2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Tumor Motion Effects on Target Definition with the 6-second HyperSight Cone-Beam CT in Adaptive Radiotherapy

Ruizhi Zuo[1,2], Tingliang Zhuang[1,2], You Zhang[1,2]
[1]Department of Radiation Oncology, UT Southwestern Medical Center, Dallas, Texas
[2]Medical Artificial Intelligence and Automation (MAIA) Lab

MAIA Laboratory

ABSTRACT

The HyperSight 6-second rapid scan has been used clinically for internal-target-volume (ITV) definition. However, limited temporal sampling may lead to ITV underestimation, particularly for irregular motion. Using a joint dynamic reconstruction and motion-estimation framework (DREME), we extracted time-resolved tumor motion and evaluated its impact on target definition.

DREME reconstructs a dynamic CBCT sequence from a conventional CBCT scan by estimating a reference CBCT and a motion model, which generates per-projection deformation-vector-fields (DVFs) to deform the reference into projection-specific CBCTs. Each patient has two 60-second CBCT scans from two treatment fractions, both processed by DREME. Tumors were contoured on the reference CBCT and propagated to per-projection CBCTs using DVFs. Each 60-second scan was subdivided into ten 6-second rapid scans to emulate the HyperSight protocol. For each rapid scan, the ITV was derived from the maximum-intensity-projection of tumor contours and expanded to a Planning-Target-Volume (PTV) using clinically-defined margins (3-5mm). Intra-scan analysis compared each rapid-scan PTV with ITVs from the other nine rapid scans to compute ITV geometrical coverage (GC) by the PTV, defined as the fraction of ITV within the PTV. For each PTV, mean and minimum ITV GC was calculated among all comparisons. Inter-fraction analysis compared between two CBCT fractions of each patient, with each fast-scan PTV from one fraction compared to the 10 ITVs from another fraction. The impact of PTV margin was evaluated.

Across five patients, intra-scan analysis yields the mean(±s.d.) and minimum(±s.d.) ITV GC of 99.18±1.08%, and 90.4±9.4%, respectively. Inter-fraction analysis shows mean and minimum GC of 98.3±0.6% and 89.0±4.2%. PTV margins of 1–5mm were tested in intra-scan analysis, and some cases showed <95% minimum GC despite a 5 mm margin, demonstrating the potential need of motion-customized PTV margin for fast HyperSight scans.

For HyperSight rapid scans, both intra-scan and inter-fraction analyses achieved overall high mean ITV GC. However, tumors with irregular motion may be inadequately covered.

CONTACT

You Zhang
The Medical Artificial Intelligence and Automation (MAIA) Laboratory, Department of Radiation Oncology, University of Texas Southwestern Medical Center
2280 Inwood Road, Dallas, TX, 75390, USA
You.Zhang@UTSoutherstern.edu

INTRODUCTION

HyperSight CBCT offers rapid image acquisition and enhanced image quality, supporting its clinical integration for internal target volume (ITV) definition [1]. Due to its short acquisition time, the HyperSight 6-second rapid scan typically captures only one to two respiratory cycles, which may not fully represent the range and variability of respiration-induced tumor motion. This limited temporal sampling may result in incomplete characterization of tumor motion and, consequently, underestimation of the resulting ITV, particularly for tumors with irregular or nonperiodic respiratory motion. To better quantify motion-related uncertainties in target definition, we employed a joint dynamic reconstruction and motion-estimation framework (DREME, Figure 1) [2], which enables dynamic CBCT sequence reconstruction and per-projection volumetric tumor motion tracking, allowing more accurate characterization of respiratory motion and its impact on target delineation. Using DREME, we conducted a comprehensive motion analysis that includes: (1) **quantitative assessment of intra-scan and inter-fraction ITV geometrical coverage (GC)**; and **(2) quantitative evaluation of the effect of PTV margin size on ITV GC.**

METHODS AND MATERIALS

Figure 1 illustrates the workflow of DREME. DREME employs a Hash encoding-based implicit neural representation (INR) to reconstruct a patient-specific CBCT reference image and a motion model. The motion model represents deformation vector fields (DVFs) in a low-rank form, enabling the generation of per-projection DVFs and the corresponding dynamic CBCT volumes, allowing accurate tumor motion tracking and ITV definition based on maximum intensity projection.

