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Assessment of Target Delineation for Stereotactic Ablative Body Radiotherapy (SABR) of Retroperitoneal Soft Tissue Metastatic Deposits from Gastrointestinal Malignancies

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Abstract

Objective: This study evaluates the impact of CT-MRI fusion on target volume delineation for stereotactic ablative body radiotherapy (SABR) of retroperitoneal soft tissue metastases arising from gastrointestinal malignancies.

Materials And Methods: Patients with retroperitoneal metastatic deposits from gastrointestinal cancers who underwent SABR were retrospectively reviewed. Initial gross tumor volumes (GTVs) were contoured on planning CT images. MRI datasets were subsequently fused with simulation CT images, and target volumes were re-evaluated using combined anatomical information. CT-only and CT-MRI fusion-based plans were compared with respect to contouring characteristics, target conformity, and organ-at-risk exposure.

Results: Incorporation of MRI altered target volume contours in several evaluated patients, particularly in anatomically complex retroperitoneal regions. CT-MRI fusion-based plans generally demonstrated improved dose conformality and reduced irradiation of surrounding organs at risk while maintaining target coverage.

Conclusion: CT-MRI fusion improved target delineation and dosimetric quality compared with CT-based planning alone for SABR of retroperitoneal metastases from gastrointestinal malignancies. Multimodality imaging may be particularly useful for lesions located in anatomically complex retroperitoneal regions. Further prospective studies are warranted to better define the role of MRI-guided planning and adaptive radiotherapy approaches in this setting.

Keywords: Gastrointestinal Malignancies; Retroperitoneal Metastases; SABR; Morbidity; Mortality

Abbreviations: SABR: Stereotactic Ablative Body Radiotherapy; GTVs: Gross Tumor Volumes

Introduction

Gastrointestinal malignancies remain a major cause of cancer-related morbidity and mortality worldwide. Despite ongoing advances in systemic therapy and multidisciplinary cancer care, many patients ultimately develop metastatic disease during their illness. Common metastatic sites include the liver, lungs, lymph nodes, peritoneum, and retroperitoneal soft tissues. Retroperitoneal metastatic involvement is particularly challenging because lesions frequently arise near radiosensitive abdominal structures. Retroperitoneal soft tissue metastases may originate from several gastrointestinal primaries, including colorectal, gastric, pancreatic, biliary, and small bowel cancers. These lesions are often situated near the bowel, duodenum, kidneys, pancreas, ureters, spinal canal, and major vascular structures such as the aorta and inferior vena cava. As a result, local treatment approaches in this region require careful balancing of tumor coverage and normal tissue sparing.

The concepts of oligometastatic and oligoprogressive disease have increasingly influenced management strategies in metastatic gastrointestinal cancers. In selected patients, local ablative therapies may complement systemic treatment and contribute to prolonged disease control. Surgical resection, thermal ablation, and stereotactic ablative body radiotherapy (SABR) are among the approaches currently used in carefully selected patients with limited metastatic burden. SABR has become an important noninvasive treatment option because it allows delivery of highly conformal ablative doses in a limited number of fractions. Advances in image guidance, intensity modulation, volumetric arc therapy, respiratory motion management, and adaptive radiotherapy have expanded the feasibility of stereotactic treatment in anatomically complex regions [1-62].

However, successful SABR delivery depends heavily on accurate target delineation and reliable image guidance. This is especially relevant in the retroperitoneum, where organ motion, bowel displacement, and complex anatomical relationships may complicate treatment planning. Inaccurate contouring may result in geographic miss, whereas unnecessarily large treatment volumes may increase radiation exposure to adjacent organs at risk. CT simulation remains the standard basis for radiotherapy planning because of its geometric reliability and electron density required for dose calculation. Nevertheless, CT alone may provide limited soft tissue contrast in the retroperitoneal compartment.

