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Evaluation of Different Strategies to Reduce the Dose to Normal Tissues in VMAT Planning of Esophageal Carcinoma Using the Eclipse Treatment Planning System

Md. Mahmudul H. Manna1[1], Mohammad A. Islam[1], Md O. Rahman[2]

[1]Medical Physicist, Radiation Oncology Department, Cancer Center, Combined Military Hospital (CMH) Dhaka, Bangladesh

[2]Professor, Department of Physics, Jahangirnagar University, Savar, Dhaka, Bangladesh

*Corresponding author: Md. Mahmudul H. Manna, Email: hasansaccount@gmail.com

Abstract- The aim of this study is to quantify the dosimetric impact of the normal tissue objective (NTO) on volumetric-modulated arc therapy (VMAT) for mid-thoracic esophageal cancer and to identify an optimal NTO configuration in Varian Eclipse Planning System. VMAT plans with prescription dose 50.40 Gy in 28 fractions were generated in Eclipse v15.1 for 22 patients using dual 6-MV arcs and the Anisotropic Analytical Algorithm (AAA). Organs at risk (OARs) included lungs, heart, liver, spinal cord and normal tissue (NT). All plans were normalized such that 95% of the planning target volume (PTV) received ≥95% of the prescription dose. Five strategies were compared per patient: (1) without NTO, (2) ring only, (3) Auto-NTO, (4) Auto-NTO + ring, and (5) manual NTO (ManNTO). Systematic parameter sweeps were performed for ManNTO. Among non-manual strategies, Auto-NTO + ring provided the most favorable balance between PTV coverage and OAR sparing. ManNTO further improved plan quality. The optimal ManNTO setting (start dose 105%, end dose 10%, 1-mm distance from the PTV, fall-off 1.0 mm^{-1}, priority 150) yielded superior PTV coverage (D95% = 98.95%), lower mean normal-tissue dose (13.125 Gy), reduced 50% isodose volume (60.47 cc), and enhanced delivery efficiency (MU/PD = 2.378) compared with all other strategies. A carefully optimized manual NTO configuration in Eclipse planning system significantly enhances OAR sparing, steepens normal-tissue dose fall-off, and improves delivery efficiency while maintaining or exceeding target coverage, and can reduce planning time significantly.

Keywords: Normal Tissue Objective (NTO); ring structure; esophageal cancer; VMAT; treatment plan evaluation

I. Introduction

Concurrent chemoradiotherapy with external beam radiotherapy is a cornerstone of treatment for locally advanced esophageal cancer [1–3]. In the middle thoracic esophagus, achieving adequate planning target volume (PTV) coverage while sparing organs at risk (OARs) such as the lungs, heart, liver, and spinal cord is particularly challenging because of the close proximity of these structures and the often elongated, irregular geometry of the target [4–8].

Volumetric-modulated arc therapy (VMAT) enables highly conformal dose distributions and efficient delivery for many thoracic and upper gastrointestinal malignancies [9–12]. However, VMAT plan quality is strongly influenced by the choice of optimization objectives and constraints. In the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA), the normal tissue objective (NTO) is intended to control dose fall-off outside the PTV by penalizing intermediate and low doses in normal tissues, but no site-specific guidance on parameter selection is available [13–15].

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In routine clinical practice, many planners rely on ring structures, default Auto-NTO settings, or trial-and-error adjustment of NTO parameters. Although these approaches can produce clinically acceptable plans, there is limited published evidence comparing different NTO and ring strategies specifically for esophageal VMAT. Systematic evaluation of their relative impact on dose distribution, low-dose spread, and efficiency for a homogeneous patient cohort is lacking.

The present study compares five VMAT optimization strategies in Eclipse planning system—without NTO, ring-only, Auto-NTO, Auto-NTO plus ring, and a series of manual NTO (ManNTO)—for middle thoracic esophageal cancer. The goal was to quantify the dosimetric and efficiency trade-offs between these strategies, identify a practical manual NTO configuration that improves conformity and reduces the low-dose bath, and provide practical guidance for users.

II. Materials and Methods

2.1 Patient Selection

This retrospective planning study included 22 patients with middle thoracic esophageal carcinoma. All patients had a prescription dose of 50.40 Gy in 28 fractions and had previously undergone VMAT planning in Eclipse v15.1. Patients with prior thoracic radiotherapy or incomplete planning CT or contour data were excluded. The study was conducted in Cancer Center, Combined Military Hospital (CMH), Dhaka, Bangladesh for the period of February-2024 to April-2025 in accordance with institutional policies for retrospective analyses.

