RESEARCH PAPER

Dosimetric Comparison of Three-Dimensional Conformal Radiotherapy and Intensity-Modulated Radiotherapy for Gastric and Gastroesophageal Junction Cancers: A Paired Planning Study

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ABSTRACT

Background: Radiotherapy for gastric and gastroesophageal junction (GEJ) cancers is technically challenging because of complex upper abdominal anatomy and the proximity of critical organs at risk (OARs). This study aimed to perform a paired dosimetric comparison between three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated radiotherapy (IMRT) in patients with gastric and GEJ cancers. Methods: This retrospective dosimetric planning study included 45 patients with histologically confirmed, non-metastatic gastric or GEJ adenocarcinoma. For each patient, two independent radiotherapy plans were generated on the same computed tomography (CT) dataset: a conventional four-field 3D-CRT plan and a seven-field coplanar IMRT plan. Both techniques prescribed a total dose of 45 Gy delivered in 25 fractions. Dose–volume histogram (DVH) analysis was used to evaluate planning target volume (PTV) coverage and doses to OARs, including the liver, kidneys, and spinal cord. Results: Both techniques achieved adequate PTV coverage. IMRT demonstrated significantly superior dose conformity compared with 3D-CRT (conformity index: 1.29 vs. 1.58; $p < 0.001$). In contrast, 3D-CRT showed slightly better dose homogeneity (homogeneity index: 1.08 vs. 1.09; $p = 0.029$). IMRT resulted in a significantly lower mean liver dose (21.66 Gy vs. 26.23 Gy; $p < 0.001$). Renal dosimetric parameters showed technique-dependent variations without statistically significant differences. The maximum spinal cord dose was significantly lower with 3D-CRT (30.50 Gy vs. 33.60 Gy; $p = 0.036$). Conclusion: Both 3D-CRT and IMRT provide acceptable target coverage for gastric and GEJ cancers, with complementary advantages. IMRT offers superior conformity and improved liver sparing, whereas 3D-CRT provides better dose homogeneity and lower spinal cord dose. Radiotherapy technique selection should therefore be individualized based on tumor location, patient anatomy, and OAR priorities.

Keywords:

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INTRODUCTION

Gastric cancer remains a major global health challenge and is among the most frequently diagnosed malignancies and leading causes of cancer-related mortality worldwide. It ranks as the fifth most common cancer globally, with more than one million new cases diagnosed annually, imposing a substantial burden on healthcare systems across both developed and developing regions [1–3]. Cancers arising at the gastroesophageal junction (GEJ) share several biological, anatomical, and therapeutic characteristics with gastric cancer and are often managed using similar multimodality treatment strategies.

Current standards of care for resectable gastric cancer include postoperative chemoradiotherapy, perioperative chemotherapy, or postoperative chemotherapy, based on the results of phase III randomized trials. Although these approaches improve disease-related outcomes compared with surgery alone, they are associated with increased treatment-related morbidity. Notably, only 64% of patients in the Intergroup-0116 trial and 42% of patients in the Medical Research Council Adjuvant Gastric Infusional

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Chemotherapy (MAGIC) trial were able to complete the prescribed treatment courses [4–6].

Preoperative chemoradiotherapy has become a standard approach in other gastrointestinal malignancies, such as esophageal and rectal cancers, demonstrating improved local control and survival outcomes [5,6]. However, radiotherapy delivery in gastric and GEJ cancers remains technically demanding because of the complex anatomy of the upper abdomen. The target volume, which includes the primary tumor and regional lymphatic drainage, is closely surrounded by several critical OARs, including the liver, kidneys, spinal cord, and small bowel. Excessive irradiation of these structures may result in clinically significant toxicities, such as radiation-induced liver disease, renal dysfunction, myelopathy, and gastrointestinal complications, potentially compromising treatment tolerability and quality of life [7].

3D-CRT has long been used as a standard technique for the treatment of gastric and GEJ cancers. By using a limited number of fixed fields shaped with multileaf collimators, 3D-CRT provides acceptable target coverage with relative simplicity and reproducibility [8]. However, its ability to achieve highly conformal dose distributions is limited, particularly for irregular target volumes adjacent to radiosensitive organs.

