Evaluation of Markerless Spine Position Monitoring for Auto Beam Hold Based on Triggered Imaging

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Background & Purpose

Spine stereotactic body radiation therapy (SBRT) requires highly accurate patient positioning to minimize the risk of spinal cord injury. Accurate spine position verification during treatment is therefore strongly desired.

Markerless spine position monitoring on standard C-arm linear accelerators remains limited in clinical practice. This study evaluates the performance of a 2D markerless spine position monitoring technique for Auto Beam Hold using gantry-mounted kV imaging.

Conclusion

The markerless spine position monitoring technique achieved robust, sub-millimeter accuracy across clinically relevant conditions without implanted fiducials. This enables continuous, automatic intrafraction spine monitoring on standard linacs and has the potential to improve treatment safety and precision in spine SBRT.

Methods

- kV triggered images acquired on a TrueBeam during delivery of 6 or 10 MV FFF VMAT
- **Phantom data** (**Figure 1**):
  - kV images acquired at 0.33 and 2 fps
  - CIRS Dynamic Thorax Motion Phantom
  - 3D-printed anthropomorphic lumbar spine phantom with removable rings simulating patient sizes of 25–45 cm
  - 3D-printed anthropomorphic thoracic spine phantom with and without arms
- **Patient data**: kV images acquired every 10° of gantry rotation during spine SBRT in 20 patients

- Monitoring of a single vertebra using a template-based tracking algorithm (**Figure 2**)
- Evaluation of **imaging parameters**: kVp (80–120 kVp) and mAs (5, 10, and 15 mAs)
- Assessment of **geometric accuracy**: phantoms positioned at isocenter, with positional offsets (0.5–2.5 mm in individual directions and combinations), and during stepwise (parallel and perpendicular to the kV detector) and gradual motion