2.2 Simulation and Imaging

Simulation has been done in a Siemens Biograph mCT PET CT Simulator. Patients were immobilized in the supine position with arms raised using a dedicated thoracic immobilization device. Planning CT scans were acquired from the lower neck to below the liver with a slice thickness of 3.0 mm. Intravenous contrast was used when clinically indicated to aid target and OAR delineation.

2.3 Target and OAR Delineation

Gross tumor volume (GTV), clinical target volume (CTV), and planning target volume (PTV) were contoured by experienced radiation oncologists following institutional practice and published guidelines for esophageal cancer radiotherapy. A margin from CTV to PTV was typically added to account for setup uncertainties and residual motion, with minor adjustments allowed at the physician's discretion. OARs included total lungs (combined left and right lungs minus PTV when relevant), heart, liver, spinal cord, and the body minus PTV to evaluate mean global dose to non-target Normal Tissue (NT). One virtual structure around the PTV has been created as Ring. Distance from the target and the thickness was 5mm. During optimization objectives has been given to achieve dose fall-off. Visual description of Normal Tissue (NT) and Ring is given in Fig. 1.

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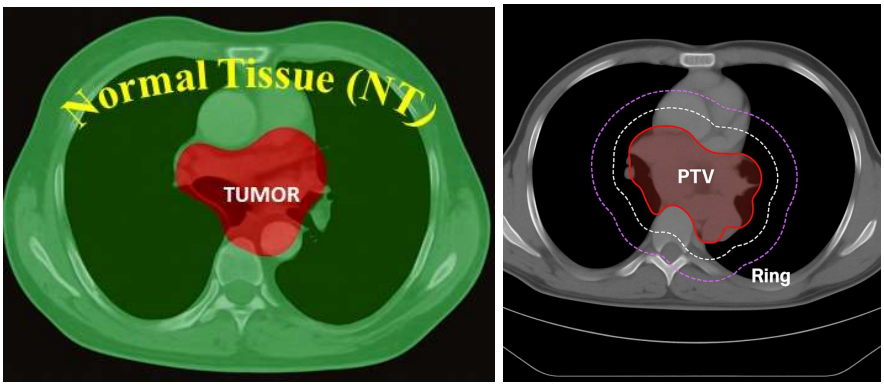

Fig. 1. Illustration of Normal Tissue (NT) (Left) and Ring Structure (Right)

2.4 VMAT Planning and Dose Calculation

All plans were generated using Eclipse v15.1 with 6-MV photons. Dual coplanar VMAT arcs were used for each plan to ensure comparability. Dose was calculated with the Anisotropic Analytical Algorithm (AAA) using a calculation grid size of 2.5 mm. All plans were normalized such that at least 95% of the PTV received ≥95% of the prescription dose (D95% ≥ 95%). Plans were optimized to achieve the OAR dose constraints as per Table I. The Machine parameters, including maximum dose rate and gantry speed, were kept constant across all the planning strategies.

TABLE I. OAR DOSE CONSTRAINTS

OAR	**Constraints**
Total Lung	Mean<20Gy
	V20<30%
Heart	33%<35Gy
Spinal Cord	Max<45Gy
Liver	50%<35Gy
Normal Tissue (NT)	Mean (As low as possible)

2.5 Planning Strategies

Five optimization strategies were created for each patient:

a) Without NTO: conventional VMAT with target and OAR objectives only, no NTO or rings.
b) Ring structure only (Ring): one or more concentric ring structures around the PTV with upper-dose constraints to shape dose fall-off, without NTO.
c) Auto-NTO: vendor default Auto-NTO settings applied without rings.
d) Auto-NTO + Ring: combination of Auto-NTO with the same ring structures used in strategy (2).
e) Manual NTO (ManNTO): Auto-NTO disabled and an NTO manually configured; parameter sweeps were performed to identify an optimal configuration.

