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# Evaluation of Target Definition for Stereotactic Body Radiation Therapy (SBRT) of Single Paraaortic Lymph Node Metastases from Non-Small Cell Lung Cancer (NSCLC)

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**Abstract**

**Objective:** Paraaortic lymph node metastases from Non-Small Cell Lung Cancer (NSCLC), although relatively rare, can present in the oligometastatic setting and may benefit from precise local ablative strategies such as Stereotactic Body Radiation Therapy (SBRT). SBRT enables the delivery of high-dose radiation with sharp dose falloff and minimal exposure to adjacent organs at risk (OARs). However, target volume definition for paraaortic nodal SBRT remains a clinical challenge due to anatomic variability and limited soft tissue contrast on conventional imaging. In this study, we aimed to evaluate the accuracy of target delineation using Computed Tomography (CT) alone versus CT-Magnetic Resonance Imaging (MRI) fusion for SBRT planning in NSCLC patients with isolated paraaortic lymph node metastases.

**Materials and methods**: We conducted a comparative evaluation of target volume definition using CT-simulation images alone versus fused CT-MRI datasets in NSCLC patients with a single paraaortic lymph node metastasis.

**Results**: We observed notable differences in target volume delineation between CT-only and CT-MRI fusion-based approaches. The fusion of MRI allowed more precise identification of soft-tissue boundaries and differentiation of the nodal target from adjacent vascular and gastrointestinal structures.

**Conclusion:** Our results support the incorporation of multimodal imaging, particularly MRI, in the target definition process for SBRT of paraaortic lymph node metastases from NSCLC. The integration of MRI reduces uncertainties in target delineation and may improve treatment precision and outcomes. Future multicenter studies are warranted to confirm these findings and establish evidence-based guidelines.

**Keywords:** Paraaortic Lymph Node Metastases; Stereotactic Body Radiation Therapy (SBRT); Target Delineation; Non-Small Cell Lung Cancer (NSCLC); MRI Fusion

**Abbreviations:** NSCLC: Non-Small Cell Lung Cancer; SBRT: Stereotactic Body Radiation Therapy; IGRT: Image-Guided Radiotherapy; IMRT: Intensity-Modulated Radiotherapy; ART: Adaptive Radiotherapy; MRI: Magnetic Resonance Imaging; CT: Computed Tomography; CBCT: Cone-Beam CT; LINAC: Linear Accelerator AC

## Introduction

Non-Small Cell Lung Cancer (NSCLC) continues to represent a major global health burden, accounting for a substantial proportion of cancer-related mortality worldwide [1-7]. Within the broad spectrum of metastatic spread in NSCLC, paraaortic lymph node involvement constitutes a clinically significant pattern, particularly in the context of oligometastatic disease-a state characterized by limited metastatic burden that may be amenable to curative-intent local therapies [4]. This paraaortic involvement is increasingly recognized as a potential target for aggressive local treatment, especially as systemic therapies improve survival and shift the therapeutic focus toward local control of residual disease.

The advent and ongoing evolution of Stereotactic Body Radiotherapy (SBRT) have transformed the therapeutic landscape for such patients. By delivering highly conformal, ablative radiation doses to well-defined targets with sub-millimeter precision, SBRT has emerged as a viable and efficacious modality in managing isolated metastases, offering improved local control with minimal toxicity. However, the successful application of SBRT hinges on the accuracy of target definition. This becomes particularly challenging in anatomically complex regions such as the paraaortic space, where physiological motion, overlapping organs, and intricate vascular structures contribute to substantial uncertainty in target localization.

Advancements in radiotherapy technology-including Image-Guided Radiotherapy (IGRT), Intensity-Modulated Radiotherapy (IMRT), Adaptive Radiotherapy (ART), and the use of multimodal imaging—have significantly expanded our ability to treat small-volume, difficult-to-localize disease [8-49]. In particular, the integration of Magnetic Resonance Imaging (MRI) with conventional Computed Tomography (CT) during simulation has enhanced visualization of soft tissue structures and improved delineation of tumors in anatomically ambiguous regions.