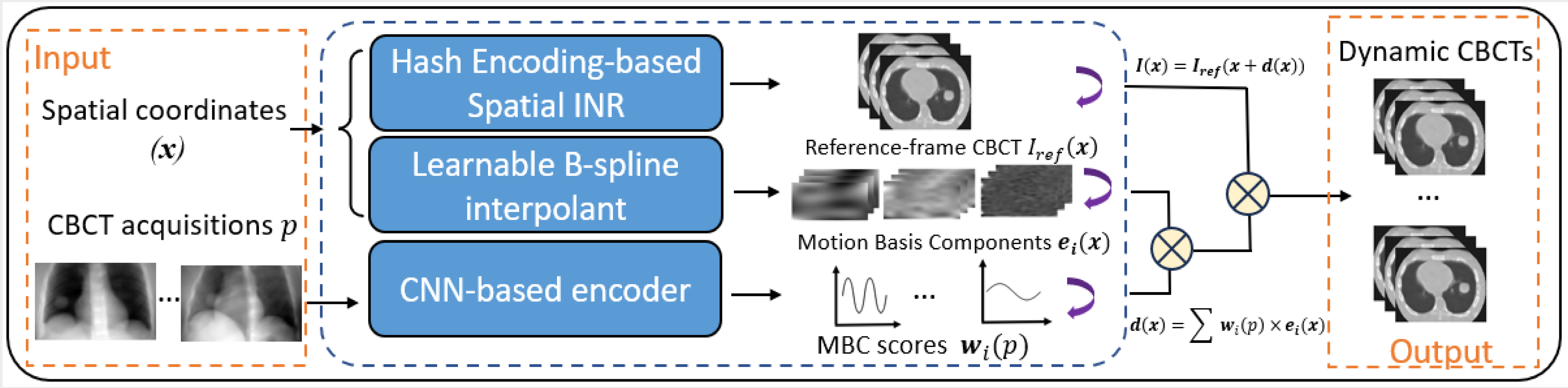

Fig. 1. The DREME framework can reconstruct a dynamic CBCT sequence from a conventional 3D CBCT scan. A Hash encoding-based spatial implicit neural representation is used to generate the reference CBCT image $I_{ref}(x)$. A learnable B-spline interpolant is used to generate the motion basis components $e_i(x)$. For each projection, a CNN-based encoder infers MBC scores $w_i(p)$, which are used to derive deformation vector fields (DVFs), $d(x) = \sum w_i(p) \times e_i(x)$, and corresponding dynamic CBCTs $I(x) = I_{ref}(x + d(x))$.

The motion analysis involved two in-house HyperSight patients and three patients from a public dataset. Each patient has two 60-second scans acquired at two fractions, denoted as Fraction A and B. Each 60-second scan is divided into ten 6-second rapid scans (A1–A10 and B1–B10) to emulate the HyperSight 6-s protocol, and ITVs and PTVs are derived for each rapid scan. The intra-scan and inter-fraction comparison methods are illustrated in Figure 2(a). Mean and minimum ITV GC was calculated for each PTV among intra-scan and inter-fraction comparisons. Figure 2(b) illustrates example ITVs contoured from two different 6-second scans of patient 1 (P1) in the sagittal and coronal views. Differences between the two ITVs, for the tumor located near the diaphragm, are observed due to variations in motion.

