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Research Article

Dosimetric Comparison of 3D-Conformal and IMRT Techniques used in Radiotherapy of Gastric Cancer: A Retrospective Study

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Abstract:

This study aimed to compare three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated radiotherapy (IMRT) planning techniques commonly used in gastric cancer radiotherapy with dose volume histograms. Computed tomography (CT) images of 20 gastric cancer patients were retrospectively analyzed. 3D-CRT, 5F- IMRT and 7F-IMRT treatment plans were created for each patient. The 3 plans were compared on dose volume histogram (DVH). 3D-CRT, 5F-IMRT and 7F-IMRT plans achieved a prescribed dose of 45 Gy for 95% of PTV volume. D_{95} values were 45.06±0.47 Gy for 3D-CRT, 46.39±0.38 Gy for 5F-IMRT and 45.20±0.11 Gy for 7F-IMRT. In 3D-CRT, 5F-IMRT and 7F-IMRT techniques, the 13 Gy receiving volumes of the right kidney were found to be 35.08+9.59, 36.25+7.97 and 37.03+9.03 respectively. Moreover, the volume of the right kidney receiving a 20 Gy and 30 Gy dose received less dose with 5F-IMRT than with 7F-IMRT. Since each patient's critical organs are at different distances from the target and each technique has its own advantages in terms of critical organs, we suggest that the useful technique should be decided by clinical consensus.

1. Introduction

Stomach cancer is the fifth most common disease in the world, with more than one million new cases occurring each year [1-3]. The main treatment method for stomach cancer is surgery. Since chemotherapy increases the response of tumor cells to radiation, simultaneous application of chemoradiotherapy is thought to be better according to radiotherapy alone [4,5]. By adding radiotherapy (RT) and chemotherapy to surgery, better results were achieved in terms of local recurrence and survival [6-8]. Adjuvant radiotherapy administered with concurrent chemotherapy is recommended for patients with stomach cancer [9]. In stomach cancers, the most important prognostic factor is the extent of the tumor. Among these, known prognostic factors include the number of involved lymph nodes, age, grade, histological type, diffuse type, and Lymphovascular invasion (LVI) [10]. As developments in the field of RT increased, clinical results and side effect evaluations began to be made according to the chosen technique. The planning target volume (PTV) is generally large in stomach cancers [11]. The stomach is surrounded by critical organs such as the liver, kidneys, heart and spinal cord [12]. With the development of radiotherapy application techniques, various planning techniques have begun to be applied to further reduce late complications [13-16]. Classically, the application of adjuvant radiotherapy has traditionally been carried out using two-dimensional (2D) or three-dimensional conformal RT (3D-CRT). However, there exists a distinction between intensity-modulated radiotherapy (IMRT) and 3D planning in terms of the administration of radiation dose, whereby the former allows for the delivery of treatment through the division of a treatment field into multiple fields of varying shapes. The National Comprehensive Cancer Network Guidelines have acknowledged that IMRT surpasses 3D-CRT in terms of tumor coverage, the probability of tumor control, and the reduction in risk to certain organs (OARs). Consequently, when considering the target tissue and critical organs, it is imperative to select highly conformal treatment methods, such as IMRT, volumetrically modulated arc therapy (VMAT), and helical tomotherapy (HT), for use in gastric cancer radiotherapy [17-19].

This study aimed to compare 3D-CRT and IMRT planning techniques commonly used in gastric cancer radiotherapy with dose volume histograms.

2. Material and Methods

2.1. Patient Selection

Twenty individuals diagnosed with gastric cancer through pathological examination were chosen as the subjects of this retrospective investigation. Among these individuals, 13 were of the male gender, while the remaining 7 were of the female gender. The age of the participants varied between 43 and 62 years, with an average age of 50 years. All patients were taken for computed tomography (CT) in the supine position with both arms raised over the wings towards the head. Computed tomography (Siemens Emotion Duo, Germany) was performed with a slice thickness of 3 mm. The acquired images were transferred via Digital Imaging and Communications in Medicine (DICOM) to the Eclipse treatment planning system (TPS) (Eclipse, version 8.9.08, Varian Medical System, Palo Alto, CA, USA).

