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Dosimetric Comparison and Acute Toxicity Analysis between IMRT and 3DCRT in Mid and Lower Esophageal Cancers: A Randomized Prospective Study

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ABSTRACT

Background: Esophageal cancer is a major cause of cancer-related morbidity and mortality worldwide. Concurrent chemoradiotherapy is the standard treatment for patients with locally advanced unresectable disease. Intensity-modulated radiotherapy (IMRT) has the potential to improve target conformity and spare surrounding organs at risk compared with three-dimensional conformal radiotherapy (3DCRT). This study was an attempt to compare the dosimetric parameters, acute toxicities, and early treatment response of IMRT and 3DCRT in patients with locally advanced esophageal cancer receiving definitive concurrent chemoradiotherapy.

Methods: In this prospective randomized study, 31 patients with histologically proven, locally advanced esophageal carcinoma were randomized to receive either 3DCRT (n=16) or IMRT (n=15) with concurrent cisplatin and 5-fluorouracil chemotherapy. Dosimetric parameters including planning target volume (PTV) coverage, lung doses, heart doses, spinal cord dose, homogeneity index (HI), and conformity index (CI) were compared. Acute toxicities were assessed using the Common Terminology Criteria for Adverse Events (CTCAE) version 4.03, and treatment response was evaluated according to Response Evaluation Criteria in Solid Tumors (RECIST) version 1.1.

Results: Twenty-four patients were evaluated for final anlysis (3DCRT, n=13; IMRT, n=11). PTV coverage was comparable between the treatment arms. IMRT demonstrated significantly improved cardiac sparing, with lower mean heart dose, V30 and V45 ($p<0.001$), and significantly reduced maximum spinal cord dose ($p<0.001$). IMRT also achieved superior dose conformity and homogeneity during Phase II planning ($p<0.001$). However, lung dose parameters (V5 and V20) were significantly higher with IMRT. Acute toxicities were generally mild and manageable in both groups. Radiation dermatitis was more frequent in the IMRT arm, whereas no significant differences were observed in dysphagia, nausea/vomiting, or neutropenia. Complete response rates were 50.0% in the 3DCRT arm and 46.7% in the IMRT arm, with no statistically significant difference in overall response distribution ($p=0.313$).

Conclusions: IMRT provided superior dose conformity and significantly improved heart and spinal cord sparing compared with 3DCRT while maintaining equivalent target coverage. Despite these dosimetric advantages, acute toxicity profiles and early treatment responses were comparable between the two treatment techniques. Larger prospective studies with longer follow-up are required to determine whether the dosimetric benefits of IMRT translate into improved long-term clinical outcomes.

***Keywords**: Esophageal cancer, IMRT, 3DCRT, Concurrent chemoradiotherapy, Dosimetric comparison, Acute toxicity, RECIST.*

INTRODUCTION

Esophageal cancer is one of the most aggressive malignancies worldwide and remains a major cause of cancer-related mortality. It is the eighth most common cancer and the sixth leading cause of cancer-related death globally [1]. Despite advances in diagnostic and therapeutic modalities, the prognosis remains poor, largely because the majority of patients present with locally advanced disease [2]. In India, esophageal cancer constitutes a significant health burden, particularly in the North-Eastern Region, where a relatively high incidence has been reported[3].

Concurrent chemoradiotherapy has emerged as a standard treatment option for patients with locally advanced, unresectable, or medically inoperable esophageal carcinoma. The combination of chemotherapy and radiotherapy improves locoregional control and overall survival compared with radiotherapy alone. However, treatment-related toxicities, particularly radiation-induced esophagitis, pneumonitis, and cardiac toxicity, remain major concerns due to the close proximity of the esophagus to critical thoracic organs such as the lungs, heart, and spinal cord.