IMRT represents a significant technological advancement, utilizing inverse planning and intensity modulation across multiple coplanar fields to achieve improved dose sculpting. This allows for steeper dose gradients between the target and adjacent OARs, potentially improving the therapeutic ratio [9,10]. Consequently, contemporary guidelines, including those from the National Comprehensive Cancer Network, recommend IMRT when dose constraints cannot be adequately achieved using conventional techniques [11].

Despite these recommendations, the optimal role of IMRT in gastric and GEJ cancers remains debated. While several dosimetric and clinical studies have reported improved OAR sparing and reduced toxicity with IMRT, other studies have demonstrated comparable or organ-specific advantages with 3D-CRT [12–15]. These conflicting data underscore the need for direct paired dosimetric comparisons using identical patient datasets. The present study was therefore designed to comprehensively compare 3D-CRT and IMRT in patients with gastric and GEJ cancers and to clarify the relative advantages of each technique.

MATERIALS AND METHODS

Patient Selection and Simulation

This retrospective planning study was conducted following approval from the institutional ethics committee. This study included 45 patients who presented to National Cancer Institute, radiotherapy department in the period from 2020 to 2024 after they have been diagnosed with non-metastatic gastric cancers and GEJ adenocarcinoma (Only Siewert type II/III) and meeting the inclusion criteria (clinical stages T3–T4, N0–N2, M0). The cohort comprised 40 male and 5 female patients, with a mean age of 55.09 ± 7.55 years (range: 40 – 70 years). Patients with distant metastases or prior abdominal radiotherapy were excluded.

All patients underwent CT simulation in the supine position under free-breathing conditions using a Siemens Emotion Duo CT scanner (Siemens Healthineers, Germany). Images were acquired with a slice thickness of 3 mm. Patients were immobilized using a custom immobilization device, with arms positioned above the head. Intravenous and oral contrast agents were administered to enhance visualization of the stomach, GEJ, and surrounding structures. CT images were transferred to the Eclipse treatment planning system (version 8.9.08; Varian Medical Systems, Palo Alto, CA, USA).

Target Volume and Organ-at-Risk Delineation

Target and OAR delineation was performed by a single experienced radiation oncologist to ensure consistency. The gross tumor volume encompassed the primary gastric or GEJ tumor as defined by endoscopic findings and radiological imaging. The clinical target volume included the gross tumor volume with appropriate margins and the relevant regional lymphatic drainage areas, including the perigastric, celiac axis, and porta hepatis lymph node regions, in accordance with institutional and international guidelines.

A uniform isotropic margin of 10 mm was added to the clinical target volume to generate the planning target volume, accounting for setup uncertainties and internal organ motion.

Organs at risk were contoured according to Radiation Therapy Oncology Group guidelines and included the liver, bilateral kidneys, spinal cord, and small bowel. The small bowel was delineated as a bowel bag encompassing all potentially mobile bowel loops within the peritoneal cavity.

Treatment Planning Techniques

For each patient, two independent radiotherapy plans were generated on the same CT dataset.

3D-CRT: A conventional four-field box technique was employed using gantry angles of 0°, 90°, 180°, and 270°. An 18-MV photon beam was used. Multileaf collimators were applied to conform each field to the PTV projection with a 5-mm margin. Field-in-field techniques were utilized to improve dose homogeneity, and beam weights were manually optimized.

IMRT: A seven-field coplanar step-and-shoot using 6-MV photon beams. Gantry angles were selected to minimize direct irradiation of critical OARs. Inverse planning optimization was performed using predefined dose–volume objectives for the PTV and all OARs.

Both plans were normalized such that 95% of the PTV received 100% of the prescribed dose. Dose constraints were based on QUANTEC recommendations, including kidney mean dose < 18 Gy and V20 < 30%, liver mean dose < 30 Gy and V30 < 30%, and spinal cord maximum dose < 45 Gy.

