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Diagnostic Imaging for Vertebral Metastases (DIVERT): A Simulation-Free VMAT Pilot Patient Study

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INTRODUCTION

- Vertebral metastases represent the most common site of painful bone metastases, at up to 80%
  - Expedient treatment has the potential to address pain, pathologic fracture, and neurologic impairment, improving quality of life
- The conventional radiotherapy pathway includes a dedicated treatment planning CT (TPCT)
  - By omitting this step and planning on previously acquired diagnostic imaging CT (DICT), there is the potential to save treatment center resources and patient time
- Recent studies have assessed the feasibility of simulation-free workflows, showing good potential
  - These studies were limited to simple forward-planned beam arrangements
- Palliative patients are now routinely receiving multiple courses of radiotherapy – interest in using more conformal techniques to reduce normal tissue dose

OBJECTIVES

- The primary objective of this prospective study was to assess the feasibility, in terms of target coverage and doses to organs at risk, of using previously acquired diagnostic CT to create and deliver VMAT treatment plans for palliative radiotherapy to vertebral metastases
- The secondary objectives were to:
  - Quantify the in-room time required to set up patients in their diagnostic position and deliver treatment
  - Assess the degree of disease progression, potentially identifying an upper limit on the age of the DICT to be used for planning

METHODS AND MATERIALS

- Single institution, non-randomized prospective cohort study
  - Approved by local Institutional Review Board
- 30 patients recruited (43 individual plans)
- Inclusion criteria:
  - 18+ years; written, informed consent
  - Thoracic, lumbar, or vertebral metastases intended for palliative radiotherapy
    - 800 cGy/1 fraction; 1600 cGy/2 fractions; or 2000 cGy/5 fractions
- Exclusion criteria:
  - Unwilling to provide informed consent
  - No pre-existing DICT, or a DICT not encompassing the intended target
- Unique DICT considerations were evaluated case-by-case in collaboration with a medical physicist

The study workflow is illustrated in Figure 1.

- Of note, the CTV was defined as the entire involved vertebral segment
- The PTV was a uniform 1.0 cm expansion from the CTV

- Offline, the DICT and TPCT were rigidly registered at the level of the target
  - ±3 degrees of rotation was permitted along any rotational axis
- The plan made on the DICT was recalculated on the TPCT
  - Standard dose-volume metrics following recalculation were recorded
  - Contour similarity metrics between DICT and TPCT CTVs were evaluated in 3D Slicer following registration
- Further evaluation of secondary objectives was achieved through the distribution of electronic questionnaires to treating staff