2.6 Manual NTO Parameter Sweep

For the ManNTO strategy, key NTO parameters were varied across clinically reasonable ranges to assess their impact on plan quality. As shown in Fig. 2 parameters included the start dose and end dose (expressed as percentages of the prescription dose), the

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distance from the PTV border, the dose fall-off (mm^{-1}), and the NTO priority. For each patient 20 retrospective treatment plan has been generated varying the *Distance from target border* 0, 0.1, 0.3, 0.5 & 10mm and Dose fall off 0.1, 0.3, 0.5 & 1.0 mm^{-1}. The *Start Dose* and *End dose* were kept unchanged as 105% and 60% respectively. For each parameter combination, a VMAT plan was optimized and evaluated using PTV, OAR, normal-tissue, and efficiency metrics.

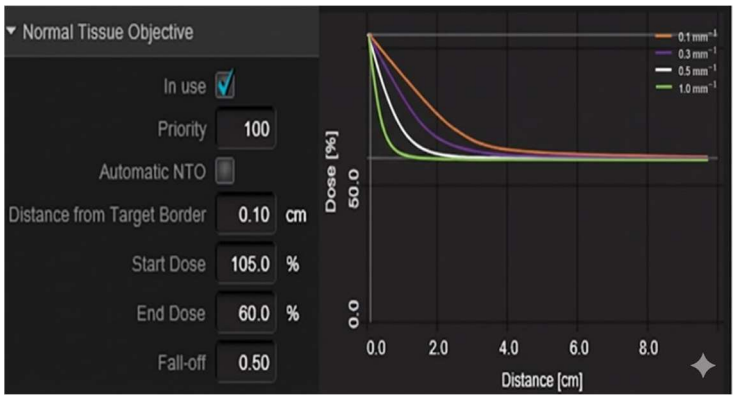

Fig. 2. Normal Tissue Objective (NTO) parameters

2.7 Plan Evaluation and Statistics

Dose–volume histograms (DVHs) were used to extract PTV and OAR metrics for each plan. PTV metrics included conformity index (CI), homogeneity index (HI), gradient index (GI), modified gradient index (mGI), PTV coverage (V95%) and Treatment Time (MU) which are described in Table II.

TABLE II. EVALUATION METRICS

Plan metrics	**Formula**	**Ideal values**
Conformity Index (CI)	$CI = \frac{TV_{RI}}{V_{RI}}$	CI = 1 (perfect conformity)
Homogeneity Index (HI)	$HI = \frac{D_{max}}{D_{PD}}$	HI = 1 (perfect homogeneity)
Gradient index (GI)	$GI = \frac{V_{50\%}}{V_{100\%}}$	as small as possible
Modified gradient index (mGI)	$mGI = \frac{V_{50\%}}{TV_{RI}}$	as small as possible
PTV Coverage	V95%	95% of the PTV received at least 95% of the prescribed dose
Treatment Time	MU	as small as possible

The Conformity Index evaluates how well the prescribed radiation dose conforms to the target where TV_{RI}= Target volume covered by the reference isodose and V_{RI}= Volume of reference isodose. The Homogeneity Index measures how uniformly the dose is distributed within the PTV. Where D_{max}= the maximum dose inside the target volume and D_{PD} = the prescription dose.

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The Gradient Index measures how quickly the dose falls off outside the target volume. The GI is defined as the ratio of the volume of 50% prescribed dose to the volume covered by the prescribed dose. The mGI is defined as the ratio of the volume of 50% prescribed dose to the target volume covered by the prescribed dose.

III. Results

3.1 Target Coverage

All five strategies achieved clinically acceptable PTV coverage after normalization (D95% ≥ 95% of the prescription dose). Among the non-manual strategies, Auto-NTO + Ring produced the most favorable combination of PTV coverage and homogeneity. The optimized ManNTO configuration further improved CI (0.990±0.07 vs 0.979±0.08) and HI (1.062±0.05 vs 1.064±0.07). All the results of the evaluation indices are given in Table III. The ManNTO configuration also improved PTV coverage (98.95 vs 98.07%), achieving the best PTV coverage among all the plan categories which is shown as Fig. 3. No clinically relevant underdosage of the PTV was observed with ManNTO.

