

Hypersight CBCT on C-arm Linac for Adaptive Prostate Radiotherapy: Evaluating Image Quality, HU Stability, and Metal Artifact Reduction

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ABSTRACT

Purpose: Kilovoltage cone-beam CT (kV-CBCT) is routinely used for image-guided radiotherapy (IGRT). However, image artifacts and limited Hounsfield unit (HU) stability strict its application in adaptive radiotherapy. Recently, HyperSight CBCT was introduced to C-arm linear accelerators with improved detective quantum efficiency (DQE) and advanced reconstruction techniques, offering potential opportunities for CBCT-based adaptive planning. This study evaluates the feasibility of C-arm-mounted HyperSight CBCT for adaptive prostate radiotherapy by assessing image quality, HU stability, and metal artifact reduction using phantom and prostate patient data.

Methods: HyperSight CBCT images were acquired on a Varian Edge linear accelerator, and reconstructed using three methods: standard CBCT, iterative CBCT (iCBCT), and metal artifact-reduced iterative CBCT (MAR-iCBCT). Longitudinal HU stability was evaluated in CBCTs from six prostate cancer patients (five fractions each) using mean absolute deviation (MAD), as well as in a phantom scanned on multiple days. CBCTs from five additional patients acquired with a pre-HyperSight system were compared. Pelvic organs were auto-segmented using an AI-based tool, and metal artifacts were quantified by measuring HU standard deviation (SD) in regions surrounding implanted fiducial markers. Agreement between reconstruction methods was assessed using intraclass correlation coefficients (ICC).

Results: MAR-iCBCT showed the lowest near-marker HU variability, indicating the most effective suppression of fiducial-related artifacts. HyperSight-based reconstructions demonstrated stable inter-fraction HU reproducibility across nearly all evaluated organs, whereas pre-HyperSight CBCT showed greater variability, particularly in bony structures. HU agreement between iCBCT and MAR-iCBCT was consistently high across all organs, while agreement between iCBCT and standard CBCT was substantially lower. Phantom measurements confirmed stable HU consistency across repeated scans, and spatial resolution was comparable across reconstruction methods, with improved high-frequency performance for MAR-iCBCT and iCBCT relative to standard and pre-HyperSight CBCT.

Conclusion: C-arm-based HyperSight MAR-iCBCT significantly improves image quality, reduces metal artifacts, and demonstrates robust HU stability and agreement, supporting its feasibility for CBCT-based adaptive prostate radiotherapy.

INTRODUCTION

Kilovoltage cone-beam CT (kV-CBCT) is widely used in radiotherapy, but its limitations have historically restricted its role beyond image guidance. Conventional CBCT is limited by image artifacts, metal-induced streaking, and inconsistent Hounsfield unit (HU) values, all of which reduce its reliability for dose calculation and adaptive planning. HyperSight CBCT incorporates improved detective quantum efficiency (DQE) and advanced reconstruction techniques, including iterative CBCT (iCBCT) and metal artifact-reduced iterative CBCT (MAR-iCBCT), with the potential to improve the quantitative reliability of CBCT imaging. Recently, HyperSight CBCT was introduced on C-arm linear accelerators, creating new opportunities for CBCT-based adaptive planning.

This study evaluates the feasibility of C-arm-mounted HyperSight CBCT for adaptive prostate radiotherapy. The novelty of this work lies in its longitudinal, prostate-specific assessment of HU stability and metal artifact behavior across all three HyperSight CBCT reconstruction methods. This evaluation used multi-fraction prostate SBRT patient imaging, complemented by longitudinal phantom measurements, and included comparison with pre-HyperSight CBCT systems. These findings support the clinical translation of HyperSight CBCT from an alignment-focused imaging tool to a quantitatively reliable modality for CBCT-based adaptive prostate radiotherapy.

METHODS AND MATERIALS

Study design

- Retrospective comparison of HyperSight CBCT reconstructions in prostate SBRT patients with implanted fiducial markers.
- Reconstruction methods evaluated:
 - standard CBCT
 - iCBCT
 - MAR-iCBCT
- Pre-HyperSight CBCT was included as a historical comparison.