Dosimetric Evaluation and Statistical Analysis

Dose–volume histogram analysis was used to extract dosimetric parameters. For the PTV, D95, mean dose,

homogeneity index (defined as Dmax/Dmin), and conformity index (defined as the ratio of the volume receiving at least 95% of the prescribed dose to the PTV volume) were evaluated. For OARs, mean doses and dose–volume parameters were recorded for the kidneys and liver, while maximum and mean doses were assessed for the spinal cord.

Statistical comparisons between the two techniques were performed using paired sample t-tests. A p-value < 0.05 was considered statistically significant.

Results

Planning Target Volume Dosimetry

Both 3D-CRT and IMRT achieved adequate PTV coverage, with no statistically significant differences in D95 or mean PTV dose. IMRT demonstrated significantly superior conformity, whereas 3D-CRT showed slightly improved homogeneity.

Table 1. Dosimetric Parameters for the Planning Target Volume

Parameter	3D-CRT (Mean ± SD)	IMRT (Mean ±SD)	p-value
D95 (Gy)	45.06±0.47	45.20±0.11	0.695
Mean Dose (Gy)	46.60±0.62	46.62±0.58	0.988
Conformity Index	1.58±0.21	1.29±0.17	**<0.001**
Homogeneity Index	1.08±0.03	1.09±0.04	**0.029**

Organ-at-Risk Dosimetry

IMRT resulted in a significantly lower mean liver dose compared with 3D-CRT. Renal dose parameters demonstrated numerical differences between techniques without reaching statistical significance. The maximum spinal cord dose was significantly lower with 3D-CRT.

Table 2. Dosimetric Parameters for Organs at Risk

Organ	Parameter	3D-CRT (Mean ± SD)	IMRT (Mean ± SD)	p-value
Right kidney	Mean dose (Gy)	11.80 ± 3.12	12.77 ± 3.44	0.631
	V20 (%)	24.08 ± 8.31	16.65 ± 7.94	0.105
Left kidney	Mean dose (Gy)	12.64 ± 3.45	13.80 ± 3.71	0.433
	V20 (%)	28.42 ± 9.02	24.32 ± 8.76	0.477
Liver	Mean dose (Gy)	26.23 ± 4.88	21.66 ± 4.11	**<0.001**
	V30 (%)	28.72 ± 9.35	21.98 ± 8.62	0.075
Spinal cord	Maximum dose (Gy)	30.50 ± 4.91	33.60 ± 2.22	**0.036**

DISCUSSION

This paired dosimetric comparison demonstrates that both 3D-CRT and IMRT provide acceptable target coverage for gastric and GEJ cancers, while offering distinct advantages in organ-specific dose sparing. IMRT achieved significantly superior dose conformity, reflecting its capacity for highly conformal dose distributions. In contrast, 3D-CRT demonstrated marginally better dose homogeneity, consistent with its simpler beam arrangements.

The most clinically relevant advantage of IMRT observed in this study was the significant reduction in mean liver dose. Given the dose-dependent risk of radiation-induced liver disease, this finding is particularly important for proximal gastric and GEJ tumors that are anatomically adjacent to the liver [16–18].

Renal dosimetry demonstrated a mixed pattern, with IMRT showing lower intermediate-dose volumes and 3D-CRT yielding lower mean doses, although none of these differences reached statistical significance. These findings highlight the importance of individualized treatment planning based on patient anatomy and baseline renal function [17].

The significantly lower maximum spinal cord dose observed with 3D-CRT underscores its continued relevance, particularly in cases where the spinal cord represents the primary dose-limiting structure [19].

CONCLUSION

This fully corrected dosimetric analysis confirms that three-dimensional conformal radiotherapy and intensity-modulated radiotherapy offer complementary advantages in the treatment of gastric and gastroesophageal junction cancers. IMRT provides superior dose conformity and improved liver sparing, whereas 3D-CRT offers slightly better dose homogeneity and lower maximum spinal cord dose. Radiotherapy technique selection should therefore be individualized according to tumor location, anatomical considerations, and organ-at-risk priorities to optimize the therapeutic ratio.

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