MRI offers superior contrast resolution for soft tissues compared to CT, enabling clinicians to better differentiate pathological lymph nodes from adjacent structures such as the aorta, inferior vena cava, renal vessels, pancreas, and bowel loops. Given these advantages, MRI is increasingly utilized to complement CT-based planning in radiotherapy, particularly for targets where precision is essential and the margin for error is minimal. This study was designed to evaluate the impact of MRI integration on target definition in the SBRT planning process for NSCLC patients presenting with isolated paraaortic lymph node metastases. By comparing target volumes derived from CT alone versus those refined using CT-MRI fusion, we aimed to determine whether MRI contributes clinically meaningful improvements in delineation accuracy and treatment quality.

## Materials and Methods

The study was conducted at the Department of Radiation Oncology, University of Health Sciences, Gulhane Medical Faculty, involving patients with biopsy-proven or radiographically evident NSCLC who presented with a solitary paraaortic lymph node metastasis without other distant metastases. All patients provided informed consent, and inclusion criteria were based on radiological findings consistent with oligometastatic disease, performance status, and eligibility for SBRT.

For each enrolled patient, simulation was initially performed using a CT scanner (GE Lightspeed RT, GE Healthcare, UK), which acquired high-resolution axial images for initial treatment planning. Patients were immobilized in supine position. Rigid immobilization was secured to minimize intra- and inter-fraction motion, which is particularly relevant in the paraaortic region due to respiratory excursion and peristaltic activity. The MRI and CT datasets were imported into the treatment planning systems for registration based on anatomical landmarks and soft tissue correlation.

Target delineation was initially performed on CT simulation images alone. Subsequently, the CT-MRI fusion dataset was used to refine the contours, adjusting boundaries based on enhanced visualization of nodal margins and surrounding anatomy. Treatment planning was performed using a Synergy Linear Accelerator (LINAC) system (Elekta, UK) with kilovoltage cone-beam CT (CBCT) for daily IGRT. Radiation prescriptions followed AAPM Task Group reports and ICRU guidelines, with special emphasis placed on maintaining safe dose constraints for organs-at-risk (OARs) such as the kidneys, spinal cord, duodenum, and major blood vessels.

## Results

Analyses revealed that target volumes defined with CT alone were consistently less precise compared to those delineated using CT-MRI fusion. In multiple cases, CT-based contours either overestimated the target by incorporating adjacent vascular structures or underestimated nodal extent due to poor soft tissue discrimination. MRI-based refinement enabled clearer identification of nodal boundaries, especially in regions adjacent to the aorta and bowel, where contrast on CT was insufficient.

MRI-enhanced contours led to modifications in target volume in overwhelming majority of cases, depending on the anatomical location and degree of motion artifact. The improved accuracy in target delineation directly translated into better dose conformality in SBRT plans, with tighter dose gradients around the target and significantly reduced dose exposure to surrounding critical structures. Dose-volume histogram (DVH) analysis showed reductions in maximum and mean doses to the bowel and kidneys in plans derived from MRI-defined contours.

## Discussion

NSCLC remains a significant global health challenge, contributing substantially to cancer-related mortality worldwide [1–7]. Among the various metastatic patterns observed in NSCLC, paraaortic lymph node involvement represents a clinically important manifestation—particularly within the context of oligometastatic disease, a state defined by a limited number of metastases that may be amenable to curative-intent local therapies [4]. With the advancement of systemic treatments leading to improved survival outcomes, there is a growing emphasis on achieving durable local control in sites of residual disease such as paraaortic lymph nodes, which are increasingly viewed as viable targets for aggressive local interventions.

The emergence and continual refinement of SBRT have revolutionized treatment strategies for patients with limited metastatic disease. SBRT enables the precise delivery of high-dose, ablative radiation to well-defined targets, maximizing tumor control while minimizing toxicity. However, its effectiveness is heavily dependent on the accuracy of target delineation-an especially complex task in anatomically challenging regions like the paraaortic space. Factors such as physiological motion, adjacent organ overlap, and intricate vascular anatomy introduce substantial uncertainties in accurately identifying the treatment


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target. Recent advances in radiotherapy technologies-including IGRT, IMRT, ART, and the incorporation of multimodal imaging-have significantly enhanced our capacity to treat small-volume, anatomically ambiguous disease sites [8-49].

Of note is the integration of MRI with conventional CT during simulation, which provides superior soft tissue contrast and facilitates more accurate tumor delineation. Compared to CT, MRI offers enhanced resolution for differentiating pathological lymph nodes from neighboring structures such as the aorta, inferior vena cava, renal vasculature, pancreas, and bowel loops. As a result, MRI has become an increasingly valuable adjunct to CT in radiotherapy planning, especially when targeting regions that demand high precision and allow minimal margin for error. This study aimed to assess the impact of MRI integration on target delineation during SBRT planning for NSCLC patients presenting with isolated paraaortic lymph node metastases.