Patient data

- 6 prostate SBRT patients with fiducial markers
- 5 fractions/patient
- 90 HyperSight CBCT datasets total (6 patients $\times$ 5 fractions $\times$ 3 reconstructions)
- 5 pre-HyperSight patients used for historical comparison (25 datasets)

Phantom data

- CT density phantom scanned on multiple non-consecutive days
 - HU stability
 - spatial resolution

Image analysis

- Metal artifact quantification:
 - Fiducial markers were contoured, and a 1-cm isotropic expansion excluding the marker volume was used to define the near-marker ROI.
 - HU standard deviation (SD) was used as a surrogate for artifact severity.
- HU stability:
 - Organs and bony structures were auto-segmented using an AI-based contouring tool and reviewed by physicists.
 - Median absolute deviation (MAD) across fractions was used to assess inter-fraction HU reproducibility.
- HU agreement:
 - Agreement between reconstructions was evaluated using intraclass correlation coefficients (ICC).
- Spatial resolution:
 - Phantom spatial resolution was assessed using MTF analysis, with MTF50 and MTF60 used for comparison.

RESULTS

Image quality

- MAR-iCBCT showed the strongest metal artifact reduction around fiducial markers.
- iCBCT and MAR-iCBCT improved soft-tissue visibility relative to standard CBCT.
- Spatial resolution was comparable at MTF50, with better high-frequency performance for HyperSight iterative reconstructions.

HU stability

- iCBCT and MAR-iCBCT demonstrated stable organ HU values across treatment fractions.
- Pre-HyperSight CBCT showed greater inter-fraction HU variability, especially in bone.
- Phantom scans confirmed stable HU reproducibility.

Quantitative agreement

- HU agreement between iCBCT and MAR-iCBCT was near perfect across all evaluated organs.
- Agreement between iCBCT and standard CBCT was substantially lower.
- Findings support the use of HyperSight iterative reconstructions for quantitative CBCT applications.



Figure 1. Representative prostate CBCTs with MAR-iCBCT (a), iCBCT (b), and standard (c) reconstruction methods.

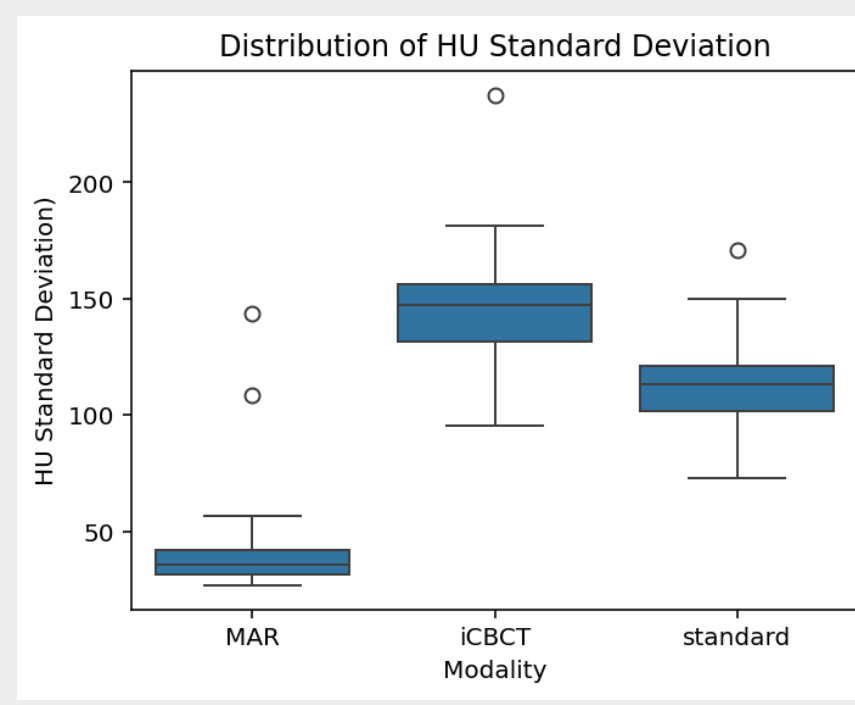


Figure 2. Box plots of HU standard deviation in a 1 cm region around fiducial markers.

