).

Table 2.4: HI, CI, mean dose and PTV cover of 3D-CRT and IMRT for brain tumor patient for PTV of 39Gy.

Dosimetric parameters	Radiation dose by modality	
	3D- CRT	IMRT
HI	0.10	0.10
CI	0.98	1.00
Mean dose (Gy)	39.57	39.63
PTV cover	98.32%	99.86%

As shown in table 2.5: both right and left cochlea in IMRT (right cochlea=37.99Gy and left 10.01Gy) was better than 3D-CRT (right 40.38Gy and left 41.36Gy).

Table2.5: Maximum dose delivered to the OAR for both plans.

OAR	3D-CRT/ Gy	IMRT/ Gy
Right eye	1.38	9.07
Right Cochlea	40.38	37.99
Right lens	0.64	2.84
Right optic nerve	18.87	35.37
Optic chiasm	40.02	41.55
Left eye	1.41	10.01
Left Cochlea	41.36	10.01
Left lens	0.61	3.02
Left optic nerve	17.04	36.10

Dosimetric analysis and OAR comparison between two techniques with the prescribed dose of 60Gy, which include one patient

As shown in table 2.6. PTV cover in 3D-CRT was better than in IMRT.

Table 2.6: HI, CI, mean dose and PTV cover of 3D-CRT and IMRT for chordoma tumor patient for PTV of 60Gy.

Dosimetric parameters	Radiation dose by modality	
	3D- CRT	IMRT
HI	0.08	0.23
CI	0.98	0.92
Mean dose (Gy)	60.08	60.93
PTV cover	97.80%	91.77%

As shown in table 2.7: both right and left cochlea in the IMRT plan was better than 3D-CRT, and also both right and left optic nerve in the IMRT provides a lower dose than in 3D-CRT.

Table 2.7: Maximum dose delivered to OAR for both plan for chordoma tumor of 60 Gy.

OAR	3D-CRT/ Gy	IMRT/ Gy
Right eye	23.35	42.25
Right Cochlea	58.92	49.81
Right lens	1.26	12.81
Right optic nerve	57.94	51.18
Brain stem	59.70	57.69
Left eye	23.49	23.81
Left Cochlea	60.16	39.93
Left lens	1.11	7.70
Left optic nerve	57.49	42.16

IV. DISCUSSION

various studies were compared 3D-CRT plan versus IMRT plan for many different types of cancer to achieve which plan is better according to cover of planning target volume, conformity index, homogeneity index and sparing maximum dose delivered to various organ at risk that is surrounding the target tumor.

IMRT plan provided better target cover (PTV95%) (97.33± 1.16) for (prescribed dose of 40Gy) than 3D-CRT (96.96±1.83), this result was similar with study done by Al

Zayat et al, 2014, in Egypt they selected twelve patients in compared the IMRT and 3D-CRT techniques in patients treated with different diagnosis brain tumor. Prescription dose and normal-tissue constraints were identical for both plans. Showed that the mean and standard deviation value of PTV (PTV 95%) in IMRT was 96.56 ± 1.67 while, for 3D-CRT was 95.58 ± 1.24 respectively(24).

Also, another study was done by Lorentini et al, 2013 which selected seventeen previously irradiated patients who had glioblastoma (GBM) were retrieved and re-planned with both 3D-CRT and IMRT. Their result was that IMRT and 3D-CRT achieved comparable results in terms of dose homogeneity and conformity (25) this result was similar with present study for prescribed dose 30Gy the homogeneity index and conformity index for both plan was not statistically significant $p= 0.1$ and $p=0.77$ respectively. However, IMRT provided better target coverage (PTV95%) than 3D-CRT. MacDonald et al, 2007; Zach et al, 2009 highlighted no differences in terms of PTV V95% (26)(27). At the same time, in their comparative dosimetric study Wagner et al, 2009 and Thilmann et al, 2001, pointed out that IMRT achieved better target coverage with respect to 3D-CRT, scoring a V95% improvement of 13.5 and 13.1%, respectively(28)(29). This advantage was much more significant when PTV was in proximity of OARs (28).

3DCRT plans were performed using two or three treatment fields with wedges incomparable with the IMRT plans which performed with five fields, this small number of the treatment fields given advantages to the 3D conformal technique where this will make small low-dose areas, less monitor units and short treatment time. This is important because low-dose areas are suspected to induce secondary cancer as late toxicity and smaller number of monitor units implicates less scattered radiation(30)(31)(32).

For a prescribed dose of 40Gy both right and left cochlea received lower dose in IMRT (right cochlea= 9.52 ± 12.79) (left cochlea= 10.57 ± 14.05) compared with 3D-CRT (right cochlea= 15.85 ± 18.29) (left cochlea= 16.1 ± 19.42) also for a prescribed dose of 39Gy both cochlea showed reduce

received dose from IMRT than 3DCRT. however, for both right and left lenses IMRT was slightly higher than 3D-CRT, this result was similar with result that done by Gupta et al, 2017 they found that IMRT plan provided reduced mean dose to cochlea (right 10.4 Gy and left 10.9 Gy) relative to the 3DCRT plans (right 15.5 Gy and left 15.8 Gy) with $P = 0.032$ for the right cochlea and 0.02 for the left cochlea. IMRT plans showed slightly increased lens doses relative to 3D-CRT (33).

3D-CRT plan provided better target cover (PTV95%) (97.80%) for (prescribed dose of 60Gy) than IMRT (91.77%). Both plans were not statistically significant because of the rare samples of brain cancer.

CONCLUSIONS

PTV%95 cover and the conformity index for the 3D-CRT plan and the IMRT plan were similar. IMRT plan provides reduce the dose delivered to the various organs at risk than 3D-CRT especially for both optic nerve and both eye.

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