2.2. Target Volume and Organ Delineations

Clinical target volume (CTV), PTV and critical organs were defined by a radiation oncologist. CTV has obtained microscopic disease and lymph nodes according to clinical protocol. PTV was created by adding 10 mm margin to CTV isotropically. Kidneys, liver and spinal cord were defined as OARs.

2.3. Treatment Planning

In this study, 3D-CRT, 5F-IMRT (five-field IMRT) and 7F-IMRT(seven-field IMRT) plans were made for all patients. The plans were made using Eclipse TPS which is used for Siemens Primus Plus (Siemens, Germany) linear accelerator. 18 MV photon energies were used in 3D-CRT plans and 6 MV photon energies were used in IMRT plans. Plans were made to deliver 45 Gy from 1.8 Gy fractions to the PTV in 25 fractions. While planning, it was ensured that 95% of the target received 100% of the dose. On the other hand, non-pass criteria were taken into consideration such as the average dose of each kidney should be below 18 Gy the volume receiving the 20 Gy dose should not exceed 30%, the liver's volume receiving 30 Gy should not exceed 30% and average doses should be below 30 Gy and finally, the spinal cord dose should not exceed 45 Gy.

Four field box techniques were used in 3D-CRT plans and treatment angles were selected as 0^0, 90^0, 180^0 and 270^0 degrees. The center of PTV was selected as an isocenter. Multi-leaf collimator (MLC) used for PTV coverage with 5 mm auto margin and verified MLCs according to OARs positions. 3D-CRT field weights were given considering appropriate PTV and critical organ doses. Gantry angles of 15^0, 60^0, 95^0, 175^0 and 315^0 were selected in the 5F-IMRT plans, and 0^0, 15^0, 60^0, 95^0, 175^0, 265^0 and 310^0 gantry angles were selected in the 7F-IMRT plans. The plans required to reach the targeted doses were normalised.

2.4. Comparison of Plannings

In this study dose volume histograms (DVH) were obtained for all 3D-CRT, 5F-IMRT and 7F-IMRT plans. For target tissue PTV, doses taking up 95% of the volume (D_{95}) and mean doses (D_{mean}) were compared for the three techniques. The homogeneity index (HI) and conformity index (CI) of the plans were calculated by the formula below according to the recommendation of the Radiation Therapy Oncology Group (RTOG) and compared[1].

$$\text{Homogeneity index} = \frac{Imax}{RI}$$

Imax : Maximum dose in the target

RI : Reference isodose

$$\text{Conformity index} = \frac{V_{RI}}{TV}$$

V_{RI} : Volume of reference isodose

TV : Target volume

Also the max and mean dose of the spinal cord; mean dose and volume receiving dose of 30 and 40 Gy of the liver; mean dose and volume receiving dose of 13, 20 and 30 Gy of each kidney were compared.

2.5. Statistical Analysis

Statistical Package for Social Sciences (SPSS) v.25.0 was used for statistics (SPSS Inc. Chicago, II. USA). Anova test was used to compare the PTV, kidneys, liver and spinal cord among the desired parameters of the three plans. A P value less than 0.05 was calculated as significant.

3. Results and Discussions

The dose distribution of a patient for three plans in transverse, sagittal and coronal space is shown in Figure 1. and the DVH plan of a patient for three techniques is shown in Figure 2.

The dosimetric results for PTV, CI and HI are summarised in Table 1. 3D-CRT, 5F-IMRT and 7F-IMRT plans achieved a prescribed dose of 45 Gy for 95% of PTV volume. D_{95} values were 45.06±0.47 Gy for 3D-CRT, 46.39±0.38 Gy for 5F-IMRT and 45.20±0.11 Gy for 7F-IMRT. The D_{95} of the 5F-IMRT get more dose than other techniques significantly. For the mean dose of PTV all results were close to each other. CI for IMRT plans is significantly superior according to 3D-CRT but very close to each other for IMRT techniques. But despite of close values HI for each techniques, 3D-CRT plans are significantly superior according to IMRT techniques.

