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Improved OAR Sparing in Lung Lattice SFRT Using Breath-Hold Respiratory Motion Management

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ABSTRACT

Purpose:
Lattice Spatially Fractionated Radiation Therapy (Lattice SFRT) creates steep peak-to-valley dose gradients within bulky tumors. In lung treatments, respiratory motion may displace high-dose lattice vertices toward adjacent organs at risk (OARs), compromising the intended spatial dose distribution. This study evaluated whether SDX breath-hold respiratory motion management improves target fidelity and OAR sparing during lung Lattice SFRT.

Methods:
Five lung cancer datasets with about 5mm respiratory motion, were retrospectively analyzed. VMAT-based Lattice SFRT plans were generated in Eclipse using 6 MV FFF beams on Edge and Halcyon linear accelerators. Three planning scenarios were compared: planning on the mean CT using the internal target volume (ITV), transfer of the lattice geometry from the mean CT to the SDX breath-hold CT, and lattice optimization directly on the SDX breath-hold CT. Dosimetric evaluation included rib D1cc, lung V7Gy, liver V7Gy, skin D10cc, dose profile analysis, and preservation of lattice geometry.

Results:
Respiratory motion displaced lattice vertices relative to the tumor, causing high-dose regions to migrate toward adjacent normal tissues. Compared with mean CT planning, SDX-guided planning reduced rib D1cc from approximately 10–12 Gy to 7–8.5 Gy, lung V7Gy from 29–35 cc to 7–8 cc, liver V7Gy by approximately 15–20%, and skin D10cc. A simulated 5-mm displacement reduced the point-based peak-to-valley dose ratio (PVDR) by approximately 25%, demonstrating degradation of the intended lattice dose distribution without motion management.

Conclusions:
SDX breath-hold respiratory motion management preserves lattice geometry, maintains the intended peak-to-valley dose distribution, and significantly improves OAR sparing in lung Lattice SFRT. These findings support breath-hold motion management as a practical strategy for improving the robustness and safety of Lattice SFRT for moving thoracic tumors.

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INTRODUCTION

Lattice SFRT is an emerging technique for the treatment of bulky tumors by delivering highly heterogeneous dose distributions, consisting of high-dose vertices embedded within a lower-dose background. This approach enhances tumor dose escalation while limiting radiation exposure to surrounding normal tissues. Modern volumetric modulated arc therapy (VMAT) has enabled clinically feasible Lattice SFRT through precise delivery of complex three-dimensional dose distributions.
Unlike conventional radiotherapy, Lattice SFRT relies on maintaining steep peak-to-valley dose gradients and accurate spatial positioning of individual vertices. Consequently, respiratory motion presents a significant challenge for tumors, where displacement of only a few millimeters can shift high-dose vertices outside the intended target or closer to adjacent OARs. Such motion may reduce the PVDR, blur the intended lattice dose distribution, and increase irradiation of critical normal tissues, potentially compromising both treatment effectiveness and safety.
Breath-hold respiratory motion management has been widely adopted in thoracic radiotherapy to reduce tumor motion and improve treatment reproducibility. However, its dosimetric impact on Lattice SFRT has not been well characterized. This study investigates the role of the SDX breath-hold system in preserving lattice geometry and reducing OAR dose during lung Lattice SFRT by comparing plans generated with and without breath-hold motion management.

METHODS AND MATERIALS

Five retrospective lung cancer datasets exhibiting respiratory motion greater than 5 mm on 4D CT were evaluated. VMAT-based Lattice SFRT plans were created in Eclipse TPS (Acuros XB v16) using 6 MV flattening filter-free beams for both Edge and Halcyon linear accelerators. To investigate the dosimetric impact of respiratory motion, three planning scenarios were compared: (1) planning on the mean CT with the lattice target derived from the internal target volume (ITV), (2) transferring the lattice geometry designed on the mean CT to the SDX breath-hold CT to simulate treatment without motion adaptation, and (3) re-optimizing the lattice geometry directly on the SDX breath-hold CT using the breath-hold gross tumor volume. The SDX Respiratory Gating System was used to acquire breath-hold CT images with reduced respiratory motion. Dosimetric evaluation included dose profile analysis, preservation of lattice geometry and PVDR, and OAR metrics including rib D1cc, lung V7Gy, liver V7Gy, and skin D10cc.