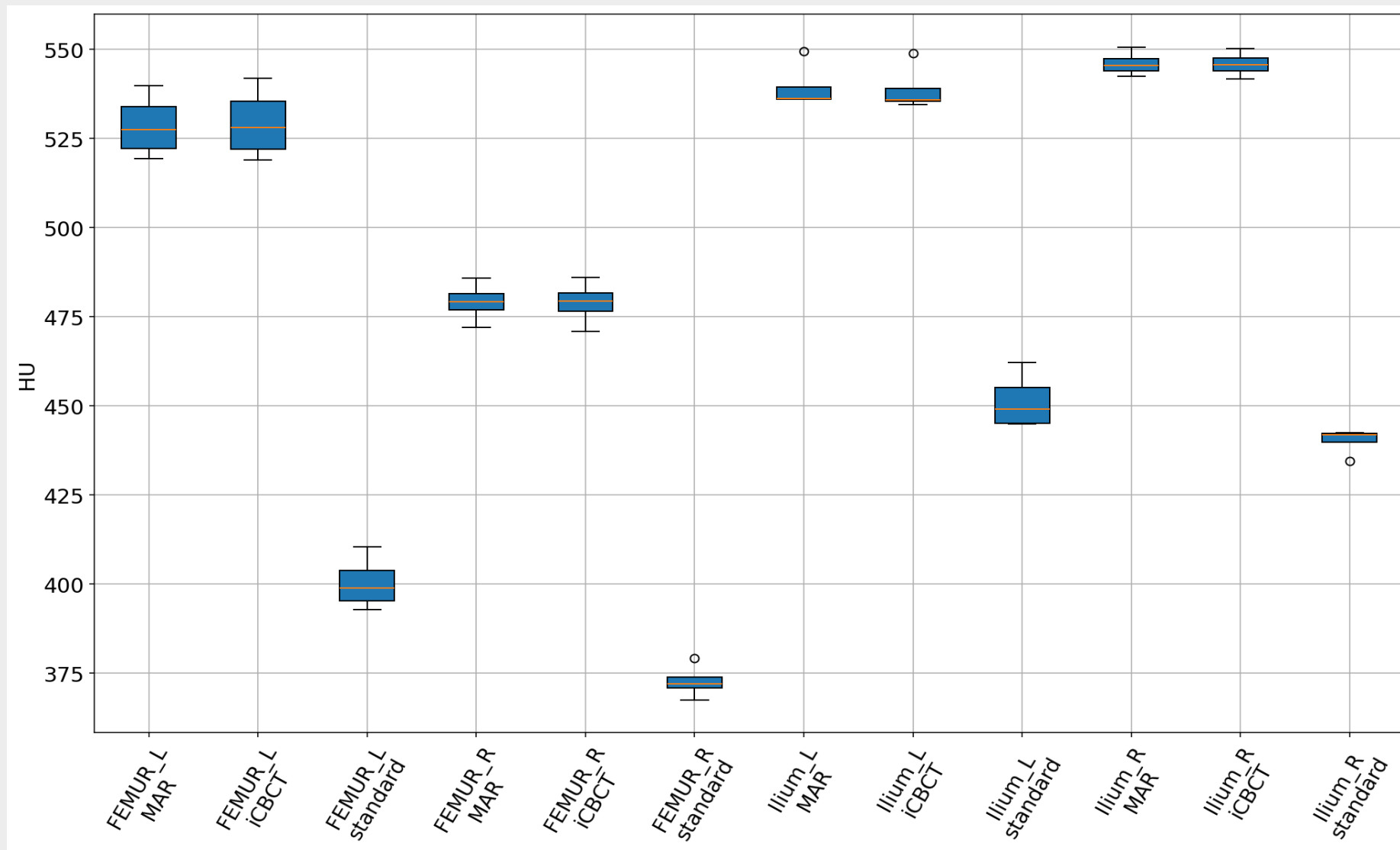