Three-dimensional conformal radiotherapy (3DCRT) has been widely used in the treatment of esophageal cancer and provides improved target localization compared with conventional radiotherapy techniques [4]. Nevertheless, the ability of 3DCRT to conform radiation dose around irregular target volumes is limited, often resulting in higher radiation exposure to surrounding normal tissues[5]. Intensity-modulated radiotherapy (IMRT) represents an advanced radiotherapy technique that allows superior dose conformality and improved sparing of organs at risk while maintaining adequate target coverage. Several dosimetric studies have demonstrated the potential advantages of IMRT over 3DCRT in reducing radiation dose to the lungs, heart, and spinal cord [6,7].

Although the dosimetric superiority of IMRT has been reported in several retrospective and planning studies, prospective randomized data evaluating both dosimetric outcomes and treatment-related toxicities remain limited, particularly in the Indian population. Furthermore, evidence regarding whether improved dose distribution translates into clinically meaningful reductions in toxicity continues to evolve.

Despite significant advances in multimodality treatment for esophageal cancer, concurrent chemoradiotherapy remains a cornerstone of management for patients with locally advanced, unresectable, or medically inoperable disease. Three-dimensional conformal radiotherapy (3DCRT) has been widely used and has demonstrated acceptable treatment outcomes; however, radiation-induced toxicities involving the lungs, heart, spinal cord, and esophagus continue to be a major concern [8]. Intensity-modulated radiotherapy (IMRT), an advanced conformal radiotherapy technique, has the potential to improve target dose conformity while reducing radiation exposure to adjacent organs at risk. Although several dosimetric and retrospective studies have suggested the superiority of IMRT over 3DCRT in terms of organ sparing and toxicity reduction, prospective randomized evidence remains limited, particularly in the Indian population. Furthermore, data correlating dosimetric advantages with clinically relevant treatment-related toxicities are scarce. Given the high burden of esophageal cancer in Northeast India and the lack of region-specific prospective studies, the present randomized study was undertaken to compare the dosimetric parameters and treatment-related toxicities of IMRT and 3DCRT in patients with mid and lower esophageal carcinoma receiving concurrent chemotherapy.

Therefore, the present study aimed to evaluate and compare the dosimetric characteristics, treatment-related toxicities, and early clinical response of Intensity-Modulated Radiotherapy (IMRT) and Three-Dimensional Conformal Radiotherapy (3DCRT) in patients with locally advanced mid and lower esophageal carcinoma undergoing concurrent chemoradiotherapy.

MATERIALS AND METHODS

Study Design and Participants:

This is a prospective randomized clinical trial conducted in the Department of Radiation Oncology, Dr. B. Borooah Cancer Institute, Guwahati, after approval from the Institutional Ethics Committee and Srimanta Sankaradeva University of Health Sciences. The study was conducted over a period of one year.

Thirty-one patients with histologically proven esophageal carcinoma (T2–T3, N0–N2, M0), aged 18–65 years, with ECOG performance status <2 (or KPS >70%) and adequate hematological and renal function were enrolled after obtaining written informed consent. Patients with metastatic disease, gastroesophageal junction tumors, tracheoesophageal fistula, poor performance status, or unwillingness to participate were excluded.

Randomization and Treatment:

Eligible patients were randomized into two treatment arms:

Arm A: 3DCRT with concurrent chemotherapy (n=16)

Arm B: IMRT with concurrent chemotherapy (n=15)

All patients underwent contrast-enhanced CT simulation with 3-mm slice thickness and appropriate immobilization. Target volumes (GTV, CTV, and PTV) and organs at risk were contoured according to established guidelines. Patients received 63 Gy in 35 fractions using 6 MV photons.

Concurrent chemotherapy consisted of two cycles of cisplatin (75 mg/m², Day 1) and 5-fluorouracil (750 mg/m²/day, continuous infusion on Days 1–4), repeated every 21 days.

Assessment and Follow-up:
Dose-volume histograms were analyzed to compare PTV coverage and doses to organs at risk, including lungs (mean dose, V5, V20), heart (mean dose, V30, V45), and spinal cord (maximum dose).