Table 1. *Dose statistic comparison for planning target volume*

Parameters		3D-CRT	5F-IMRT	7F-IMRT	*p*
PTV	D_{95}	45.06	46.39	45.20	<0.001
PTV	D_{mean}	46.6	46.52	46.62	0.503
CI		1.58	1.30	1.29	0.000
HI		1.08	1.09	1.09	0.029

The dosimetric results for OARs are summarised in Table 2 and a comparison of statistical significance for PTV and OARs is shown in Table 3. In 3D-CRT, 5F-IMRT and 7F-IMRT techniques, the 13 Gy receiving volumes of the right kidney were found to be 35.08+9.59, 36.25+7.97 and 37.03+9.03 respectively. For right kidney volume receiving a 20 Gy and 30 Gy dose, 5F-IMRT received significantly less dose than 3D-CRT. Moreover, the volume of the right kidney receiving a 20 Gy and 30 Gy dose received less dose with 5F-IMRT than with 7F-IMRT. Regarding the average dose received by the right kidney for the 3 techniques, it received the lowest dose in the 3D-CRT technique, the highest dose in the 7F-IMRT technique, and the highest dose in the 5F-IMRT technique. Although the volumes receiving 13 Gy for the left kidney were close to each other among the three techniques, they had the lowest value with the 7F-IMRT technique. For the left kidney, the lowest value in the volume receiving a dose of 20 Gy was reached with the 7F-IMRT technique, while the highest volume was reached with the 3D-CRT technique. For the volume receiving a dose of 30 Gy, the lowest value was obtained with the 5F-IMRT technique, while the highest value was obtained with the 7F-IMRT technique. The average dose value for the left kidney was lower in the 3D-CRT technique compared to both 5F-IMRT and 7F-IMRT techniques. Liver volumes receiving 30 Gy dose were found as 7F-IMRT, 5F-IMRT and 3D-CRT, respectively, from low to high and 5F-IMRT and 7F-IMRT techniques were better than the 3D-CRT technique. The lowest value in liver volume receiving a dose of 40 Gy was reached with the 5F-IMRT technique, while the highest value was found with the 7F-IMRT technique. As for the average dose to the liver, the 5F-IMRT technique and the 7F-IMRT technique were significantly lower than the 3D-CRT technique, and 5F-IMRT was also lower than the 7F-IMRT technique. The highest average maximum dose to the spinal cord was reached with the 5F-IMRT technique, with a value of 34.47±2.22 Gy, while the lowest value, with a value of 30.50±4.91 Gy, was reached with the 3D-CRT technique. As for the average doses of the spinal cord, they were found to be quite close to each other for all three techniques.

Table 2. *Dose distribution parameters for OARs*

Parameters		3D-CRT	5F-IMRT	7F-IMRT	*p*
RT Kidney	V_{13}	35.08	36.25	37.03	0.886
	V_{20}	24.08	13.91	16.65	0.021
	V_{30}	8.47	4.11	4.88	0.068
	D_{mean}	11.80	12.91	12.77	0.525
LT Kidney	V_{13}	38.46	38.95	37.15	0.890
	V_{20}	28.42	26.02	24.32	0.506
	V_{30}	9.55	8.94	9.76	0.915
	D_{mean}	12.64	14.65	13.80	0.114
Liver	V_{30}	28.72	23.18	21.98	0.068
	V_{40}	17.38	12.85	21.98	0.036
	D_{mean}	26.23	20.02	21.66	<0.001
Spinal cord	D_{max}	30.50	34.47	33.60	0.036
	D_{mean}	13.35	13.35	13.48	0.992