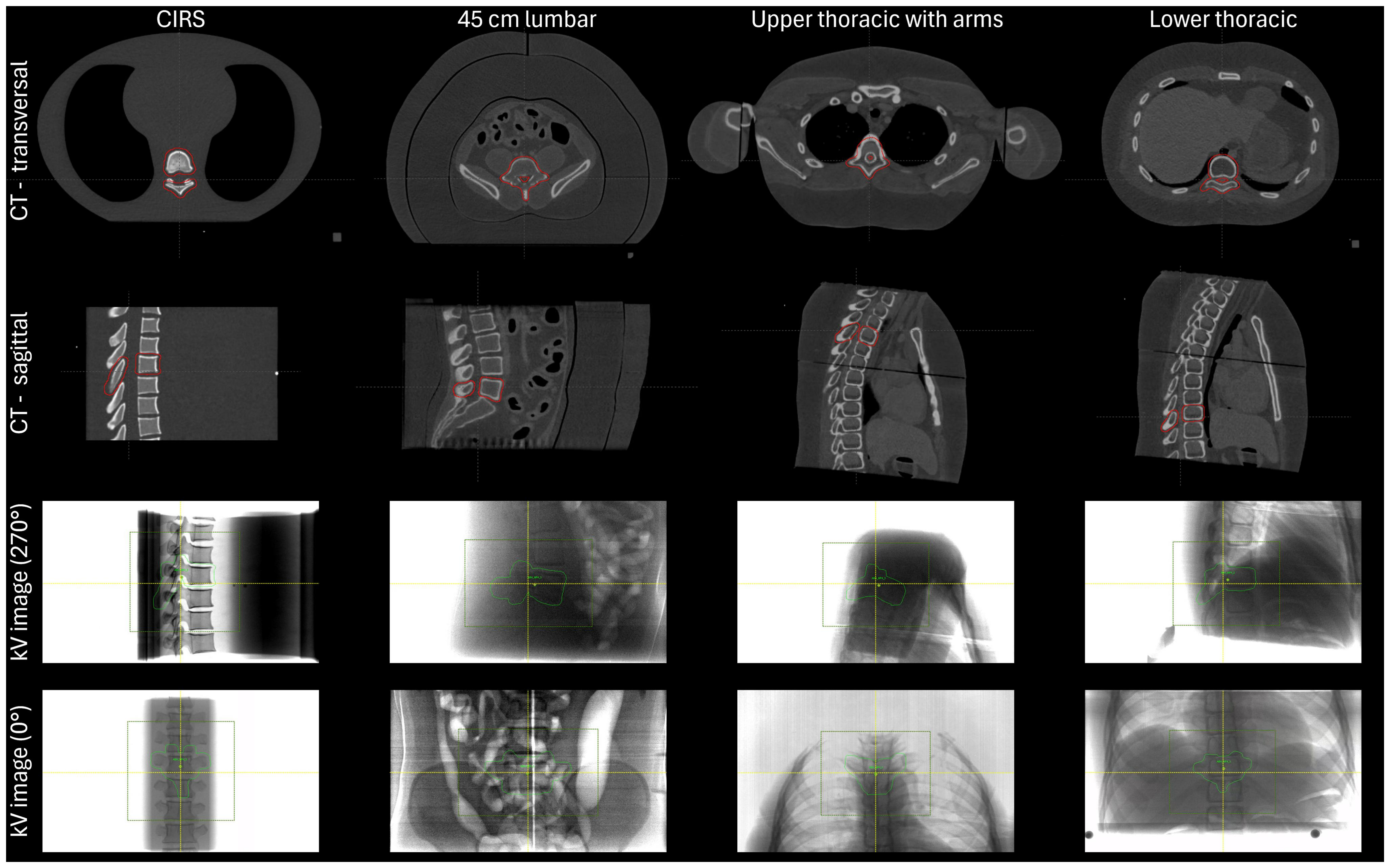

Figure 1: CT and kV images of the phantoms with the selected target vertebrae depicted in red (CT) and green (kV images).

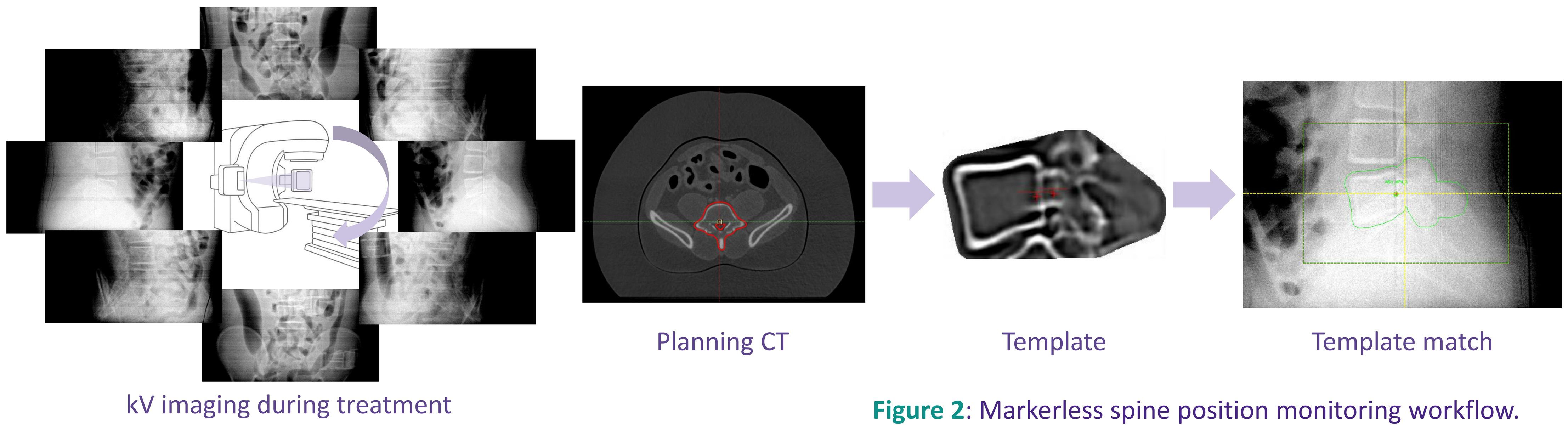

Figure 2: Markerless spine position monitoring workflow.

Results

- **Imaging parameters**: **Figure 3** & optimized kVp/mAs settings in **Tables**

Lumbar	kVp	mAs
⌀ 25 cm	80	5
⌀ 33 cm	90	5
⌀ 38 cm	90	10
⌀ 45 cm	120	10

Thoracic	kVp	mAs
Upper with arms (⌀ ~41 cm)	90	5
Upper without arms (⌀ ~26 cm)	80	5
Lower (⌀ ~28 cm)	80	5

- **Geometric accuracy**: mean localization error in the isoplane **≤ 0.2 mm** across static and dynamic phantom experiments (**Figure 4**)

- **Patient data**:
  - **98% detection success** across 6,955 images; failures were associated with overlapping anatomy and higher attenuation when imaging through the arms/shoulders
  - Detected patient positioning deviations exceeded 1 mm in 29.4% and 2 mm in 3.6% of images