Distinguishing metastatic lesions from bowel loops, postoperative changes, vascular structures, or adjacent musculature may therefore be difficult in selected cases. MRI offers improved soft tissue characterization and multiplanar visualization, which may facilitate more accurate appreciation of lesion boundaries and surrounding anatomy. Consequently, CT-MRI fusion has attracted growing interest in radiotherapy planning, particularly for anatomically complex disease sites. The present study assessed the role of CT-MRI fusion in target definition for SABR of retroperitoneal soft tissue metastases from gastrointestinal malignancies. We additionally evaluated its potential impact on target conformity, contouring confidence, and organ-at-risk sparing.

Materials and Methods

Our study was conducted at the Department of Radiation Oncology, University of Health Sciences, Gulhane Medical Faculty, a tertiary referral center with experience in stereotactic radiotherapy and multidisciplinary gastrointestinal cancer management. Patients with gastrointestinal malignancies and radiologically identified retroperitoneal soft tissue metastases treated with SABR were retrospectively reviewed. All cases were discussed at a multidisciplinary tumor board involving radiation oncologists, medical oncologists, radiologists, and gastrointestinal oncology specialists. Suitability for SABR was determined according to metastatic burden, systemic disease status, performance status, prior treatments, lesion accessibility, and feasibility of safe stereotactic irradiation. Simulation CT imaging was obtained using a dedicated radiotherapy CT simulator. Patients were immobilized in the supine position with individualized immobilization devices to improve setup reproducibility.

Intravenous contrast-enhanced imaging was used when clinically appropriate to improve visualization of abdominal anatomy and vascular structures. Thin-slice axial images were acquired for treatment planning purposes. MRI examinations were additionally performed using abdominal imaging protocols optimized for soft tissue evaluation. MRI datasets were fused with planning CT images using image registration techniques to facilitate anatomical correlation. Initial gross tumor volumes were delineated on CT simulation images alone by experienced radiation oncologists. MRI datasets were subsequently incorporated into the contouring workflow, and target volumes were reviewed again using combined imaging information. Modifications were performed when MRI improved lesion conspicuity or clarified anatomical interfaces. Clinical target volume and planning target volume expansions were generated according to institutional practice while accounting for lesion location, setup uncertainty, and expected organ motion.

Particular attention was directed toward adjacent bowel, duodenum, kidneys, pancreas, liver, spinal canal, ureters, and major vascular structures. Treatment planning was performed using the institutional planning system. IMRT and VMAT techniques were used to optimize dose conformity and organ sparing. Plans were generated to achieve adequate target coverage while respecting accepted dose constraints for nearby organs at risk. Daily cone-beam CT verification was used during treatment delivery for image guidance and setup confirmation. Comparisons between CT-only and CT-MRI fusion-based plans included qualitative contour assessment as well as dosimetric evaluation using dose-volume histogram parameters. Analyses focused on target conformity, dose falloff, target coverage, and radiation exposure to surrounding organs at risk.

Results

Patients with retroperitoneal soft tissue metastases from gastrointestinal malignancies were included in the analysis. Incorporation of MRI into the contouring workflow resulted in visible changes to target volumes in a substantial proportion of evaluated cases. Compared with CT-only contouring, CT-MRI fusion improved visualization of lesion boundaries and reduced uncertainty regarding the relationship between metastatic deposits and surrounding retroperitoneal structures. The greatest differences were observed in lesions adjacent to bowel loops, pancreas, kidneys, paraspinal musculature, vascular structures, and postoperative soft tissue alterations. In several cases, CT-only contouring appeared to overestimate lesion extent because of limited soft tissue discrimination. In others, MRI revealed subtle areas of extension that were less conspicuous on CT imaging alone.