Table 3. *Comparison of statistical significance for PTV and OARs*

Parameters		3D-CRT vs 5F-IMRT	3D-CRT vs 7F-IMRT	5F-IMRT vs 7F-IMRT
PTV	D_{95}	0.000	0.695	0.000
RT Kidney	D_{mean}	0.525	0.988	0.617
	V_{13}	0.953	0.876	0.979
	V_{20}	0.020	0.105	0.718
LT Kidney	V_{30}	0.076	0.164	0.915
	D_{mean}	0.550	0.631	0.990
	V_{13}	0.991	0.938	0.886
	V_{20}	0.772	0.477	0.878
Liver	V_{30}	0.951	0.994	0.913
	D_{mean}	0.096	0.433	0.639
	V_{30}	0.165	0.075	0.913
	V_{40}	0.076	0.052	0.982
	D_{mean}	0.000	0.000	0.220

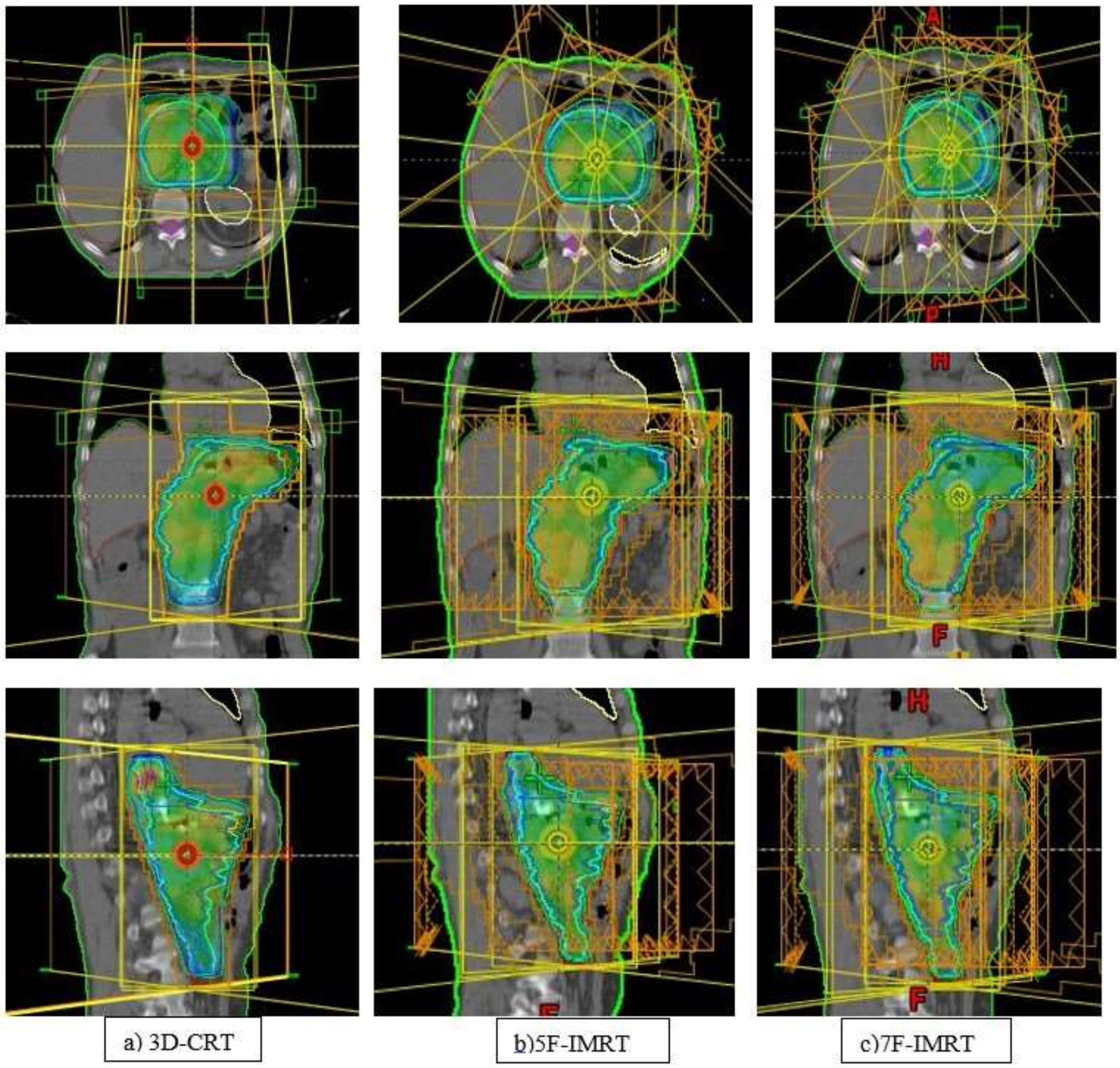

Figure 1. *Dose distribution of a: 3D-CRT, b: 5F IMRT and c: 7F IMRT*

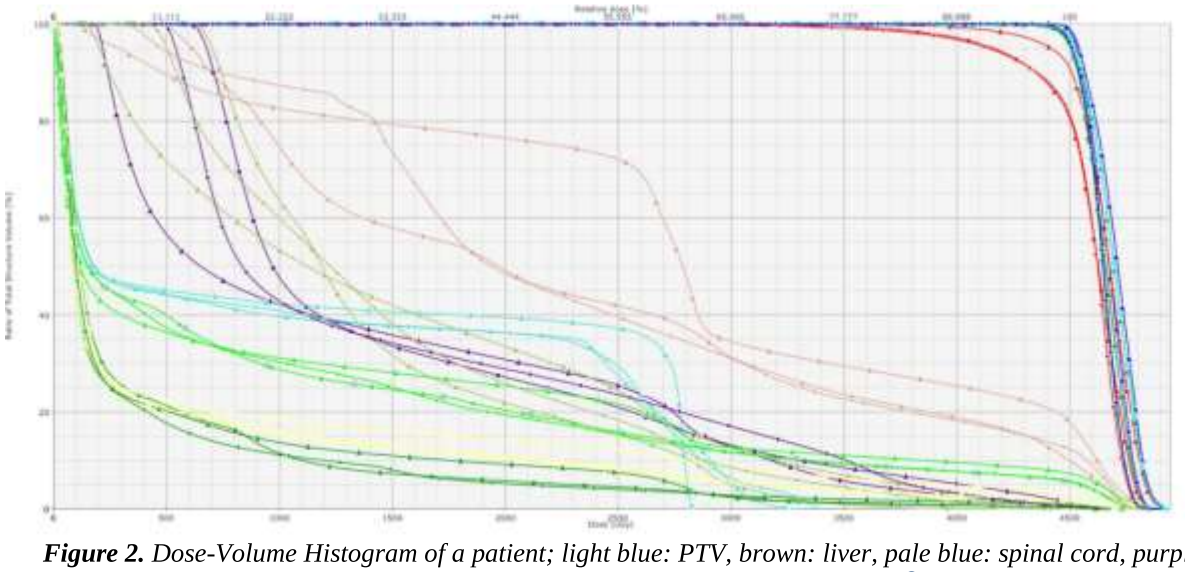

Figure 2. *Dose-Volume Histogram of a patient; light blue: PTV, brown: liver, pale blue: spinal cord, purple: left kidney, chartreuse: light kidney, ▬ : 3D-CRT, ▲:5F-IMRT, ⬮ : 7F-IMRT*

