



Review article

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Appraisal of Target Volume Definition for Stereotactic Irradiation of Single Retroperitoneal Lymph Node Metastases from Colorectal Cancers



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Abstract

Objective: There is growing recognition that isolated retroperitoneal lymph node metastases (RLNMs) may be amenable to aggressive local treatments, including stereotactic body radiotherapy (SBRT). However, success of SBRT critically depends on precise target volume definition—particularly in the retroperitoneal space, where overlapping gastrointestinal, vascular, and renal structures pose significant challenges to accurate delineation. In this study, target definition was assessed by using Computed Tomography (CT)-simulation only images vs CT-Magnetic Resonance Imaging (MRI) fusion.

Materials and Methods: Simulation involved CT acquisition in supine position with individualized immobilization devices to minimize motion. Axial images were acquired. MRI imaging was also obtained including multiple sequences.

Results: MRI fusion led to meaningful modifications in target borders, most notably, retraction of margins from adjacent vessels or bowel loops that had been erroneously included in CT simulation-alone planning. MRI integration allowed for sharper definition of nodal boundaries, particularly in cases involving perivascular or retrocrural locations, where CT contrast was inadequate.

Conclusion: CT-MRI fusion improved contouring precision and plan quality. Integration of MRI into radiotherapy planning should be considered standard practice in such anatomically complex scenarios.

Keywords: Colorectal Cancer (CRC); Retroperitoneal lymph node metastases; Stereotactic Body Radiation Therapy (SBRT); Target delineation; MRI fusion

Abbreviations: CT: Computed Tomography; CRC: Colorectal Cancer; SBRT: stereotactic body radiotherapy; RLNMs: retroperitoneal lymph node metastases; MRI: Magnetic Resonance Imaging; OAR: Organ-at-Risk

Introduction

Colorectal cancer (CRC) remains a leading cause of cancer morbidity and mortality worldwide, with distant metastases representing a major cause of disease-related death [1]. While hepatic and pulmonary metastases have been extensively studied and frequently targeted for curative-intent local therapies, retroperitoneal lymph node metastases (RLNMs) represent a distinct and less commonly addressed pattern of spread [2-7]. However, in the era of precision oncology and oligometastatic disease management, there is growing recognition that isolated

RLNMs may be amenable to aggressive local treatments, including stereotactic body radiotherapy (SBRT).

This strategy is particularly appealing to patients with well-controlled primary disease and limited systemic burden, wherein durable local control may translate to improved progression-free and even overall survival. Stereotactic body radiotherapy (SBRT) has emerged as a transformative modality for treating small-volume, anatomically complex metastases by delivering high-dose, conformal radiation in a limited number of fractions.

SBRT has been shown to achieve excellent local control rates with limited toxicity when applied judiciously. However, its success critically depends on precise target volume definition-particularly in the retroperitoneal space, where overlapping gastrointestinal, vascular, and renal structures pose significant challenges to accurate delineation.

The retroperitoneum represents a dynamic and intricate anatomical region, characterized by physiologic motion, substantial inter-patient variability, and proximity to radiosensitive structures such as the kidneys, duodenum, pancreas, ureters, and major vessels (aorta and inferior vena cava). Traditional CT-based simulation, while commonly used, often lacks sufficient soft tissue contrast to distinguish metastatic nodes from adjacent non-target tissues. In contrast, magnetic resonance imaging (MRI) offers superior soft tissue visualization, especially in differentiating pathological lymph nodes from bowel loops, vascular landmarks, and fibrotic tissues.

Integration of MRI with CT-via rigid or deformable registration-has been proposed as a means of enhancing contouring accuracy and treatment confidence. This study aims to assess and refine target volume definition for SBRT in patients with solitary retroperitoneal lymph node metastases from colorectal cancer. By comparing planning approaches based on CT-alone versus CT-MRI fusion, we investigate the degree to which MRI contributes to improved target accuracy, dosimetric quality, and organ-at-risk (OAR) sparing. We also contextualize these findings within the broader framework of oligometastatic CRC management and emerging paradigms in image-guided adaptive radiotherapy.

Materials and Methods

This study was conducted at the Department of Radiation Oncology, University of Health Sciences, Gulhane Medical Faculty. Patients with histologically confirmed colorectal adenocarcinoma and radiographically or biopsy-confirmed solitary retroperitoneal lymph node metastases were studied. All cases were evaluated by a multidisciplinary tumor board and deemed appropriate for SBRT due to limited metastatic burden, absence of other active sites, adequate performance status (ECOG 0-2), and lack of contraindications to ablative radiotherapy.

Simulation involved CT acquisition using a GE Lightspeed RT scanner (GE Healthcare, UK) in a supine position with individualized immobilization devices to minimize motion. Axial images were acquired. MRI imaging was also obtained including multiple sequences. Datasets were registered to facilitate precise anatomical correlation. Initial target volumes were delineated on CT images by experienced radiation oncologists. MRI datasets were then fused, and target volumes were re-contoured with MRI input, allowing for refinements based on superior soft tissue discrimination.

Treatment planning was executed on the treatment planning system available at our department, with delivery via Elekta

Synergy LINAC equipped with cone-beam CT (CBCT) for daily IGRT. Plans were prescribed to achieve 95% PTV coverage, with prioritization of organ-at-risk constraints per QUANTEC and AAPM guidelines. Dose-volume histogram (DVH) metrics were compared between CT-only and CT-MRI fusion-based plans.