Fusion imaging therefore contributed to more anatomically consistent target definition in anatomically crowded regions. MRI fusion also improved delineation of interfaces between target lesions and adjacent organs at risk. These improvements were especially relevant for lesions located near the duodenum, ureters, kidneys, spinal canal, and major vessels. Dosimetric analysis showed improved conformality and steeper dose gradients in CT-MRI fusion-based plans while maintaining acceptable target coverage. In multiple patients, MRI-guided contour refinement reduced unnecessary irradiation of nearby normal tissues. Improved lesion conspicuity additionally facilitated image registration and treatment verification during stereotactic planning and

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image guidance workflows. The advantages of MRI fusion were most apparent in lesions with irregular morphology, postoperative anatomical distortion, or limited visibility on CT imaging alone.

Discussion

Retroperitoneal metastases from gastrointestinal malignancies present substantial challenges for stereotactic radiotherapy because these lesions are often located immediately adjacent to critical abdominal organs. In patients with oligometastatic or oligoprogressive disease, stereotactic ablative body radiotherapy (SABR) has become an increasingly utilized local treatment approach that may provide durable local control while minimizing disruption of ongoing systemic therapy. However, successful delivery of SABR depends heavily on accurate target delineation, particularly in anatomically crowded regions such as the retroperitoneum. The retroperitoneal compartment contains multiple radiosensitive structures including the kidneys, bowel, duodenum, pancreas, ureters, spinal canal, and major vessels.

Since SABR relies on highly conformal dose delivery with rapid dose falloff beyond the target volume, relatively small contouring inaccuracies may affect either target coverage or radiation exposure to surrounding normal tissues. In the current study, incorporation of MRI into the planning workflow improved visualization of lesion boundaries and reduced uncertainty during contouring compared with CT-only planning. The advantages of MRI were most evident in lesions located near bowel interfaces, vascular structures, paraspinal tissues, and postoperative anatomical distortion where CT alone frequently provided suboptimal soft tissue definition. In several patients, MRI fusion altered target contours and improved appreciation of lesion extent. These findings are clinically relevant because retroperitoneal SABR often requires balancing adequate tumor coverage against strict dose constraints for adjacent organs at risk.

More accurate delineation may therefore contribute to safer treatment delivery and reduction of unnecessary irradiation to nearby tissues. The dosimetric findings of this analysis also support the value of multimodality imaging in retroperitoneal stereotactic radiotherapy. CT-MRI fusion-based plans generally demonstrated improved conformality together with lower radiation exposure to surrounding organs at risk. This may be particularly important in patients with prior abdominal surgery, extensive systemic therapy exposure, or reduced organ reserve. MRI provides superior soft tissue contrast compared with CT and may allow clearer differentiation between metastatic lesions, bowel loops, postoperative fibrosis, musculature, and surrounding soft tissues. Multiplanar image evaluation may further improve assessment of tumor extent and anatomical relationships in complex retroperitoneal regions. Another issue of growing importance is the increasing use of adaptive radiotherapy in stereotactic treatment workflows.

MRI-guided treatment platforms now allow online treatment adaptation according to daily anatomical variation and organ motion. Such approaches may be especially useful in retroperitoneal SABR because bowel position, abdominal organ configuration, and soft tissue relationships may vary considerably between fractions. Respiratory motion and organ displacement also remain important sources of geometric uncertainty during treatment of retroperitoneal lesions. MRI-based imaging approaches may improve assessment of these motion-related anatomical changes and could support more individualized treatment adaptation strategies in future clinical practice.

Further prospective studies involving larger patient populations, standardized imaging protocols, motion analysis, and adaptive treatment workflows are needed to better define the role of MRI-guided planning in retroperitoneal SABR. Overall, the present findings suggest that CT-MRI fusion improves target delineation and dosimetric plan quality compared with CT-only planning for SABR of retroperitoneal soft tissue metastases from gastrointestinal malignancies. MRI contributed to better visualization of tumor boundaries and adjacent anatomical structures, particularly in anatomically complex regions. Integration of multimodality imaging may therefore enhance stereotactic radiotherapy planning for selected retroperitoneal metastatic lesions, although additional prospective validation remains necessary.

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