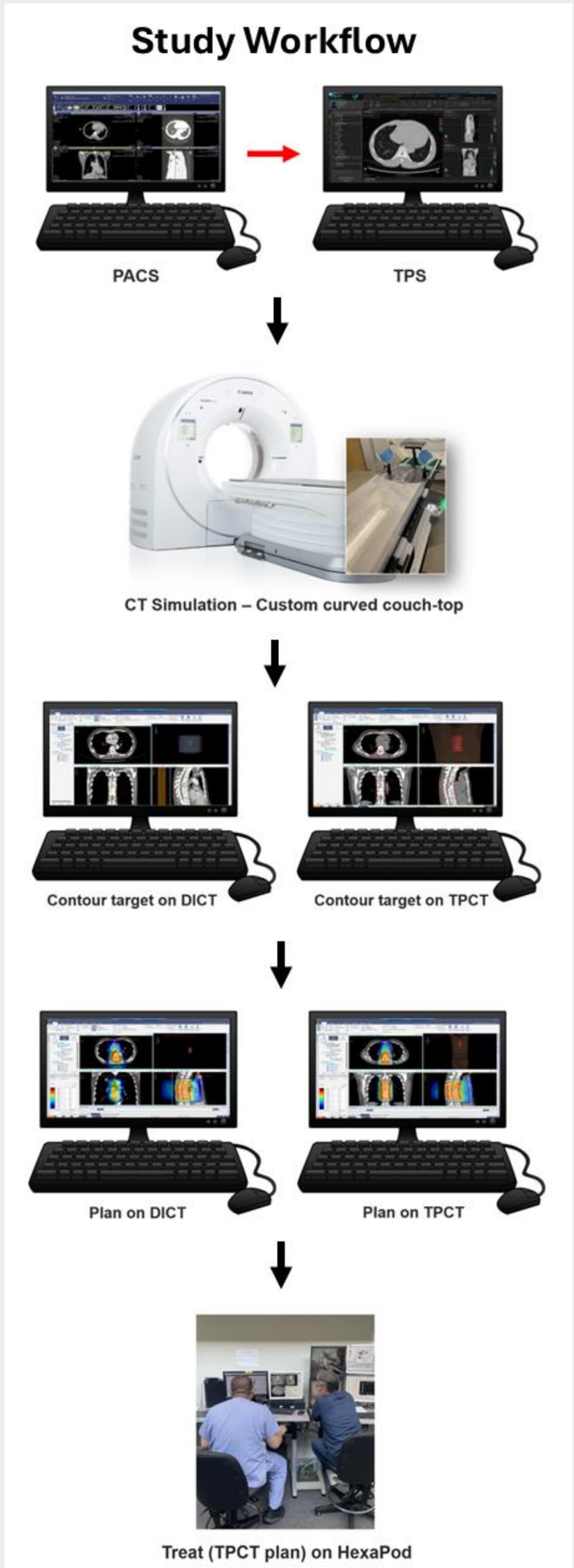

Figure 1. The study workflow started by identifying the relevant DICT in PACS and transferring it to the TPS (Monaco) for setup reference. The patient was simulated in a position to mimic their DICT position, with a custom-fabricated curved foam used to replicate the diagnostic bed's curvature. Contours were completed independently on both DICT and TPCT (simulation) scan sets, and separate plans made on each. The patient was treated with the TPCT plan on a 6-DOF couch, with all accessories used at the time of simulation.

RESULTS

Table 1. Dose-volume metrics following recalculation of the diagnostic CT plan on the treatment planning CT (treatment planning CT contours), with *n* being the number of plans

Structure	Metric	Mean ± SD as a percentage (%) of the prescription dose [range]			
		All sites (n = 43)	Thoracic (n = 14)	Thoracolumbar or lumbar (n = 19)	Sacral or lumbosacral (n = 10)
CTV	$V_{95\%}$	99.3 ± 3.4	98.2 ± 5.5 [78.3, 100.0]	99.9 ± 0.2 [99.0, 100.0]	99.6 ± 0.8 [97.5, 100.0]
	$D_{95\%}$	100.4 ± 2.3	99.6 ± 3.3 [92.8, 105.6]	100.0 ± 1.1 [98.1, 102.0]	101.6 ± 1.6 [98.3, 103.6]
	$D_{2\%}$	107.0 ± 2.3	106.3 ± 3.3 [100.7, 112.9]	107.0 ± 1.2 [103.8, 109.1]	108.3 ± 1.3 [106.3, 110.8]
PTV	$V_{95\%}$	97.0 ± 6.4	95.2 ± 10.3 [59.4, 100.0]	98.4 ± 1.8 [93.3, 100.0]	97.1 ± 3.5 [89.6, 99.7]
	$D_{95\%}$	97.4 ± 6.6	96.4 ± 8.1 [68.7, 103.2]	98.7 ± 2.3 [92.0, 101.3]	96.2 ± 8.8 [72.5, 102.6]
	$D_{2\%}$	107.6 ± 2.3	107.9 ± 3.4 [100.8, 113.4]	107.1 ± 1.3 [104.7, 110.1]	108.4 ± 1.3 [106.6, 110.4]

Table 2. Contour similarity metrics, using the CTV contoured on the TPCT as the reference.

	Mean ± SD (n = 43)
% volume difference	-1.1 ± 12.7%
Dice Similarity Coef.	0.86 ± 0.08
Hausdorff Distance	2.1 ± 1.4 mm

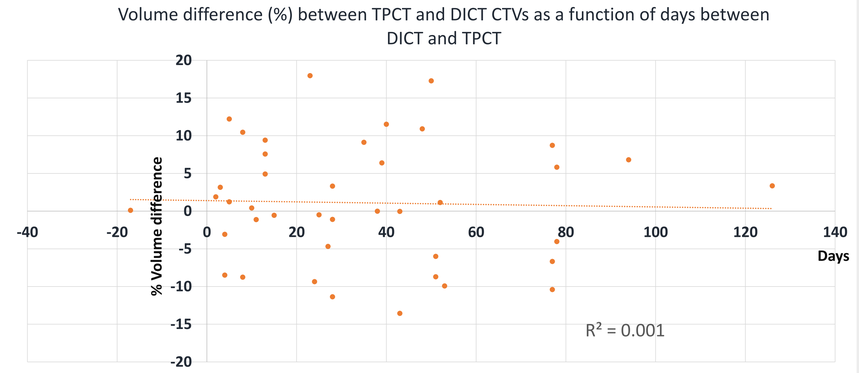

Figure 2. When using the operational definition of the CTV as the entire involved vertebral segment, there was no relationship ($R^2 = 0.001$) between time between DICT and TPCT acquisition and CTV volume.

- Average patient in-room time was within the standard twenty-minute booking slot for a single treatment site

DISCUSSION & CONCLUSIONS

- VMAT planning using previously acquired diagnostic CT imaging represents a clinically robust and resource-efficient approach to expediting the treatment pathway for patients with vertebral metastases
- On average, both CTV and PTV coverage exceeded 97% for the $V_{95\%}$ and $D_{95\%}$
- CTV = entire involved vertebral segment
  - The same (number of) vertebrae were contoured on both DICT and TPCT scan sets – 100% accuracy
  - No relationship between number of days between DICT and TPCT acquisition and the size of the target volume
    - No upper limit to age of DICT scan
- Clinical implementation suggestions:
  - Only one target per plan, isocenter at level of target
  - Diagnostic scan to have at least 2 vertebrae sup/inf of target to help with patient setup
  - T3 as superior-most target vertebra
  - PRV on kidneys – breath-hold (DICT) vs. free-breathing (TPCT and treatment)

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