Results

Patients with solitary RLNs from colorectal cancer were studied. MRI fusion led to meaningful modifications in target borders-most notably, retraction of margins from adjacent vessels or bowel loops that had been erroneously included in CT simulation-alone planning. MRI integration allowed for sharper definition of nodal boundaries, particularly in cases involving perivascular or retrocrural locations, where CT contrast was inadequate. DVH analysis demonstrated that MRI-refined plans yielded improved dose conformity and steeper dose gradients. Our findings demonstrated that target volumes delineated using CT alone were consistently less accurate than those obtained through CT-MRI fusion. In several cases, CT-based contours either overestimated the target by including adjacent vascular structures or underestimated the true nodal extent due to limited soft tissue contrast.

The integration of MRI significantly improved the clarity of nodal boundaries, particularly in regions near the aorta and bowel, where CT imaging lacked sufficient contrast resolution. In majority, MRI-guided contouring resulted in meaningful adjustments to the target volume, influenced by anatomical complexity and motion-related artifacts. This enhanced precision in target definition translated into improved dosimetric outcomes-yielding greater dose conformity, sharper dose gradients, and markedly reduced radiation exposure to nearby critical organs.

Discussion

CRC remains one of the most common causes of cancer-related morbidity and mortality worldwide, with distant metastases constituting a major contributor to disease-specific death [1]. While hepatic and pulmonary metastases have been well-characterized and are frequently targeted with curative-intent local therapies, retroperitoneal lymph node metastases (RLNs) represent a less common and often underrecognized pattern of disease spread [2-7]. In the context of precision oncology and evolving approaches to oligometastatic disease, there is growing interest in aggressively treating isolated RLNs-particularly through SBRT-in patients with well-controlled primary tumors and limited systemic disease. In such cases, durable local control may contribute to prolonged progression-free and overall survival.

SBRT has emerged as a powerful modality for treating small-volume, anatomically complex metastases by delivering high-dose, conformal radiation over a limited number of fractions. When appropriately applied, SBRT achieves high local control rates with minimal toxicity. However, its efficacy relies heavily on precise target delineation-an especially challenging task in the

retroperitoneum due to the proximity of critical structures such as the kidneys, duodenum, pancreas, ureters, and major vessels (e.g., the aorta and inferior vena cava), as well as the region's dynamic anatomy and inter-patient variability.

Traditional CT-based simulation, although commonly used, often lacks sufficient soft tissue contrast to accurately distinguish metastatic nodes from adjacent normal tissues. In contrast, magnetic resonance imaging (MRI) offers superior soft tissue resolution, particularly for differentiating lymph nodes from bowel loops, vessels, and fibrotic tissues. As such, integrating MRI with CT-via rigid or deformable registration- has been proposed to enhance contouring accuracy and improve confidence in treatment planning. Our study was aimed at evaluating and optimize target volume definition for SBRT in patients with solitary RLNs from colorectal cancer. Specifically, we compared CT-alone versus CT-MRI fusion-based planning to assess the impact of MRI on target delineation, dosimetric quality and sparing of OARs.

These findings were further contextualized within current frameworks for oligometastatic CRC and evolving concepts in image-guided adaptive radiotherapy. In the context of oligometastatic colorectal cancer, isolated RLNs represent a clinically relevant and increasingly actionable disease state. As systemic therapies extend survival, there is growing impetus to pursue local control strategies for limited metastatic deposits. SBRT has emerged as a key modality in this space due to its ability to deliver high-dose, ablative treatments with minimal interruption of systemic regimens. However, its therapeutic ratio is intimately linked to the precision of target volume delineation-particularly in anatomically complex zones like the retroperitoneum.

Our study reinforces the critical role of MRI in improving the accuracy of SBRT for RLNs. By enhancing visualization of soft tissue planes, MRI facilitates more accurate exclusion of non-target structures from the GTV, thereby refining the PTV and minimizing collateral dose to sensitive OARs. In addition to dosimetric advantages, this precision has implications for reducing toxicity, maintaining adjacent organ function, and increasing confidence in treatment plan quality. Our findings align with prior studies supporting MRI in pelvic and abdominal radiotherapy, including those for rectal, gynecologic, and pancreatic malignancies along with several other disease sites throughout the human body [8-112].

MRI-based adaptive approaches are increasingly being integrated into clinical trials and routine practice, and the current results support extending these workflows to retroperitoneal metastases. Challenges remain, including the availability of high-quality MRI, the need for robust registration protocols, and resource-intensive contouring workflows. Nonetheless, the benefits observed-in terms of volume reduction, dose conformity, and OAR sparing-underscore the value of multimodal imaging in this high-stakes setting.

In conclusion, our appraisal of target volume definition for SBRT in solitary retroperitoneal lymph node metastases from colorectal cancer reveals that CT-MRI fusion significantly improves contouring precision and plan quality. Integration of MRI into radiotherapy planning should be considered standard practice in such anatomically complex scenarios. Larger studies with longer follow-up are warranted to assess long-term outcomes and further validate the integration of advanced imaging in SBRT planning for oligometastatic colorectal cancer.

Conflicts of Interest

There are no conflicts of interest and no acknowledgements.

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