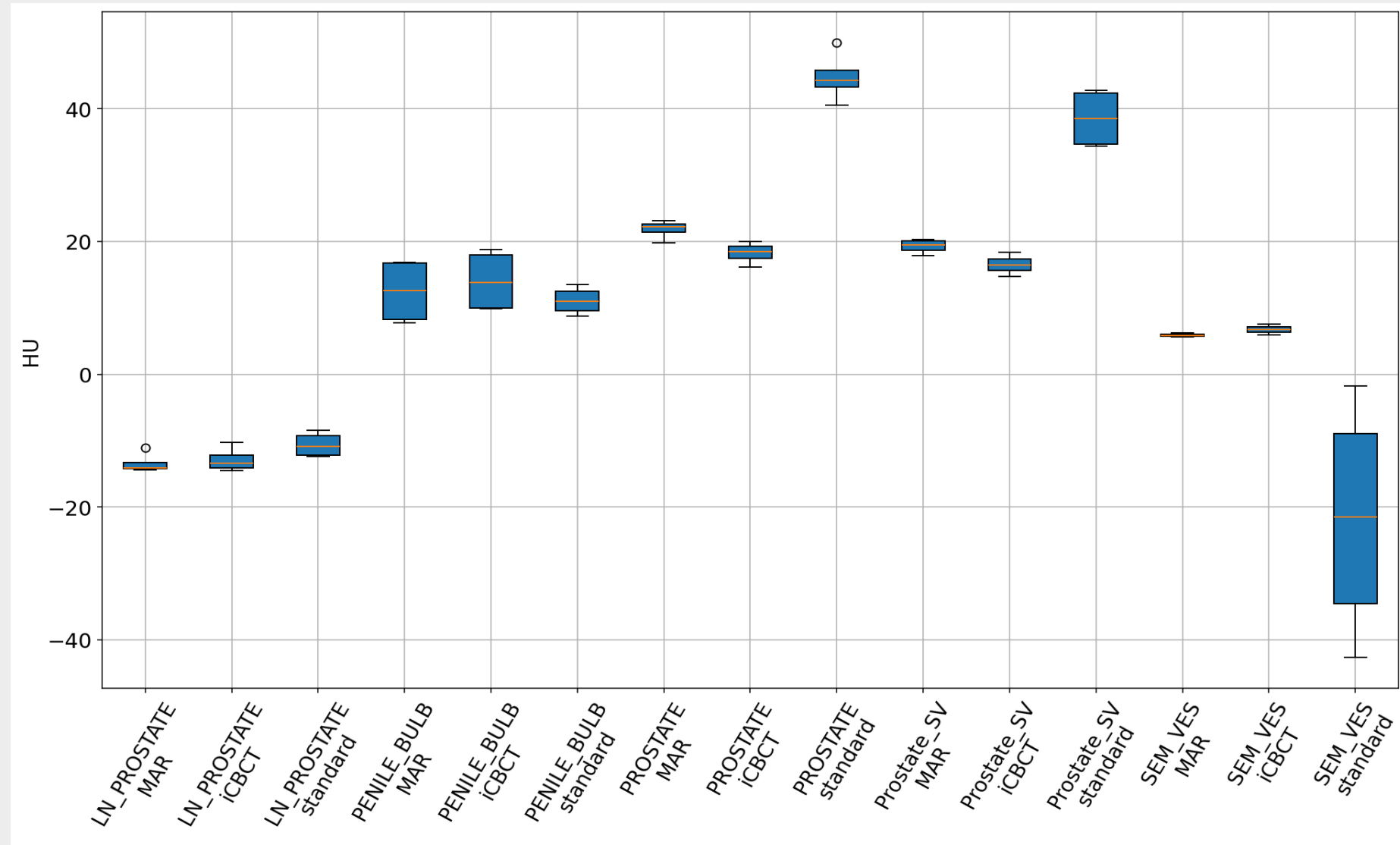


