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Evaluating the Feasibility of a Simulation-Free Pipeline in a Regional Healthcare Network

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ABSTRACT

In a typical radiation therapy treatment planning workflow, a CT simulation scan is acquired. This scan is an anatomical mapping of the patient, allowing for the delineation of both the tumor and organs that should be avoided during the treatment. Simulation free radiation therapy (SFRT) is an emerging treatment modality that removes the necessity of the planning CT(pCT) in favor of using a previously acquired diagnostic CT(dCT) scan instead. Removing pCT allows for a more efficient workflow while maintaining accuracy and precision. This study evaluates the feasibility of implementing SFRT for palliative 3D-CRT treatments in our institutes.

A cohort of 40 cancer patients treated at The University of Toledo was retrospectively selected based on tumor location, palliative intent, and 3D-CRT delivery technique. dCT scans were acquired internally or externally prior to pCT. A deformable registration was performed and the delineated structures from pCT were transferred to the diagnostic image. To evaluate the feasibility of treatment planning directly on dCT, the Hounsfield Units (HU) of the PTVs and OARs were compared, and the original pCT-based treatment plans were recalculated on the dCT to determine dosimetric effectiveness.

The median Hounsfield unit difference between pCT and dCT images was 4.34% in the PTV and 10% in organs at risk. The preliminary dose difference was 0.05% in the PTV and 0% in OARs, remaining within clinically acceptable limits for palliative treatments. Variability in deformable registration performance was identified as a limiting factor, suggestions that improved standardization could further reduce dose discrepancies.

In conclusion, the insignificant dose differences between pCT and dCT suggest that dCT is a viable method for making palliative plans. SFRT demonstrates the potential to reduce delays and improve efficiency without sacrificing dosimetric accuracy. Future efforts will focus on standardizing the SFRT workflow and integrating autoplanning to maximize clinical speed and treatment efficiency.

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INTRODUCTION

Radiation therapy (RT) is used in about 50% of all cancer patients and is often delivered via linear accelerator (LINAC). Conventional RT requires a multi-step workflow spanning couple weeks:

Consultation → CT simulation → contouring → RT planning → Chart QA → Treatment delivery

For palliative patients who need rapid symptom relief, this delay is significant. Barriers to RT access include: (1) Time: simulation, contouring, and planning alone take several days. (2) Personnel: ASTRO survey found >90% of practices report clinical staffing shortages. (3) Socioeconomic factors: geographic and financial disparities limit access.

Recent studies [4,5, and 6] demonstrate feasibility of dCT-based planning for palliative RT while maintaining dosimetric accuracy. Simulation-Free RT (SFRT) replaces the planning CT with a previously acquired diagnostic CT (dCT), removing an entire workflow step for palliative care. Key differences between dCT and pCT scanners include couch geometry, HU calibration, bore size, external laser, surface guidance and the use of immobilization devices.

At the University of Toledo Medical Center (UTMC), three-dimensional conformal radiation therapy (3D-CRT) accounts for 20% of palliative cases. Currently, patients experience a mean interval of 24 days from diagnostic imaging to simulation, followed by an average simulation-to-treatment wait time of 16 days. To address these timelines, this study evaluates the feasibility of implementing single-fraction radiotherapy (SFRT) for palliative treatments within the UTMC regional healthcare network.

METHODS AND MATERIALS

Patient Selection and Imaging

A total of 40 cancer patients receiving palliative radiotherapy with three-dimensional conformal radiation therapy (3D-CRT) were retrospectively selected for this study. The cohort included patients with lesions involving the spine (n = 15), hip (n = 10), rib (n = 6), sacrum (n = 5), and scapula (n = 4). All patients had both a diagnostic CT (dCT) and a planning CT (pCT) available for analysis, allowing direct comparison between the two imaging datasets.

Image Registration and HU Analysis

To facilitate anatomical comparison, deformable image registration (DIR) was performed in the RayStation Treatment Planning System (TPS). Target volumes and organs at risk (OARs) delineated on the pCT were propagated to the corresponding dCT using the deformation map generated by the DIR algorithm. The mean and median Hounsfield Unit (HU) values of the planning target volumes (PTVs) and OARs were then measured and compared between the pCT and dCT datasets to assess differences in tissue density representation.

Dosimetric and Statistical Analysis

The clinically approved treatment plans originally generated on the pCT were recalculated on the dCT without modifying the treatment parameters.