RESULTS

Respiratory motion displaced high-dose lattice vertices relative to the gross tumor volume, increasing the likelihood of unintended irradiation of adjacent OARs. A simulated 5-mm respiratory displacement degraded the planned lattice dose distribution, reducing the point-based PVDR by approximately 25% and demonstrating the sensitivity of Lattice SFRT to respiratory motion. Re-optimizing plans on SDX breath-hold CT images improved geometric alignment between lattice vertices and the target while reducing unnecessary dose to surrounding normal tissues. Compared with planning on the mean CT, SDX-guided planning improved all evaluated OAR dosimetric metrics, including rib D1cc, lung V7Gy, liver V7Gy, and skin D10cc **(Table 1)**. These findings indicate that breath-hold respiratory motion management preserves the intended lattice geometry, maintains the spatial dose distribution, and substantially improves OAR sparing during lung Lattice SFRT.
Figure 1 illustrates the spatial relationship of SFRT target structures on SDX breath-hold CT images in the axial, coronal, and sagittal planes.

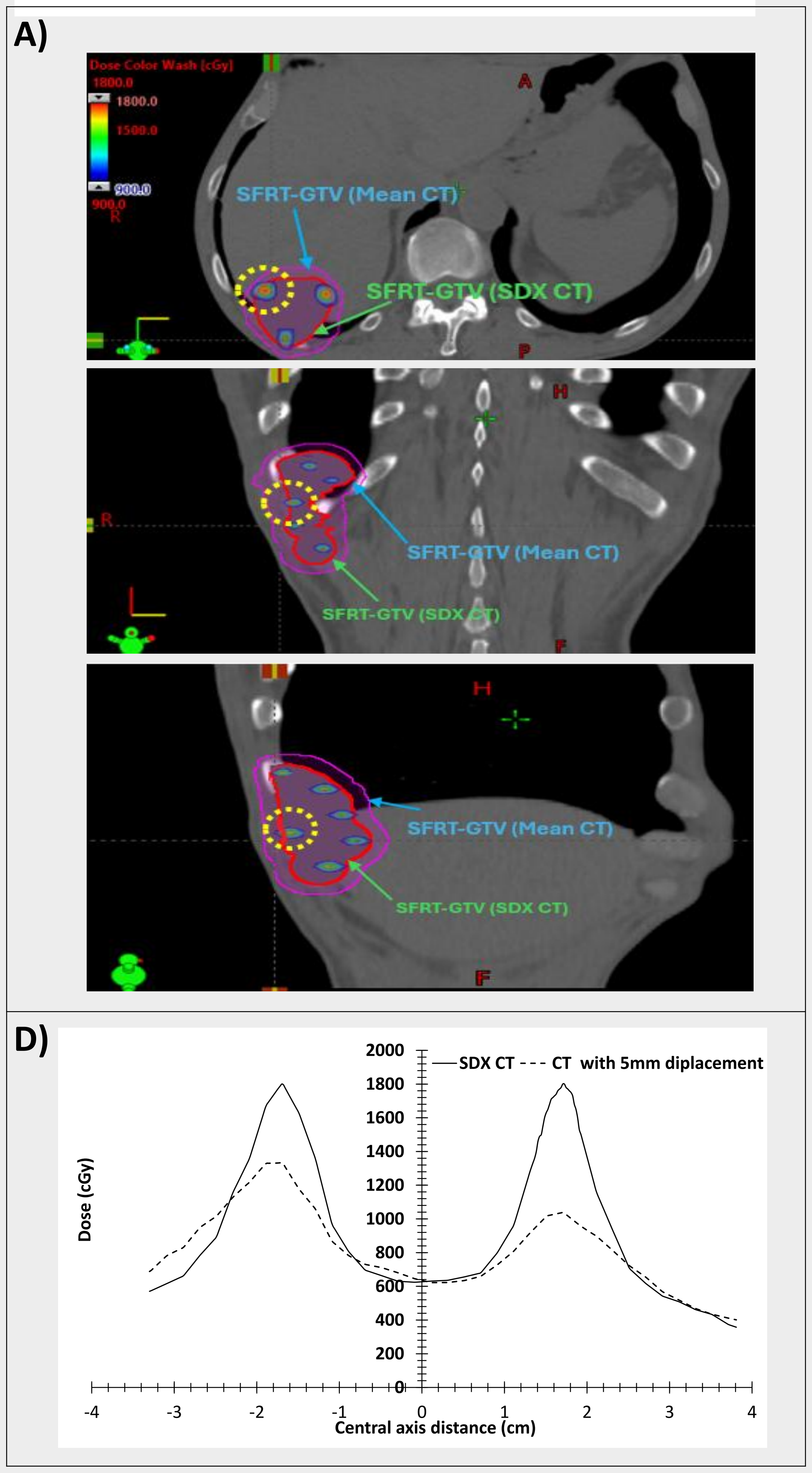

Figure 1. A) Axial (top), coronal (middle), and sagittal (bottom) views of the SDX breath-hold CT showing SFRT target structures. SFRT-GTV and vertex structures contoured on the mean CT were transferred to the SDX CT. Yellow dashed regions indicate high-dose vertices near or partially outside the SDX-based SFRT-GTV, highlighting potential increased dose to adjacent OARs due to respiratory-induced anatomical differences. B) Dose profile comparison along a line within the SFRT GTV on the SDX CT versus the dose profile along the same line with a 5 mm displacement in the superior–inferior direction.