Patients were assessed weekly during treatment and monthly for three months after treatment completion. Clinical examination, endoscopy, and contrast-enhanced CT of the chest and upper abdomen were performed during follow-up. Acute toxicities were graded according to CTCAE version 4.03, and treatment response was evaluated using RECIST version 1.1 criteria.

Toxicity Assessment
Treatment-related toxicities were assessed weekly during treatment and at follow-up visits using the National Cancer Institute Common Terminology Criteria for Adverse Events (CTCAE), Version 4.03. The following adverse events were evaluated: anemia, neutropenia, thrombocytopenia, nausea, vomiting, dysphagia, and radiation dermatitis [9].

Hematological Toxicity
- **Anemia:** Grade 1 (Hb < LLN–10.0 g/dL), Grade 2 (Hb <10.0–8.0 g/dL), Grade 3 (Hb <8.0 g/dL), Grade 4 (life-threatening consequences requiring urgent intervention), Grade 5 (death).
- **Neutropenia:** Grade 1 (<LLN–1500/mm³), Grade 2 (<1500–1000/mm³), Grade 3 (<1000–500/mm³), Grade 4 (<500/mm³).
- **Thrombocytopenia:** Grade 1 (<LLN–75,000/mm³), Grade 2 (<75,000–50,000/mm³), Grade 3 (<50,000–25,000/mm³), Grade 4 (<25,000/mm³).

Gastrointestinal Toxicity
- **Nausea:** Grade 1 (loss of appetite without alteration in eating habits), Grade 2 (decreased oral intake without significant weight loss, dehydration, or malnutrition), Grade 3 (inadequate oral caloric or fluid intake requiring tube feeding, total parenteral nutrition [TPN], or hospitalization).
- **Vomiting:** Grade 1 (1–2 episodes in 24 hours), Grade 2 (3–5 episodes in 24 hours), Grade 3 (≥6 episodes in 24 hours or requiring tube feeding, TPN, or hospitalization), Grade 4 (life-threatening consequences requiring urgent intervention), Grade 5 (death).
- **Dysphagia:** Grade 1 (symptomatic, able to eat regular diet), Grade 2 (symptomatic with altered eating/swallowing), Grade 3 (severely altered eating/swallowing requiring tube feeding, TPN, or hospitalization), Grade 4 (life-threatening consequences requiring urgent intervention), Grade 5 (death).

Dermatological Toxicity
- **Radiation Dermatitis:** Grade 1 (faint erythema or dry desquamation), Grade 2 (moderate-to-brisk erythema, patchy moist desquamation confined mainly to skin folds/creases, or moderate edema), Grade 3 (moist desquamation beyond skin folds/creases or bleeding induced by minor trauma), Grade 4 (life-threatening consequences including skin necrosis, full-thickness dermal ulceration, spontaneous bleeding, or need for skin grafting), Grade 5 (death).

Response Assessment: Treatment response was evaluated according to the Revised Response Evaluation Criteria in Solid Tumors (RECIST) version 1.1 using radiological imaging [68]. Responses were classified as Complete Response (CR), Partial Response (PR), Stable Disease (SD), and Progressive Disease (PD) based on changes in target and non-target lesions. The appearance of new lesions was considered disease progression.

Statistical Analysis:
Descriptive statistics were presented using frequencies, percentages, histograms, and pie charts, as appropriate. The association between categorical variables was assessed using the Fisher's exact test. Normality of continuous variables was evaluated using the Kolmogorov–Smirnov test and Shapiro–Wilk test. Continuous variables were expressed as mean ± standard deviation (SD). Comparisons between two independent groups were performed using the Independent Samples t-test for normally distributed data. A p-value of <0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA).

RESULTS:
Patient Characteristics and Treatment Compliance

A total of 31 patients with locally advanced esophageal carcinoma fulfilling the eligibility criteria were enrolled and randomized in a 1:1 ratio to receive either three-dimensional conformal radiotherapy (3DCRT) or intensity-modulated radiotherapy (IMRT). During the course of treatment, three patients died before completion of therapy, while four additional patients died shortly after treatment completion and before response assessment. Consequently, 24 patients were available for final evaluation, including 13 patients in the 3DCRT arm and 11 patients in the IMRT arm. All evaluable patients received concurrent chemoradiotherapy to a total dose of 63 Gy delivered in 35 fractions.