Dosimetric comparisons focused on clinically relevant metrics, including D2cc and the percentage differences in dose delivered to the PTVs and OARs. Statistical analysis was performed using the Wilcoxon signed-rank test, with statistical significance defined as $\alpha = 0.05$. The dosimetric agreement between the two image sets was evaluated against the International Commission on Radiation Units and Measurements (ICRU) recommendation of ±5% overall dose accuracy, which served as the clinical acceptance criterion.

Automated Treatment Planning

To improve workflow efficiency and planning consistency, a customized RayStation Iron Python script was developed to automate the generation of 3D-CRT treatment plans for hip palliative radiotherapy. The script automatically generated beam arrangements, optimized field shaping, and reduced dose hotspots, thereby minimizing manual planning effort while maintaining clinically acceptable plan quality.

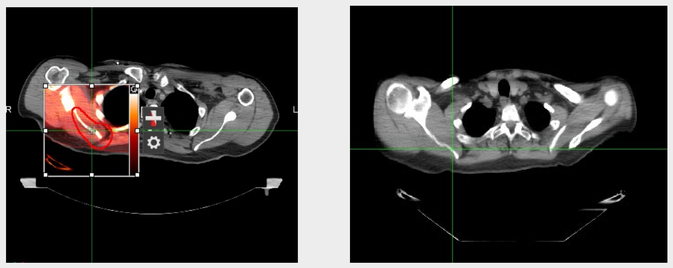

Figure 1: Image of a diagnostic CT(left) scan being registered to a sim CT(right)

RESULTS

The Hounsfield Unit (HU) analysis demonstrated that the mean absolute HU differences between planning CT (pCT) and diagnostic CT (dCT) images were clinically acceptable across all treatment sites. Median |ΔHU| values were approximately 25 HU for the spine, 30 HU for the hip, 22 HU for the rib, 28 HU for the sacrum, and 20 HU for the scapula. Overall, the population-level HU differences were small and remained within the range of expected imaging variability (Fig. 2).

The dosimetric analysis showed strong agreement between pCT- and dCT-based dose calculations. Dose differences were less than 5% across all evaluated treatment sites, and D_{2cc} values for organs at risk (OARs) were comparable between the two image sets. In addition, no statistically significant differences were observed in planning target volume (PTV) dose coverage ($p > 0.05$), indicating that dCT-based recalculations produced clinically consistent dosimetric results (Fig. 2).

For the autoplanning evaluation, a RayStation Python script successfully generated automated 3D-CRT treatment plans for the hip site. The automated plans demonstrated comparable plan quality to manually created plans, supporting the feasibility of script-assisted planning for palliative hip radiotherapy (Fig. 3).

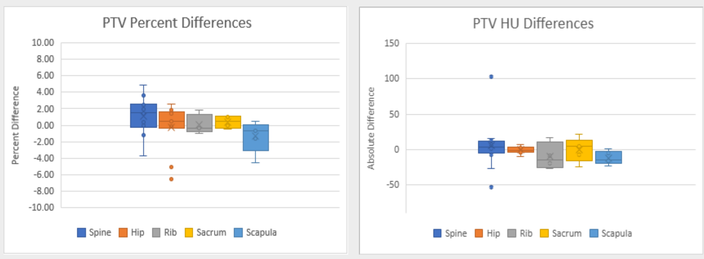

Figure 2: Box and whisker plot of the PTV HU differences (Left) and of the PTV percent dose differences (Right)

Figure 3: Dose distribution of a clinically approved plan (top) vs plan made with Autoplanning script (bottom).

DISCUSSION

HU Variability: Differences between dCT and pCT were expected due to variations in patient positioning, immobilization, and couch geometry. However, these differences had minimal dosimetric impact and remained within the ICRU ±5% acceptance threshold.

3D-CRT Suitability: The simple forward-planning workflow of 3D-CRT makes it well suited for simulation-free radiotherapy (SFRT), particularly for selected palliative patients requiring rapid treatment.

Autoplanning: The RayStation Python script automated 3D-CRT planning steps, reducing manual effort and improving workflow efficiency and plan consistency.

Special Considerations: Patients with **metallic implants** may have CT artifacts that affect planning accuracy and require individualized evaluation.

CONCLUSIONS

This study demonstrates that diagnostic CT-based treatment planning can achieve dosimetric equivalence to conventional simulation CT-based planning for palliative 3D-CRT treatments. Implementation of a simulation-free radiotherapy (SFRT) workflow has the potential to reduce treatment delays and improve clinical efficiency while maintaining treatment accuracy within the ICRU-recommended acceptance threshold of less than 5% dose difference. Additionally, automated scripting can further streamline the SFRT workflow by improving planning efficiency and consistency. Future work will focus on prospective clinical implementation with a larger patient cohort and expansion to additional treatment sites.

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