TABLE III. PLANNING EVALUATION RESULTS

Plan Type	Conformity Index (CI)	Homogeneity Index (HI)	Gradient Index (GI)	Modified Gradient Index (mGI)
	(mean±standard deviation)			
Ring+Auto NTO	0.979±0.08	1.064±0.07	4.827±0.11	3.958±0.12
ManNTO (Distance from target border 1mm & Fall off 1.0)	0.990±0.07	1.062±0.05	4.707±0.13	3.404±0.11

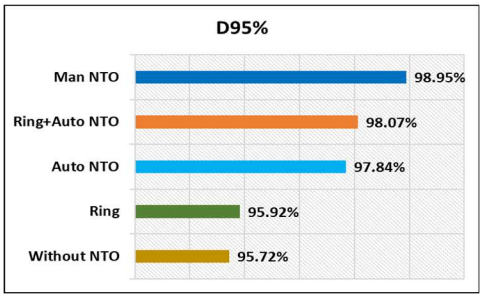

Fig. 3. PTV coverage results

3.2 OAR Sparing

OAR doses improved progressively from No-NTO and Ring-only plans to Auto-NTO and Auto-NTO + Ring. Auto-NTO + Ring provided the lowest lung, heart, and liver doses among the non-manual strategies. Fig. 4 clearly describes the ManNTO plans further reduced OAR doses, particularly total lung mean dose and lung V20Gy, heart, liver, or spinal cord doses beyond clinically acceptable levels. Normal-tissue sparing clearly distinguished the optimization strategies. ManNTO produced the lowest mean NT dose, 13.125 Gy,

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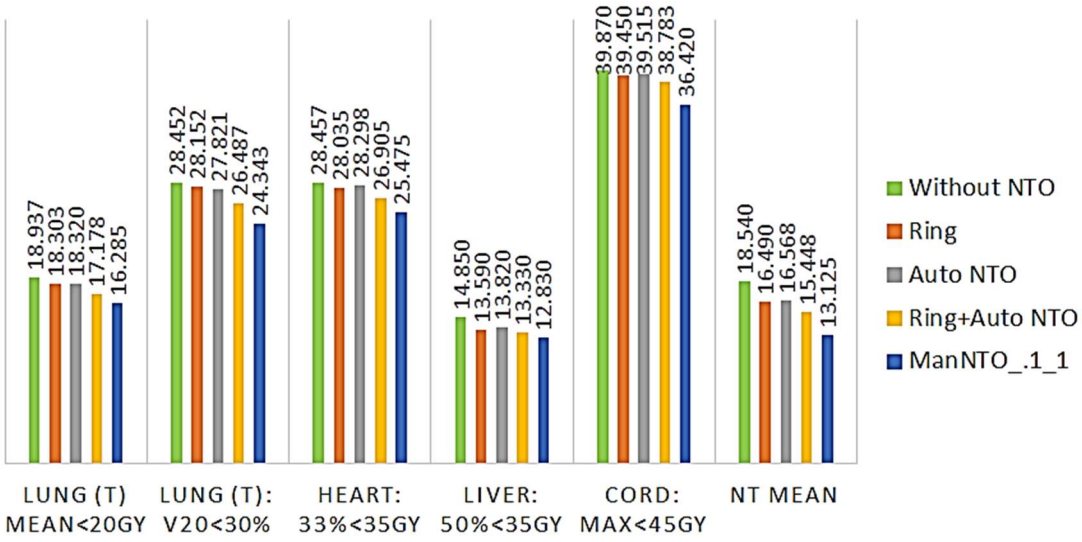

Fig. 4. OAR doses of investigated plans

3.3 Delivery Efficiency

As shown in Fig. 5, ManNTO yielded the most efficient plans, with an average MU/PD of 2.378, lower than for the No-NTO, Ring-only, Auto-NTO, and Auto-NTO + Ring strategies. This indicates that stronger normal-tissue control did not require excessively complex modulation; rather, it guided the optimizer toward more efficient fluence patterns while maintaining or improving dosimetry.

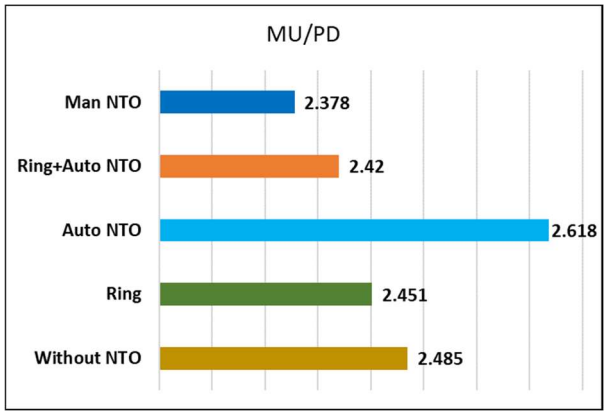

Fig. 5. Treatment delivery efficiency

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IV. Discussion

This study demonstrates that careful configuration of Eclipse's normal tissue objective (NTO) has a substantial impact on VMAT dose distributions for middle thoracic esophageal cancer. In our cohort, a manually configured NTO with a distance from the target border 1mm and dose fall-off 1.0 mm^{-1}, produced steeper dose gradients and lower normal-tissue dose than ring-only, Auto-NTO, or Auto-NTO plus ring strategies, while maintaining excellent target coverage and delivery efficiency. These findings support the concept that NTO should be regarded as a key planning parameter rather than a default "background" setting.