Baseline Patient Characteristics

The baseline demographic and disease characteristics were comparable between the two treatment arms. No statistically significant differences were observed with respect to age distribution, sex, histological subtype, tumor location, or disease stage (all $p > 0.05$), indicating successful randomization and balanced allocation of patients.

Patients aged more than 50 years constituted the majority of the study population in both treatment arms. Similarly, the sex distribution was comparable between the groups. Squamous cell carcinoma was the predominant histological subtype observed in both cohorts. Most tumors were located in the middle third of the esophagus, and Stage IIB disease represented the largest proportion of patients in both treatment arms.

Dosimetric Analysis:

Planning Target Volume Coverage

There was no statistically significant difference in Planning Target Volume (PTV) coverage between the two treatment techniques. The mean PTV volume for Phase I was 312.49 cm^3 in the 3DCRT arm and 335.04 cm^3 in the IMRT arm ($p = 0.508$). Similarly, Phase II PTV volumes were comparable between the groups (243.39 cm^3 vs. 262.33 cm^3, $p = 0.530$).

Lung Dosimetry

Although total lung volumes were comparable between the treatment arms, significant differences were observed in lung dose parameters.

For the right lung, IMRT resulted in significantly higher mean lung dose (1810.92 cGy vs. 1496.98 cGy, $p = 0.016$), V20 (34.36% vs. 19.90%, $p < 0.0001$), and V5 (91.54% vs. 69.21%, $p < 0.0001$) compared with 3DCRT.

Similarly, for the left lung, IMRT demonstrated significantly higher V20 (35.18% vs. 24.37%, $p = 0.009$) and V5 (91.34% vs. 71.72%, $p < 0.0001$). The difference in mean left lung dose was not statistically significant ($p = 0.405$).

Heart Dosimetry

IMRT provided significantly superior cardiac sparing compared with 3DCRT. The mean heart dose was substantially lower with IMRT (2514.77 cGy) than with 3DCRT (4108.80 cGy, $p < 0.0001$). Likewise, heart V30 and V45 were significantly reduced in the IMRT arm (29.82% and 12.02%, respectively) compared with the 3DCRT arm (72.02% and 60.48%, respectively; $p < 0.0001$ for both comparisons).

Table 1. Comparison of Dosimetric Parameters Between 3DCRT and IMRT

Parameter	3DCRT Mean ± SD	IMRT Mean ± SD	p-value
PTV Phase I Volume (cm^3)	312.49	335.04	0.508
PTV Phase II Volume (cm^3)	243.39	262.33	0.53
Right Lung Mean Dose (cGy)	1496.98	1810.92	0.016
Right Lung V20 (%)	19.9	34.36	<0.001
Right Lung V5 (%)	69.21	91.54	<0.001
Left Lung Mean Dose (cGy)	1496.98	1810.92	0.405
Left Lung V20 (%)	24.37	35.18	0.009
Left Lung V5 (%)	71.72	91.34	<0.001
Heart Mean Dose (cGy)	4108.8	2514.77	<0.001
Heart V30 (%)	72.02	29.82	<0.001
Heart V45 (%)	60.48	12.02	<0.001
Spinal Cord Maximum Dose (cGy)	5366.79	3522.31	<0.001
HI Phase I	0.098	0.094	0.561
HI Phase II	0.132	0.088	<0.001
CI Phase I	0.96	0.99	0.165
CI Phase II	0.97	0.99	<0.001

Footnote:
Values are presented as mean ± standard deviation (SD). P-values were calculated using the independent samples t-test. A p-value <0.05 was considered statistically significant.