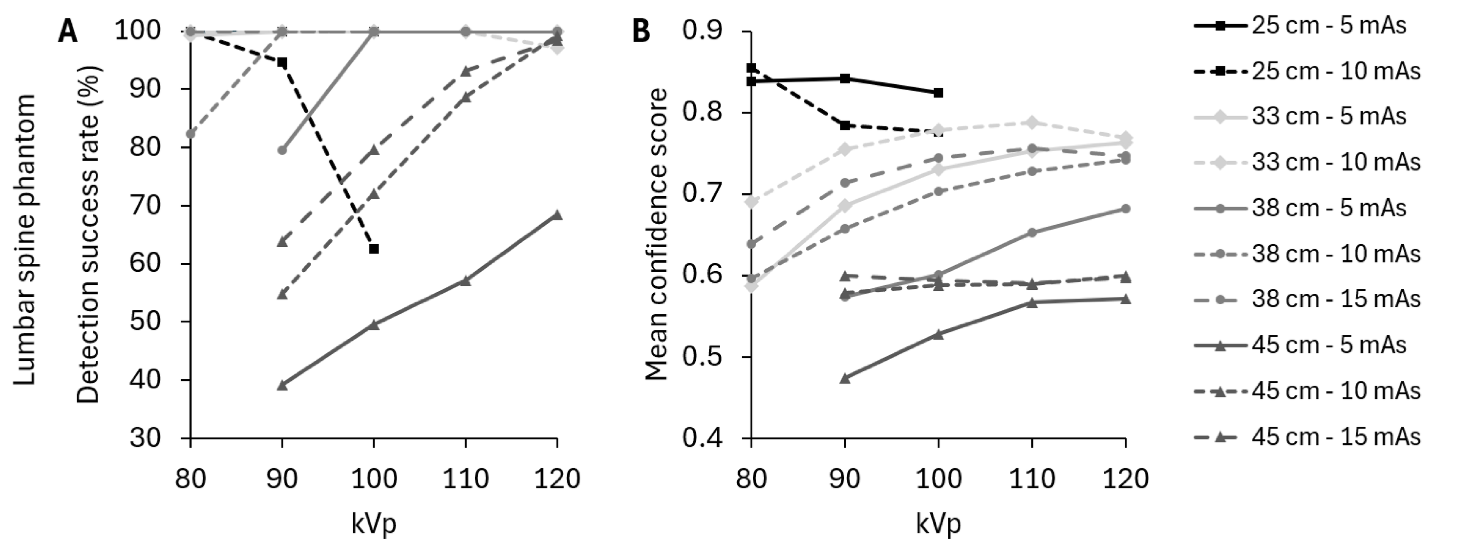

Figure 3: Percentage of projections tracked (**A**) and mean confidence score (normalized cross-correlation; **B**) for different kVp and mAs settings for the 3D-printed lumbar spine phantom with sizes of 25–45 cm.

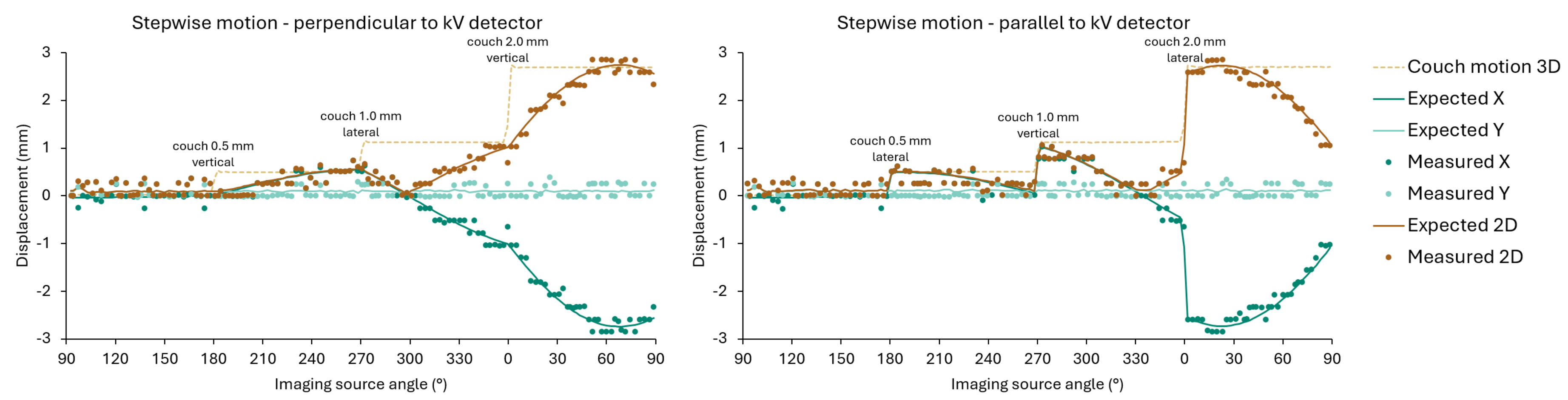

Figure 4: Example results of dynamic phantom experiments (2 fps) for the upper thoracic phantom without arms. The 2D displacement vector was calculated from the X- (combined lateral/vertical direction) and Y- (longitudinal direction) positions, and the 3D displacement vector of the couch was included to visualize how long it takes for a 3D movement to be detected in 2D.

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