Table 1. Average values for OAR dosimetric metrics for SFRT plans across different scenarios with/without SDX motion management. Values are reported for Edge / Halcyon (E/H).

OARs	Mean CT with Mean contours (E/H)	SDX CT with Mean contours (E/H)	SDX CT with SDX contours (E/H)
Rib, D1cc	10.1 Gy/ 12.4 Gy	10.2 Gy/12.2 Gy	7.3 Gy/8.5 Gy
Lung, V 7 Gy	28.6 cc/ 35 cc	21.5 cc/ 32.7 cc	7.4 cc/8.1 cc
Liver, V 7 Gy	8.4 cc/ 9.9 cc	7.8 cc/ 9.1 cc	6.8 cc/8.0 cc
Skin, D 10cc	2.3 Gy/ 3.0 Gy	2.7 Gy /3.4 Gy	2.2 Gy/2.0 Gy

DISCUSSION

Lattice SFRT is highly sensitive to respiratory motion because its dose pattern relies on stable alignment of high-dose vertices and low-dose valleys. Even small tumor shifts can distort this pattern, reduce PVDR, and increase unintended dose to nearby OARs.
This study shows that SDX breath-hold improves geometric accuracy by reducing motion during imaging and planning. Compared with mean CT–based planning, it better preserves lattice structure and lowers dose to surrounding tissues such as lung, ribs, liver, and skin.
Despite the additional setup time, breath-hold techniques appear beneficial for thoracic Lattice SFRT. Larger studies are needed to define optimal thresholds for implementing motion management in SFRT for mobile targets.

CONCLUSIONS

Even small target displacements can degrade PVDR and increase unintended dose to adjacent organs at risk. This study shows that SDX breath-hold significantly improves geometric accuracy during imaging and planning by reducing respiratory motion. SDX-based planning better preserves lattice architecture and reduces dose to surrounding normal tissues. Although it increases treatment complexity, breath-hold techniques are recommended for thoracic Lattice SFRT.

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