Abbreviations: *PTV-planning target volume; V5-percentage volume receiving ≥5 Gy; V20-percentage volume receiving ≥20 Gy; V30-percentage volume receiving ≥30 Gy; V45-percentage volume receiving ≥45 Gy; HI- homogeneity index; CI-conformity index; 3DCRT- three-dimensional conformal radiotherapy; IMRT- intensity-modulated radiotherapy.*

Spinal Cord Dose
The maximum spinal cord dose was significantly lower in the IMRT arm than in the 3DCRT arm (3522.31 cGy vs. 5366.79 cGy, $p < 0.0001$), demonstrating improved spinal cord sparing with IMRT.

Plan Quality Indices
No significant difference was observed in the Homogeneity Index (HI) for Phase I plans (0.098 vs. 0.094, $p = 0.561$). However, IMRT demonstrated significantly better dose homogeneity during Phase II treatment (HI: 0.088 vs. 0.132, $p < 0.0001$).

Similarly, Conformity Index (CI) was comparable during Phase I planning (0.99 vs. 0.96, $p = 0.165$), whereas IMRT achieved significantly better conformity during Phase II treatment (0.99 vs. 0.97, $p < 0.0001$).

Clinical Response or Treatment Response
Treatment response was evaluated at the first follow-up visit, one month after completion of concurrent chemoradiotherapy, using clinical examination, endoscopic assessment, and the Response Evaluation Criteria in Solid Tumors (RECIST) version 1.1. Computed tomography (CT) of the chest and upper abdomen was performed two months after treatment completion to assess local disease control and detect distant metastases. The distribution of treatment responses is shown in Table 3. In the 3DCRT arm, complete response (CR), partial response (PR), and progressive disease (PD) were observed in 8 (50.0%), 5 (31.3%), and 3 (18.8%) patients, respectively. In the IMRT arm, CR, PR, and PD were observed in 7 (46.7%), 2 (13.3%), and 6 (40.0%) patients, respectively. Although the complete response rate was numerically higher in the 3DCRT arm, the difference in response distribution between the two treatment groups was not statistically significant ($p = 0.313$).

Table 2. Clinical Response at First Follow-up According to RECIST Version 1.1

Response Category	3DCRT, n (%)	IMRT, n (%)	p-value
Complete Response (CR)	8 (50.0)	7 (46.7)	
Partial Response (PR)	5 (31.3)	2 (13.3)	
Progressive Disease (PD)	3 (18.8)	6 (40.0)	0.313

Footnote:
Data are presented as number of patients, n (%). Treatment response was assessed according to the Response Evaluation Criteria in Solid Tumors (RECIST) version 1.1. Statistical comparison between treatment groups was performed using Fisher's exact test. A p-value <0.05 was considered statistically significant.

Treatment Related Toxicities (Toxicity Analysis):
Acute treatment-related toxicities were assessed weekly during chemoradiotherapy according to the Common Terminology Criteria for Adverse Events (CTCAE) version 4.03. Overall, treatment was well tolerated in both treatment arms, and no Grade 4 or Grade 5 toxicities were observed. All treatment-related adverse events were managed conservatively, and no patient required intensive care unit admission during treatment.

Radiation Dermatitis
All patients in both treatment arms developed Grade 1 radiation dermatitis during the initial weeks of treatment. However, the severity of dermatitis increased with treatment duration, with a significantly higher proportion of patients in the IMRT arm developing higher-grade dermatitis during Weeks 3, 4, 6, and 7 ($p = 0.013$, 0.006, 0.041, and 0.033, respectively). By Week 7, Grade 2 dermatitis was observed in 66.7% of patients treated with IMRT compared with 18.8% of patients treated with 3DCRT. No patient developed Grade 3 or higher dermatitis.

Neutropenia
Neutropenia was generally mild and manageable in both treatment groups. Grade 1 neutropenia occurred in 43% and 57% of patients in the 3DCRT and IMRT arms, respectively, while Grade 2 neutropenia was observed only in the 3DCRT arm (7%). The difference between treatment groups was not statistically significant ($p = 0.460$). All patients with neutropenia

were managed successfully with granulocyte colony-stimulating factor (G-CSF), and no episodes of febrile neutropenia were observed.