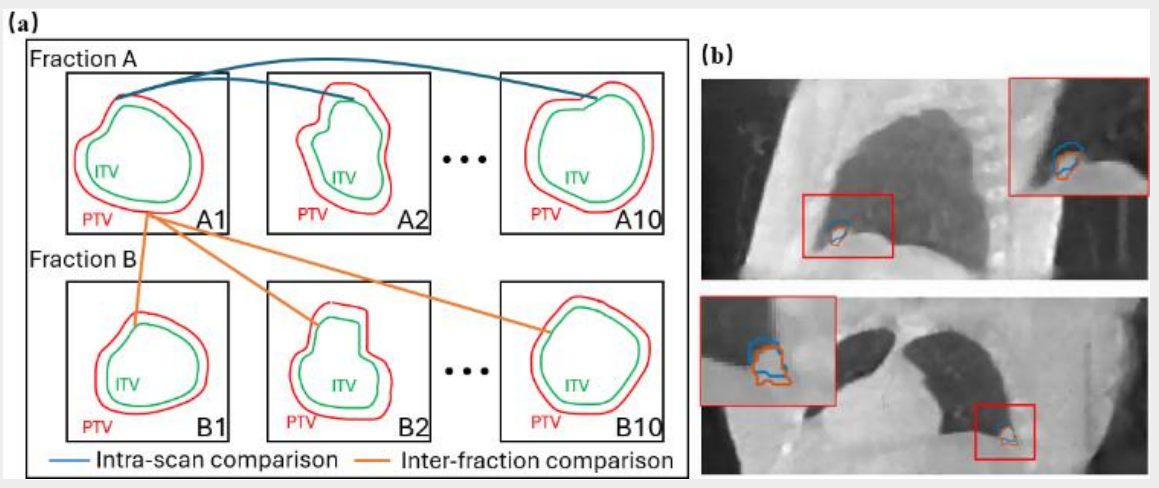

Fig. 2. (a) Intra-scan comparison (blue lines): the PTV from each rapid scan was compared with ITVs from other nine rapid scans; inter-fraction comparison (orange lines): each PTV from one fraction was compared with the ten ITVs from the other fraction. (b) Examples of ITVs contoured from two 6-s scans of same patient (orange and blue lines) in sagittal and coronal views.

RESULTS

The PTV contours of intra-scan and inter-fraction comparisons use clinically defined margins (3-5 mm), depending on the anatomical site and tumor size. Figure 3 shows the mean and minimum ITV GC versus PTV margin size, from 1 to 5 mm, among five patients' intra-scan comparison. On average, increasing the PTV margin by 1 mm leads to an increase of 1.2% in mean ITV GC and 4.2% in minimum GC. Our analysis reveals that commonly used 5mm margin may be insufficient to ensure adequate ITV geometrical coverage in some cases (<95%). Therefore, motion variability should be taken into account when defining the PTV.

Patient	Intra-scan ITV GC		Inter-fraction ITV GC	
	Mean	Minimum	Mean	Minimum
P1	96.9%±4.0%	90.4%±9.4%	96.9%±1.2%	89.0%±4.2%
P2	99.9%±0.1%	99.7%±0.5%	99.9%±0.1%	99.9%±0.2%
P3	99.7%±0.5%	99.6%±0.8%	99.6%±0.7%	96.8%±2.0%
P4	99.8%±0.2%	98.8%±0.9%	96.1%±0.5%	95.6%±0.7%
P5	99.6%±0.6%	98.7%±1.8%	99.0%±0.5%	96.5%±1.2%

Table 1. Summary of the mean and minimum ITV GC for intra-scan and inter-fraction comparisons.