Several planning studies have shown that advanced techniques such as IMRT and VMAT improve conformity and OAR sparing compared with 3D conformal radiotherapy for esophageal cancer [4–8]. Wu et al. and Yin et al. reported that VMAT can achieve comparable or superior PTV coverage with lower lung and heart doses relative to c-IMRT and conformal techniques, while preserving or improving treatment efficiency [4,5]. Wang et al. and Martini et al. further highlighted the benefits of VMAT and simultaneous integrated boost approaches for tailoring dose distributions to complex esophageal geometries [6,7]. More recent series by Xu et al., Duan et al., and Mishra et al. confirmed that VMAT offers favorable dosimetry and monitor-unit efficiency compared with IMRT and hybrid techniques across different esophageal subsites [8–10,20,21]. Within this context, our results suggest that optimization of NTO parameters is an additional, under-reported degree of freedom that can further refine the quality of VMAT plans already shown to be advantageous over older techniques.

The present work also extends prior investigations on NTO behavior in other disease sites. Indrayani et al. and Bell et al. showed that appropriate NTO tuning in Eclipse can significantly affect gradient index, low-dose bath, and OAR doses in lung stereotactic treatments [13,14]. Muthu and Mudhana reported similar observations for multiple brain metastases, where NTO settings influenced the trade-off between conformity and normal-brain sparing when using RapidArc and HyperArc strategies [15]. A recent work by Ahamed & Suvarna, evaluated the effect of the Eclipse normal tissue objective (NTO) function on solitary brain metastases using IMRT and VMAT with two NTO settings: a mild (k = 0.4 mm^{-1}, De = 20%) and a steep (k = 1.0 mm^{-1}, De = 10%) dose fall-off. The steeper NTO (Type B) improved dose gradients and reduced normal tissue exposure [22].

Interpretation of our OAR metrics should be considered in light of established dose–volume recommendations such as QUANTEC. The lung, heart, and esophagus constraints in our analysis were chosen with reference to the dose–response data compiled by Marks et al., Gagliardi et al., and Werner-Wasik et al. [16–18], as well as the broader normal-tissue complication probability framework described by Marks et al. [19]. By achieving lower lung V20/V5, reduced mean heart and liver doses, and controlled spinal cord maximum doses with the optimized ManNTO configuration, our plans remain within commonly accepted tolerance thresholds while reducing the low-dose bath, which has been associated with pulmonary and cardiac toxicity in long-term series of chemoradiation for esophageal cancer [1–3,16–19].

From a workflow perspective, adopting a standardized ManNTO configuration has the potential to decrease trial-and-error iterations, support higher planning throughput, and reduce planner-to-planner variability. Our data suggest that embedding an optimized NTO (start dose 105%, end dose 60%, distance from the target border 1mm, dose fall-off 1.0 mm^{-1} and priority 150) into such templates may provide a practical baseline that can be fine-tuned only when case-specific anatomy demands it. Future work should include multi-institutional validation, linkage of these dosimetric gains to clinical outcomes and toxicity, and exploration of how these NTO parameters interact with emerging techniques such as non-coplanar VMAT, adaptive radiotherapy, and knowledge-based planning.

V. Conclusion

In VMAT planning for middle thoracic esophageal cancer in Eclipse, the use of an optimized manual normal tissue objective substantially improves plan quality compared with plans using without NTO, Ring-only, Auto-NTO, or Auto-NTO + Ring. A configuration with start dose 105%, end dose 60%, 1mm distance from the PTV border, dose fall-off 1.0 mm^{-1}, and priority 150 yielded superior PTV coverage, lower mean normal-tissue dose, smaller 50% isodose volume, and improved MU/PD. These findings provide practical guidance for Eclipse users seeking to standardize and enhance VMAT planning for esophageal cancer.

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