Nausea and Vomiting
The incidence and severity of nausea and vomiting were comparable between the treatment arms throughout the treatment period. Most events were Grade 1 in severity, with occasional Grade 2 events observed in both groups. No statistically significant differences were observed at any weekly assessment (all $p > 0.05$).

Dysphagia
Dysphagia was a common symptom in both treatment groups throughout treatment. Most patients experienced Grade 1 dysphagia, while Grade 2 and Grade 3 dysphagia occurred less frequently. No statistically significant differences were observed between the 3DCRT and IMRT arms at any weekly assessment (all $p > 0.05$).

Overall, both treatment techniques demonstrated acceptable toxicity profiles. While IMRT was associated with a higher incidence of radiation dermatitis during later weeks of treatment, no significant differences were observed with respect to neutropenia, nausea and vomiting, or dysphagia.

Table 3. Maximum Acute Toxicities Observed During Treatment According to CTCAE Version 4.03

Toxicity	Grade	3DCRT n (%)	IMRT n (%)	p-value
Radiation Dermatitis	Grade 1	12 (75.0)	4 (33.3)	0.033
	Grade 2	4 (25.0)	8 (66.7)	
Neutropenia	Grade 1	7 (43.8)	7 (58.3)	0.46
	Grade 2	1 (6.3)	0 (0.0)	
Nausea and Vomiting	Grade 1	9 (56.3)	7 (58.3)	0.82
	Grade 2	2 (12.5)	1 (8.3)	
Dysphagia	Grade 1	6 (37.5)	5 (41.7)	0.833
	Grade 2	3 (18.8)	1 (8.3)	
	Grade 3	2 (12.5)	1 (8.3)	

Footnote: *Data are presented as number of patients, n (%). Toxicities were graded according to the Common Terminology Criteria for Adverse Events (CTCAE), version 4.03. The highest toxicity grade experienced by each patient during treatment was recorded. P-values were calculated using the Fisher's exact test. A p-value <0.05 was considered statistically significant.*

DISCUSSION:
Esophageal cancer remains a major global health challenge and is frequently diagnosed at a locally advanced stage, necessitating multimodality treatment approaches [1,2]. Concurrent chemoradiotherapy is considered a standard treatment option for patients with unresectable disease or those who are medically inoperable [11-13]. Advances in radiotherapy planning and delivery have enabled improved target coverage while minimizing radiation exposure to surrounding organs at risk (OARs) [14].

The principal finding of this study was that IMRT achieved significantly better dose conformity and homogeneity while providing superior sparing of critical organs, particularly the heart and spinal cord, without compromising target coverage. PTV coverage was comparable between the two treatment techniques, indicating that both modalities were able to adequately deliver the prescribed radiation dose to the target volume. However, IMRT demonstrated significantly improved conformity and homogeneity indices, particularly during Phase II treatment planning. These findings are consistent with previous dosimetric studies demonstrating the superior conformality of IMRT compared with 3DCRT for esophageal cancer.

With regard to organ-at-risk dosimetry, IMRT significantly reduced cardiac dose parameters, including mean heart dose, V30, and V45, compared with 3DCRT. Similarly, the maximum spinal cord dose was significantly lower in the IMRT arm. These findings are clinically relevant because increasing evidence suggests that radiation-induced cardiac toxicity may adversely affect long-term outcomes in patients with thoracic malignancies [15,16]. Improved cardiac sparing with IMRT has been reported in several planning studies and retrospective analyses and is considered one of the major advantages of inverse-planned radiotherapy techniques.

In contrast, lung dose parameters including V5 and V20 were significantly higher in the IMRT arm. This observation has also been reported in previous studies and is likely attributable to the use of multiple beam angles during IMRT planning, resulting in greater low-dose radiation exposure to larger lung volumes. Nicolini et al. similarly reported increased low-dose lung irradiation with IMRT when compared with 3DCRT. Although higher V5 and V20 values theoretically increase the risk of radiation pneumonitis, no patient in the present study developed clinically significant acute pneumonitis during

the follow-up period. Nevertheless, longer follow-up is required to determine the clinical significance of these dosimetric differences.