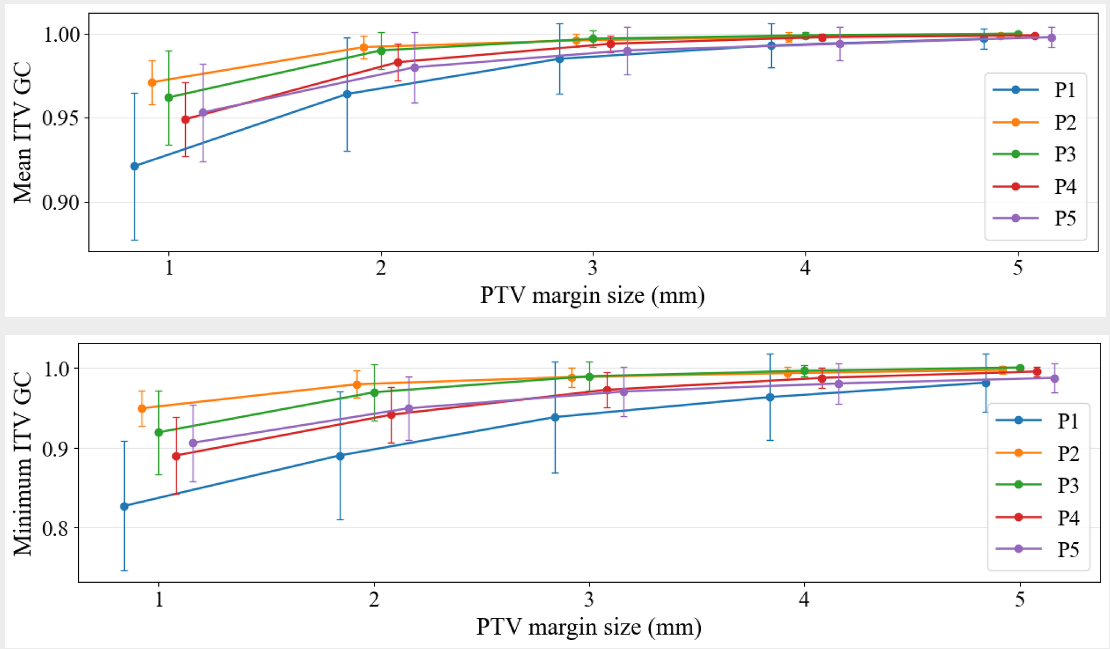

Fig. 3. (Top) Mean and (bottom) Minimum ITV GC for different PTV margin sizes for different patients. Error bars represent ±1 standard deviation and are slightly offset in the x-direction for visualization clarity.

DISCUSSION

This study evaluated motion-related target definition uncertainties in HyperSight 6-second rapid CBCT scans using DREME-enabled dynamic reconstruction and motion tracking. Although HyperSight rapid scans showed overall high mean ITV geometrical coverage in both intra-scan and inter-fraction comparisons, selected cases demonstrated inadequate ITV GC, particularly for tumors with irregular or variable respiratory motion. Therefore, respiratory motion characteristics should be considered when defining ITV/PTV for CBCT-guided radiotherapy.

The analysis was performed on a limited cohort of five patients, and larger studies are needed to further validate the observed trends across tumor sites and size, motion patterns, and margin definitions. In addition, intra-fraction while inter-scan motion comparisons are necessary to more comprehensively evaluate the impact of respiratory motion on ITV geometrical coverage.

CONCLUSIONS

A PTV defined in HyperSight rapid scans achieved overall high mean ITV geometrical coverage in both intra-scan and inter-fraction analyses. However, tumors with irregular respiratory motion may still be inadequately covered because the short acquisition may not fully capture the range of motion. These findings highlight the importance of considering patient-specific motion variability when defining ITV/PTV.

REFERENCES

[1] Wang, Yi-Fang, et al. "Impact of tumor motion on target delineation and dose calculation accuracy using rapid-acquisition HyperSight CBCT in online adaptive radiotherapy." *Journal of Applied Clinical Medical Physics* 27.1 (2026): e70428.

[2] Shao, Hua-Chieh, et al. "Real-time CBCT imaging and motion tracking via a single arbitrarily-angled x-ray projection by a joint dynamic reconstruction and motion estimation (DREME) framework." *Physics in Medicine & Biology* 70.2 (2025): 025026.