Figure 3. HU distributions across fractions for a representative patient. Left: pelvic soft tissues; right: bones. Box plots compare iCBCT, MAR-iCBCT, and standard CBCT..

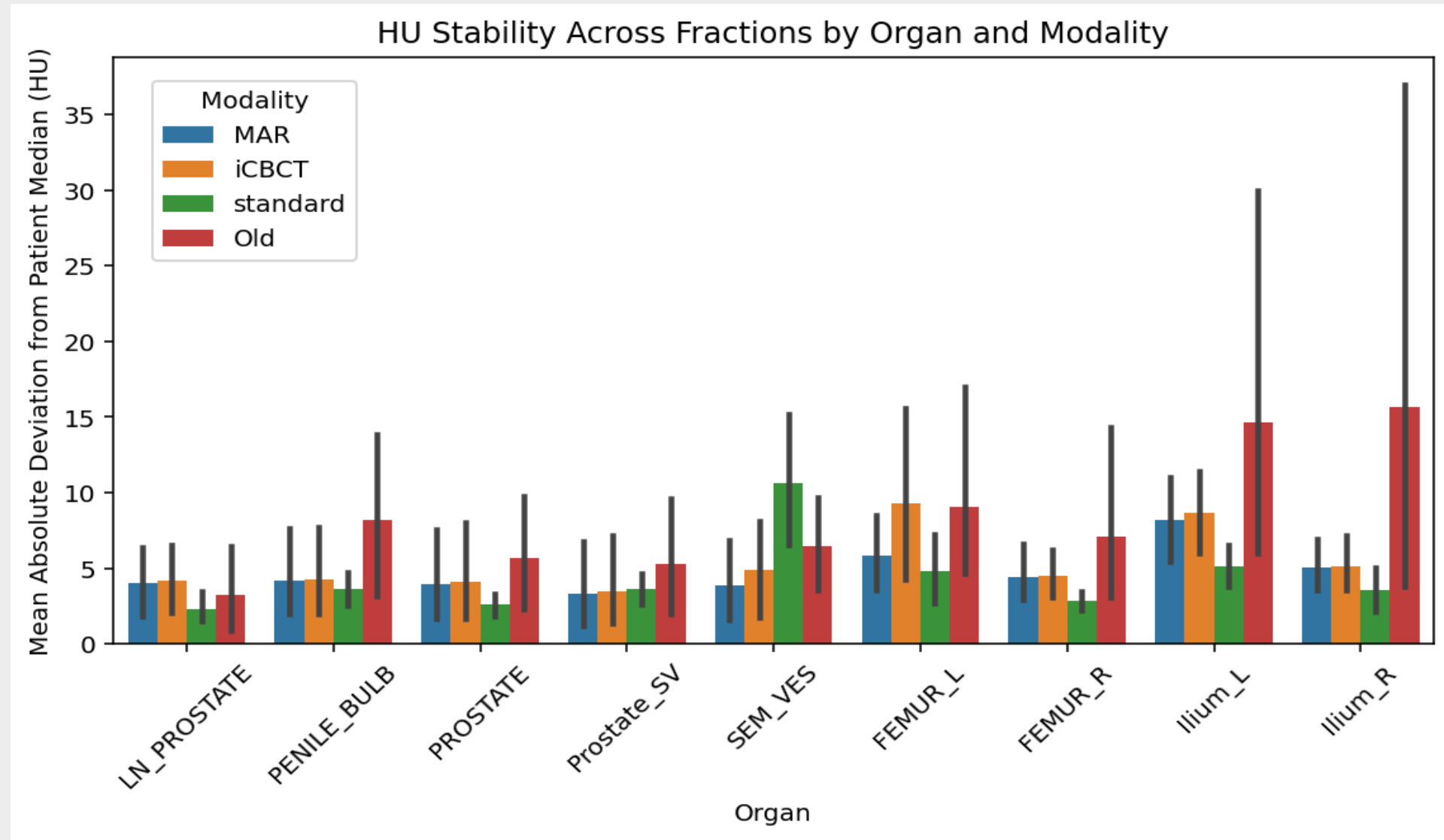


Figure 4. HU stability across fractions for all patients, summarized by organ and reconstruction method using median absolute deviation (MAD). Lower MAD indicates greater HU stability.

Table 1. ICC for HU agreement between reconstruction methods

Organ	Comparison	ICC	CI95%
LN_PROSTATE	MAR vs iCBCT	0.9993	[0.99 1.]
LN_PROSTATE	iCBCT vs standard	0.8130	[0.43 0.93]
PENILE_BULB	MAR vs iCBCT	0.9976	[0.99 1.]
PENILE_BULB	iCBCT vs standard	0.2230	[-0.22 0.58]
PROSTATE	MAR vs iCBCT	0.9743	[0.2 0.99]
PROSTATE	iCBCT vs standard	0.0390	[-0.13 0.29]
Prostate_SV	MAR vs iCBCT	0.9851	[0.32 1.]
Prostate_SV	iCBCT vs standard	0.0394	[-0.18 0.34]
SEM_VES	MAR vs iCBCT	0.9997	[1. 1.]
SEM_VES	iCBCT vs standard	-0.4021	[-0.73 0.03]
FEMUR_L	MAR vs iCBCT	1.0000	[1. 1.]
FEMUR_L	iCBCT vs standard	0.4903	[-0.03 0.84]
FEMUR_R	MAR vs iCBCT	0.9999	[1. 1.]
FEMUR_R	iCBCT vs standard	0.4026	[-0.05 0.78]
Ilium_L	MAR vs iCBCT	0.9997	[1. 1.]
Ilium_L	iCBCT vs standard	0.6140	[-0.05 0.89]
Ilium_R	MAR vs iCBCT	0.9989	[1. 1.]
Ilium_R	iCBCT vs standard	0.4708	[-0.07 0.82]

CONCLUSIONS

HyperSight-based CBCT reconstructions demonstrated improved image quality and quantitative performance compared with conventional and pre-HyperSight CBCT. MAR-iCBCT provided the most effective reduction of fiducial-related artifacts, while both iCBCT and MAR-iCBCT showed stable HU reproducibility across treatment fractions and strong agreement across evaluated pelvic structures. Together, these findings support the feasibility of using HyperSight CBCT on conventional C-arm linacs as a quantitatively reliable imaging platform for adaptive prostate radiotherapy.

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