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JOINT AAPM | COMP MEETING

Assessing the Necessity of Fiducial Markers for Image-Guided Prostate SBRT: Do Implanted Markers Add Clinical Value In the Era of CBCT-Based Soft-Tissue Registration?

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ABSTRACT

Fiducial markers (FMs) or implanted gold seeds have historically been the standard for prostate radiotherapy setup but their added value is increasingly being questioned. Recent improvements in CBCT image quality and registration algorithms have prompted mixed opinions regarding their continued necessity, especially in workflows without real-time tracking and with faster treatments using flattening filter-free beams. We retrospectively evaluated FM clinical utility in our prostate SBRT program.

Forty patients (20 with seeds, 20 without seeds) treated with SBRT were reviewed. To evaluate the specific impact of FMs, CBCT registrations (shifts/rotations) were extracted and compared between cohorts. The Fiducial registration error (FRE) was calculated via independent seed based re-registration and compared with baseline FRE from clinical accepted IGRT registrations. Additionally, residual systematic and random errors were compared between the two cohorts.

A total of 380 acquired CBCTs were analyzed for both seed and no-seed cohorts (180 per cohort, approximately 2CBCTs/fraction). Mean FRE was 0.6 mm (range 0.1–1.6 mm) for seed-based registrations vs 2.2 mm (range 0.5–9.8 mm) for clinical registrations. Using the last CBCT before treatment, systematic translation and rotation errors were small in both cohorts (≤0.28 mm, ≤0.90°) with differences ≤0.10 mm and ≤0.17°, and random errors were similarly low (≤0.46 mm, ≤1.54°) with differences ≤0.15 mm and ≤0.4°, indicating equivalent setup accuracy.

We conclude that therapists rely primarily on soft-tissue anatomy rather than fiducials for final setup decisions. CBCT soft-tissue-only setup without seeds is feasible and not inferior to seeds-based setup for 5-fraction prostate SBRT.

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INTRODUCTION

Implanted gold seeds or fiducial markers (FMs) have historically been the standard of care for patient setup in prostate radiotherapy, serving as landmarks for setup verification during image-guided treatment delivery. However, recent improvements in CBCT image quality and registration algorithms have prompted mixed opinions regarding their continued necessity.

At our center, 5-fraction prostate SBRT treatments are delivered with 10X-FFF beams at 2400 MU/min, resulting in short treatment times and reduced susceptibility to intrafraction motion. Alongside standardised bowel and bladder preparation, high-quality CBCT imaging and registration algorithms, soft-tissue based set up can be performed reliably by experienced therapists. FMs do not account for deformation in adjacent anatomy (Mutanga et al., IJROBP). As a result, particularly in workflows where intrafraction real-time fiducial tracking is not used, their added value is uncertain.

Practical challenges of FMs - including organ deformation, seed migration, growing waitlists, procedural burden, costs, and access delays motivate re-evaluating their routine use.. Given these factors, a retrospective evaluation was conducted to assess the clinical utility of FMs in our prostate SBRT workflow.

METHODS AND MATERIALS

Forty patients (20 seed, 20 non-seed) treated with SBRT (36.25 Gy/5 with seeds; 35 Gy/5 palliative, without seeds), using identical bowel and bladder preparation were reviewed. Clinically accepted CBCT registrations and resulting shifts/rotations were extracted. In the seed-cohort, an automated seed-based registration was performed using a threshold-based seed detection method, where fiducial markers were placed at the centroid of masked voxels. The fiducial registration error (FRE) for both accepted clinical registrations and seed-based registrations were calculated. Residual shifts/rotations and the number of CBCTs per fraction were compared between the seed and no-seed cohorts using the Mann-Whitney U test.

A phantom study was conducted prior to patient analysis to validate the seed detection and image registration pipeline, yielding a mean FRE of 0.076 mm. Analysis was performed using 3DSlicer, Python, and Eclipse. PTVs were 0.4 cm for the seed cohort and 0.5 cm for the no-seed cohort.

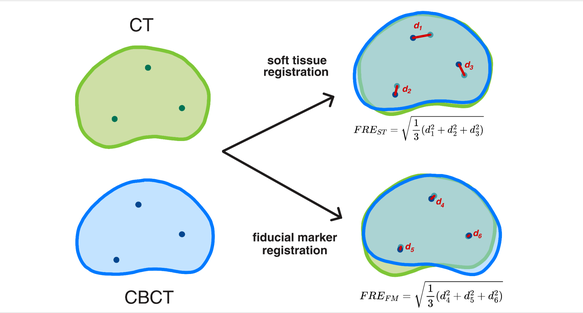
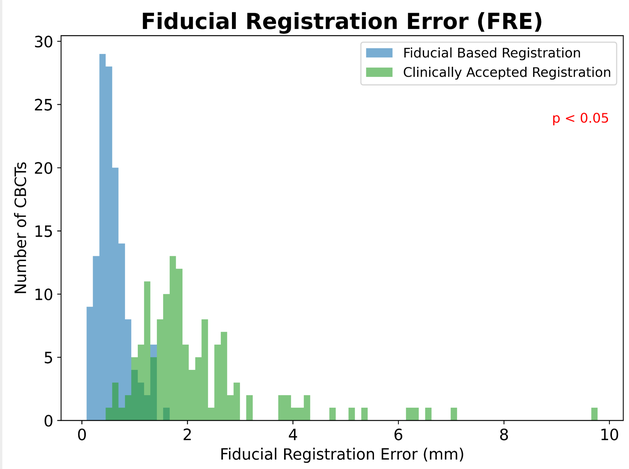


Figure 1. Illustration showing fiducial registration error.