The acute toxicity profile was generally acceptable in both treatment groups. Radiation dermatitis was the most common treatment-related toxicity and was significantly more frequent in the IMRT arm during the later weeks of treatment. Despite this difference, most cases were limited to Grade 1 or Grade 2 toxicity and were managed conservatively without treatment interruption. No Grade 3 or higher dermatitis was observed. Hematological toxicity was mild, with only a small proportion of patients developing Grade 1 or Grade 2 neutropenia, all of whom responded to supportive treatment with granulocyte colony-stimulating factor. Similarly, the incidence and severity of dysphagia and nausea/vomiting were comparable between the two treatment arms, and no statistically significant differences were observed.

Early clinical response assessment demonstrated comparable treatment efficacy between the two radiotherapy techniques. The complete response rate was numerically higher in the 3DCRT arm than in the IMRT arm; however, this difference did not reach statistical significance. Similarly, no significant differences were observed in partial response or progressive disease rates. These findings suggest that while IMRT offers dosimetric advantages, these benefits may not necessarily translate into improved short-term tumor response. Longer follow-up and larger patient cohorts are required to determine whether improved dose distribution and organ sparing lead to better local control, progression-free survival, or overall survival.

The present study has several strengths. All patients were treated using a standardized concurrent chemoradiotherapy protocol, target delineation was performed according to established contouring guidelines, and dosimetric as well as clinical outcomes were systematically evaluated. However, certain limitations should be acknowledged. The study was conducted at a single institution with a relatively small sample size, which may have limited the statistical power to detect differences in clinical outcomes. In addition, the duration of follow-up was short, precluding meaningful assessment of late toxicities, disease-free survival, and overall survival. Furthermore, the study primarily evaluated acute toxicity and early response, and therefore the long-term clinical benefits of IMRT remain uncertain.

In summary, IMRT provided superior dose conformity and significantly reduced radiation exposure to the heart and spinal cord compared with 3DCRT while maintaining equivalent target coverage. Although IMRT was associated with increased low-dose lung irradiation and a higher incidence of Grade 2 dermatitis, overall treatment-related toxicities were manageable and early treatment response was comparable between the two techniques. Larger prospective studies with longer follow-up are warranted to determine whether the dosimetric advantages of IMRT translate into meaningful improvements in long-term clinical outcomes.

Study Limitations:
The main limitations of this study include the small sample size, single-centre design, and relatively short follow-up duration. Consequently, the study had limited power to detect differences in clinical outcomes and was unable to adequately assess late toxicities, long-term local control, progression-free survival, or overall survival. Larger prospective studies with longer follow-up are required to validate these findings.

CONCLUSION

In this prospective comparative study, IMRT demonstrated superior dosimetric performance compared with 3DCRT in the treatment of locally advanced esophageal cancer receiving definitive concurrent chemoradiotherapy. While target volume coverage was comparable between the two techniques, IMRT achieved significantly better dose conformity and homogeneity, with improved sparing of critical organs, particularly the heart and spinal cord. However, IMRT was associated with increased low-dose irradiation to the lungs. Despite these dosimetric advantages, no significant differences were observed in acute treatment-related toxicities or early clinical response between the two treatment arms. Both techniques were well tolerated, with manageable toxicity profiles and no Grade 4 or Grade 5 adverse events. The findings suggest that IMRT may offer dosimetric benefits without compromising treatment efficacy. However, the small sample size and limited follow-up duration restrict definitive conclusions regarding long-term clinical outcomes. Larger prospective studies with extended follow-up are required to determine whether the dosimetric advantages of IMRT translate into improved survival and reduced late toxicity.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical committee Approval: The study was conducted after obtaining approval from the Institutional Ethics Committee of Dr. B. Borooah Cancer Institute, Guwahati, and permission from the Srimanta Sankaradeva University of Health Sciences, Assam.

Informed Consent: Written informed consent was obtained from all participants prior to their enrollment in the study.

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