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Misalignment Detection Accuracy with Dual Orthogonal kV Imaging and Thermal/Optical Surface-Guidance for SBRT Spine

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Introduction

Target alignment is critical for successful SBRT treatment for spinal oligometastatic disease. The inherent high dose fall-off coupled with proximal critical structures such as spinal cord requires high spatial accuracy.

While the standard imaging technique uses cone beam computed tomography for target alignment, ancillary imaging systems can further ensure alignment. In-treatment triggered imaging with dual orthogonal kV imaging can identify internal target movement and surface-guidance can monitor the patient's external motion.

Implementation of this system for SBRT Spine workflows requires a technical investigation of detection accuracy with simulated misalignments. This phantom study aims to explore the effects of Digitally Reconstructed Radiograph (DRR) and X-ray filters, DRR Volume of Interest (VOI), DRR contrast and energy on simulated longitudinal misalignments on an anthropomorphic phantom.

Clinical Significance

Based on this phantom study, dual Orthogonal kV Imaging and Thermal/Optical Surface Guidance can more accurately detect vertebral body misalignments with the following parameters:

- Within vendor's registration search range of 20mm
- No manipulation of the DRR VOI
- 75% Bony/25% Tissue DRR Contrast setting

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METHODS AND MATERIALS

Five variable parameters were used to test auto-registration-based detection of twelve simulated longitudinal misalignments (1, 5, 10, 20, 25 and 30mm superiorly and inferiorly) , totaling 312 measurements.

- Three DRR VOI (Large, Medium, Small)
- Six DRR Contrast settings (25% increments)
- Five DRR Filters
- Five Xray Filters
- Seven Xray Energies (90kVp – 150kVp, 10 increments

Three DRR VOI's (Large_VOI, Medium_VOI, Small_VOI) tested the influence of variable visibility of ribs and vertebra. Large_VOI had no manual manipulation while Medium_VOI was coned down to two vertebral bodies superior and inferior to T6 target without ribs and Small_VOI was reduced to one vertebral body surrounding T6 without ribs. Twelve simulated longitudinal misalignments investigated the influence of similar vertebral bodies as seen with inferior isocenter shifts.

To verify the robustness of the auto-registration detection of longitudinal misalignments, an anthropomorphic phantom with spine, ribs, and mandible was positioned centered on the T6 target with CBCT and intentionally misaligned. The simulated misalignment was verified with dual orthogonal kV imaging (120kVp, 20mAs). A detection accuracy threshold of 0.3mm was chosen to consider couch motion, image registration, and isocenter coincidence uncertainties.

Fig 1. Anthropomorphic phantom with Dual Orthogonal kV Imaging and Thermal/Optical Surface-Guidance.

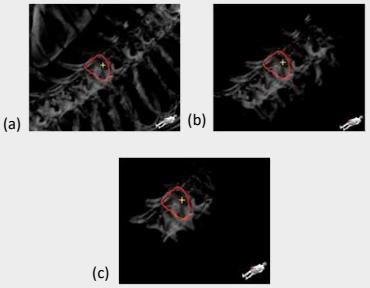


Fig 6. DRR Volume of Interest with variable visibility of ribs and vertebral body represented by Large_VOI (a), Medium_VOI (b) and Small_VOI (c)

RESULTS

Of the simulated 25mm and 30mm misalignments, 89% (n=32) and 100% (n=36) of measurements exceeded the threshold, respectively, compared to 6% (n=2), 42% (n=15), 42% (n=15) and 53% (n=19) measurements for 1mm, 5mm, 10mm and 20mm misalignments. Within 20mm, superior isocenter misalignments had 0% (n=0), 17% (n=3) and 6% (n=1) of measurements compared to inferior shifts had 39% (n=7), 17% (n=3) and 61% (n=11) measurements exceeding the threshold for Large_VOI, Medium_VOI and Small_VOI, respectively.

Of the six DRR contrast settings, the 75%bony/25%tissue and 50%bony/tissue contrast had 12.5% (n=3) and 17% (n=4) measurements, respectively, exceeding the threshold while all other contrast levels surpassed 25%. DRR and Xray filter settings had identical kV auto-registration measurements and had no effect misalignment detection. Within 20mm, kV energy had minimal effect on misalignment detection where 4% (n=1) measurements exceeded the threshold.

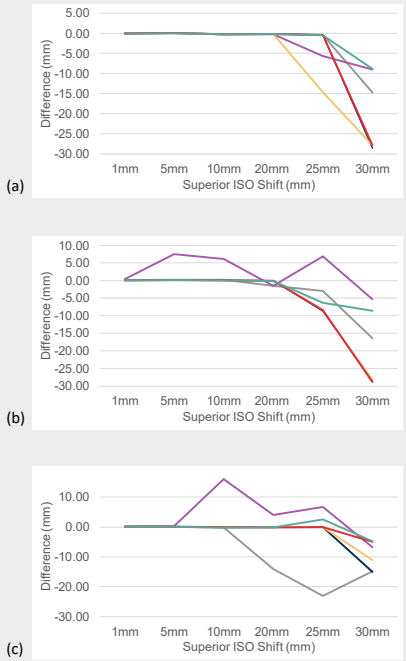


Fig 3. Magnitude difference between orthogonal kV auto-registration and simulated superior iso misalignments for Large_VOI (a), Medium_VOI (b) and Small_VOI (c).

CONCLUSIONS

Dual orthogonal kV imaging accurately displayed the superior and inferior shifts within 20mm which matches the vendor's registration search range. Potentially due to confounding similar anatomy, the system was more accurate with superior ISO shifts compared to inferior. The Large_VOI with no manual manipulation of the VOI yielded the most accurate measurements. While 75%bony/25%tissue and 50%bony/tissue contrast were most accurate in this phantom study, conclusions cannot be generalized due to variable patient depth and density. DRR and Xray filter had no effect on misalignment detection and is purely visual modification. In this phantom study, kV energy within the clinical range had minimal effect on misalignment detection and did not result in gross target misalignments. Variabilities in patient size and density were not evaluated, and patient-specific parameters may need further investigation.

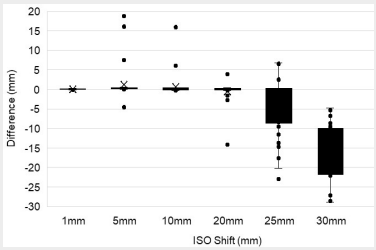
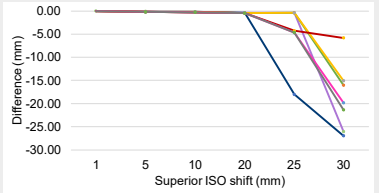


Fig 2. Spread of residual magnitude difference between simulated misalignment and auto-registration for superior and inferior isocenter misalignments.

Fig 4. DRR Contrast settings at 75% Bony/25% Tissue.



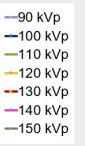


Fig 5. Magnitude difference between orthogonal kV auto-registration and simulated superior iso misalignments for variable kVp