In our study, we dosimetrically compared the 3D-CRT treatment technique, which is routinely used in gastric cancer radiotherapy, with IMRT treatment techniques, which is a newer and more frequently used approach. Many studies show that IMRT has better dose distribution in the target area and better CI and HI values[20,21]. While better dose conformity is achieved in IMRT techniques despite longer treatment times, their superiorities differ among themselves and over the 3D-CRT technique in critical organ doses. Despite of superiority of IMRT in too many cancer treatment areas, IMRT is still an issue of controversy in gastric cancer [22]. The dose received by 95% of the PTV volume received the full dose defined for 3D-CRT, 5F-IMRT and 7F-IMRT techniques. In critical organs, all three plans have advantages over each other for different values. Hong et al. compared field 3D-CRT, 5F-IMRT and 7F-IMRT plans for gastric cancer [22]. They found that 95% of PTV was not under the 45 Gy dose we found. Also, similar to us, they found that the dose conformity in PTV was superior to IMRT techniques. They found spinal cord Dmax was 35.2±1.6 Gy for the 3D-CRT technique and we found 30.50±4.91 Gy with the same technique. Both values were below the tolerable dose. While they found a lower value in the 3D-CRT technique than the IMRT technique in the 30 Gy volume and mean dose of the liver, in our study, IMRT gave better results than 3D-CRT for both parameters. One of the important organs is the kidney for gastric irradiation. In terms of kidneys, the 5F-IMRT technique was lower than the 3D-CRT technique and 7F-IMRT for the volume receiving a 20 Gy dose but they noted no significance statistically. We reached the lowest value for the volume receiving the same dose with 7F-IMRT in the right kidney and 5F-IMRT in the left kidney. So, while we achieved better results with renal IMRT, they achieved better results with 3D-CRT.

Inan et al. evaluated the dosimetric advantages of 3D-CRT, physical wedge-based CRT (WB-CRT) and IMRT technique for gastric cancer. They found similar PTV coverage in all treatment techniques but the IMRT technique was better at protecting the kidney, liver and spinal cord according to 3D-CRT [23]. In our study, 3D-CRT had better results according to other IMRT techniques for both kidney mean doses but for the mean dose of liver, IMRT had better sparing according to 3D-CRT. We found that in the IMRT techniques, as they found, the spinal cord received less dose in terms of mean doses compared to the 3D-CRT technique.

Cakir et al. compare 3D-CRT and IMRT techniques for gastric cancer [24]. They found that the IMRT technique was more advantageous than the 3D-CRT technique in terms of kidneys V20, maximum dose of the spinal cord and mean dose of the liver. These results were in agreement with our study.

Kudret et al. compare critical organs with IMRT and 3D-CRT techniques for gastric radiotherapy. They found no significant difference between the two techniques for the 95% isodose of PTV but CI and HI had superior values in the IMRT technique according to 3D-CRT [25]. In our study, we found that CI was superior in the IMRT technique than the 3D-CRT technique but for HI 3D-CRT was superior to the IMRT technique. They found that all liver dose values were superior in IMRT than the 3D-CRT technique. These results parallel our study except for V40 values. While the V40 value was lower in the 5F-IMRT technique than in the 3D-CRT technique, the dose was higher in the 7F-IMRT technique than in 3D-CRT.

4. Conclusions

In gastric radiotherapy, it is very important to spare organs very close to the target volume tissue to prevent complications and to ensure that the target tissue receives the desired dose. In our study, we dosimetrically compared 3D-CRT, 5-field and 7-field IMRT radiotherapy application techniques for gastric cancer patients. While IMRT techniques are significantly superior to 3D-CRT in terms of dose confirmation, each technique has shown different advantages in terms of critical organs. While the V20 value for the right kidney was achieved with the 5F-IMRT technique, the best result for the left kidney at the same value was achieved with the 7F-IMRT technique. However, for average kidney doses, the 3D-CRT technique gave the best results in both kidneys. At average doses to the liver, the IMRT technique was statistically significantly better. However, larger study groups are required to evolve our conclusions to more reliable results Moreover, since the IMRT technique has a longer treatment time than the 3D-CRT technique, every patient had different neighbouring to the target, selected gantries, each patient's critical organs are at different distances from the target and each technique has advantages over each other in terms of critical organs, we offer that useful technique must be decided with clinical consensus.

Author Statements:

- **Ethical approval:** Necmettin Erbakan University Faculty of Medicine gave ethics committee approval for this study. (2024/4746).
- **Conflict of interest:** The authors declare that they have no known competing financial interests

or personal relationships that could have appeared to influence the work reported in this paper

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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