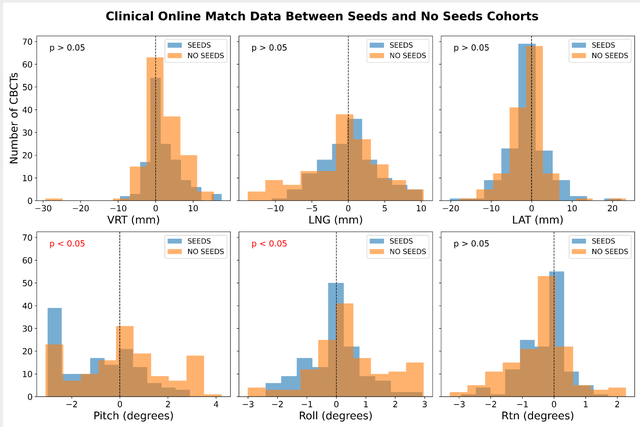
RESULTS

A total of 380 acquired CBCTs were analyzed for both seed and no-seed cohorts (180 per cohort, approximately 2 CBCTs/fraction), with no significant difference in the number of CBCTs per fraction between groups. Mean FRE was 0.6 mm (range 0.1–1.6 mm) for seed-based re-registrations vs. 2.2 mm (range 0.5–9.8 mm) for clinical registrations, indicating that clinical registrations frequently diverge from seeds-based alignment. This divergence was observed across all degrees of freedom, with shift and rotation differences between FM and clinical registrations showing high variability, suggesting that therapists routinely rely on soft-tissue anatomy rather than fiducial positioning when making final setup decisions. The patient with the largest FM FRE (1.66 mm) was associated with bladder and rectal filling, highlighting how anatomical deformation can reduce FM reliability.

Using the last CBCT before treatment, systematic translation and rotation errors were small in both cohorts (≤0.28 mm, ≤0.90°) with differences ≤0.10 mm and ≤0.17°, and random errors were similarly low (≤0.46 mm, ≤1.54°) with differences ≤0.15 mm and ≤0.4°, indicating equivalent setup accuracy.



Graph 1. Histogram of fiducial registration errors of fiducial based and clinically accepted registrations.



Graph 2. Histogram of clinical online match results separated by patients with and without seeds.

Table 1. Residual systematic and random errors setup associated with the last CBCT before beam on.

	VRT (mm)	LNG (mm)	LAT (mm)	Pitch (deg)	Roll (deg)	Rtn (deg)
SEEDS						
Systematic error	0.69	0.89	0.32	3.65	0.31	0.18
Random error	1.16	0.56	0.57	4.22	0.15	0.43
NO SEEDS						
Systematic error	0.77	0.75	0.39	5.65	0.37	0.11
Random error	0.36	0.69	0.49	3.84	0.31	0.20

DISCUSSION

This study is innovative in that it provides a systematic analysis to contribute to the debate on whether implanted gold seeds provide added value for patient setup in a modern prostate SBRT workflow with improved CBCT soft-tissue visualization and image registration algorithms.

The study shoes that CBCT-based soft-tissue matching achieves comparable setup accuracy to fiducial-based alignment within standard SBRT planning target volume (PTV) margins.

Soft tissue-based workflows incorporating MRI to CBCT registration are increasingly being adopted, supporting the feasibility of fiducial-free approaches (Brooks-Pearson et al., Radiography).

In centers without intrafraction motion tracking (e.g., no fiducial-based gating), and where treatment time is already reduced with use of high dose rate FFF beams, the relative advantage of fiducials may be reduced, and CBCT-based soft-tissue alignment alone may be sufficient for accurate treatment delivery in appropriately selected patients.

CONCLUSIONS

Clinical registrations often diverge from seed-based alignment, illustrating that therapists rely primarily on soft-tissue anatomy rather than fiducials when making final setup decisions. Setup accuracy in the no-seed cohort is not inferior, indicating that high-quality CBCT soft-tissue-only setup is feasible for 5-fraction prostate SBRT.

Fiducials add limited value in workflows where CBCT soft-tissue visualization is good, therapists are trained and experienced in CBCT matching, and no real-time intrafraction tracking is used. At our center, short treatment times with 10X-FFF beams further reduce, though do not eliminate, susceptibility to intrafraction motion. Additionally, in some patients, seeds may be unreliable due to gas motion, anatomical deformation, or image artifacts, making soft-tissue matching the more anatomically accurate approach.

We believe it is clinically relevant to re-evaluate the routine use of fiducial markers in eligible patients, given practical issues such as growing waitlists, added costs and procedural burden.

REFERENCES

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