By comparing target volumes defined using CT alone with those refined through CT-MRI fusion, we sought to evaluate whether MRI contributes meaningful improvements in contouring accuracy and treatment quality. The study was conducted at the Department of Radiation Oncology, University of Health Sciences, Gulhane Medical Faculty, and included patients with either biopsy-confirmed or radiologically evident NSCLC exhibiting a single paraaortic lymph node metastasis and no evidence of other distant disease. All participants provided informed consent. Inclusion criteria were based on radiologic features consistent with oligometastatic disease, performance status, and eligibility for SBRT. Each patient underwent simulation using a CT scanner (GE Lightspeed RT, GE Healthcare, UK), acquiring high-resolution axial images for treatment planning.

Patients were immobilized in the supine position using rigid fixation devices to minimize intra- and inter-fraction motion-an important consideration in the paraaortic region, where respiratory motion and gastrointestinal peristalsis can introduce significant variability. MRI and CT datasets were imported into the treatment planning system and registered using anatomical landmarks and soft tissue correlation. Initial target contours were delineated using CT alone, followed by refinement based on CT-MRI fusion images, allowing for more precise adjustments based on superior visualization of nodal borders and surrounding anatomy.

Treatment planning was carried out using a Synergy Linear Accelerator (Elekta, UK) equipped with kilovoltage cone-beam CT (CBCT) for daily image guidance. Dose prescriptions adhered to recommendations from AAPM Task Groups and ICRU reports, with careful attention to established dose constraints for organs-at-risk (OARs) including the kidneys, spinal cord, duodenum, and major vessels. Analysis revealed that CT-based contours often lacked precision, either overestimating target volumes by including adjacent vascular structures or underestimating nodal extent due to insufficient soft tissue contrast. The incorporation of MRI significantly enhanced delineation accuracy, especially in areas near the aorta and bowel where CT offered limited discrimination. In most cases, MRI guidance led to meaningful modifications of the target volume.

These refinements directly improved dosimetric outcomes, resulting in tighter dose conformality and reduced radiation exposure to critical structures. DVH analyses demonstrated lower doses to the bowel and kidneys in treatment plans based on MRI-enhanced contours. Treating paraaortic lymph node metastases with SBRT presents several unique challenges. These include anatomical complexity, respiratory-induced motion, and the proximity of targets to radiosensitive organs. Traditional CT-based simulation, though widely used, often fails to adequately resolve soft tissue interfaces in this region. As such, there is an inherent risk of geographic miss, where parts of the true tumor volume may be excluded from treatment, or excessive dose spillage, where non-target tissues receive high doses unnecessarily.

Our findings underscore the utility of MRI as a complementary imaging modality, offering refined visualization capabilities that meaningfully inform target contouring. In doing so, MRI helps mitigate the aforementioned risks, particularly in stereotactic settings where high dose hypofractionation magnifies the consequences of contouring errors. The ability to distinguish tumor tissue from vessels, lymphatics, and bowel loops is particularly advantageous in the retroperitoneal and paraaortic region, where boundaries are otherwise indistinct on CT. These results align with a growing body of literature advocating for the integration of multimodal imaging in radiotherapy planning for thoracic, abdominal, and several other malignancies, and studies addressing public health perspectives of cancer management [8-112].

While technical and logistical challenges persist-such as MRI availability, registration accuracy, and time/resource demands-the clinical benefits in terms of precision, safety, and potential for outcome improvement appear substantial. In summary, our study highlights the critical role of MRI in improving the accuracy of target definition for SBRT in NSCLC patients with isolated paraaortic lymph node metastases. The incorporation of MRI into standard simulation workflows enables more precise contouring, better sparing of critical organs, and improved confidence in plan quality. Given the anatomical and dosimetric challenges associated with paraaortic targets, multimodal imaging-especially CT-MRI fusion—should be considered when planning stereotactic treatments in such scenarios. Further validation in larger, multi-institutional cohorts with long-term follow-up will be instrumental in confirming these results and potentially influencing clinical guidelines for SBRT in oligometastatic NSCLC.



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## Conflicts and Acknowledgment

There are no conflicts of interest and no acknowledgement.

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