HyperSight CBCT Preserves CT-Like Radiomic Biomarkers Better Than Conventional CBCT in Pelvic Radiotherapy

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Introduction

HyperSight CBCT preserves CT-like radiomic biomarkers substantially more faithfully than conventional CBCT, supporting its use for radiomics-driven adaptive radiotherapy monitoring.

Why it matters

- **Radiomics** quantifies tissue phenotype, treatment response, and toxicity risk, but is only useful on-treatment if imaging preserves the biomarker behavior seen on planning CT.
- **Conventional CBCT** is prone to scatter, truncation, and shading artifacts that perturb voxel intensities and texture features.
- **HyperSight CBCT** targets CT-like image quality: but is that fidelity *radiomic*, not just visual?

Gap & objective

- **Gap:** whether HyperSight's image-quality gains yield CT-like *radiomic features*, not just visual similarity, is untested.
- **Objective:** quantify radiomic fidelity of HyperSight vs conventional CBCT relative to planning CT, at feature and multivariate levels.

Materials & Methods

- **Cohort:** 10 pelvic cancer patients (retrospective); paired planning CT, HyperSight CBCT, conventional CBCT (first on-treatment scan per modality).
- **Registration:** HyperSight and conventional CBCT rigidly registered to planning CT (ITK; mutual information; multi-resolution); resampled to 1-mm isotropic voxels.
- **Feature extraction:** PyRadiomics v3.0.1 within the CTV and femur ROIs, in the planning-CT reference frame; statistics in R v4.5.2.

Radiomic fidelity endpoints

- Three feature-wise endpoints quantify CT fidelity per feature (**Figure** 1): **(1)** SD ratio (variance preservation vs compression/inflation), **(2)** ICC(3,1) agreement with CT, **(3)** normalized deviation from CT.
- Normalized deviation is tested with paired one-sided Wilcoxon signed-rank tests (HyperSight < CBCT), Benjamini-Hochberg FDR corrected:

$$e = \frac{|f_{\text{mod}} - f_{\text{CT}}|}{|f_{\text{CT}}| + \varepsilon}, \qquad \varepsilon = 10^{-8}.$$

- **(4)** A CT-defined PCA space assesses patient-level Euclidean distance to CT and PC1-PC2 distributional overlap.

Acknowledgements

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References

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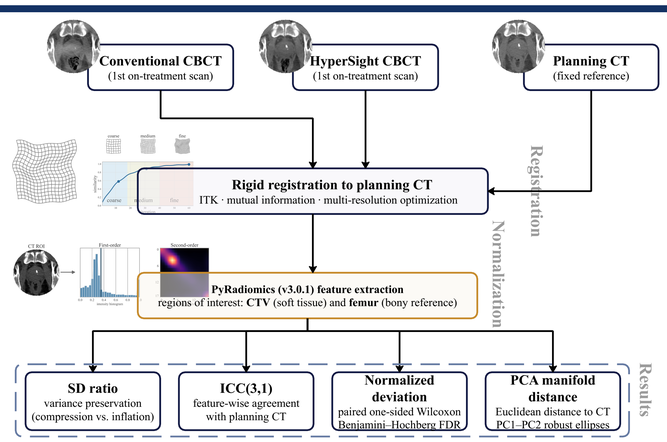

Figure 1. Study design and radiomic fidelity pipeline. Planning CT, conventional CBCT, and HyperSight CBCT ($n = 10$) are registered to CT (1-mm isotropic); CTV and femur features (PyRadiomics v3.0.1) are compared with CT via SD ratio, ICC, normalized deviation, and PCA manifold distance.

92.6% / 75.3%
features with **improved** ICC vs CT
(CTV / fumer)

↓ 56.6% / ↓ 90.5%
PCA distance to CT reduce
(CTV / fumer)

9/9 & 9/10
Patients closer to CT
(CTV & femur)

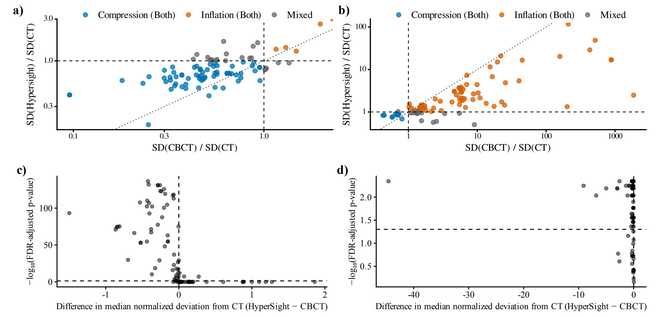

Figure 2. Radiomic variance preservation and deviation from planning CT. (a,b) SD ratio relative to CT, HyperSight (y) vs conventional CBCT (x), CTV and femur; dashed lines at 1 = perfect preservation. (c,d) Volcano: median deviation difference (HyperSight − CBCT) vs $-\log_{10}$(FDR p); negative = greater HyperSight fidelity.

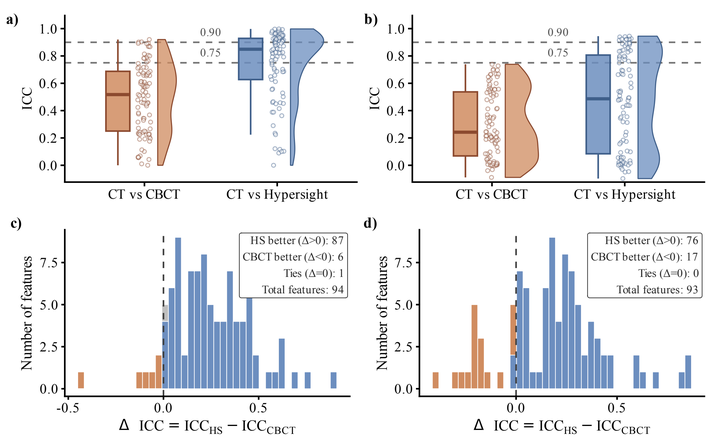

Figure 3. Feature-wise agreement with planning CT by ICC(3,1). (a,b) ICC distributions for CT vs conventional CBCT and CT vs HyperSight (CTV, femur); dashed lines mark good (0.75) and excellent (0.90). (c,d) Agreement gain $\Delta\text{ICC} = \text{ICC}_{\text{HS}} - \text{ICC}_{\text{CBCT}}$; positive = improved for HyperSight.

Contact

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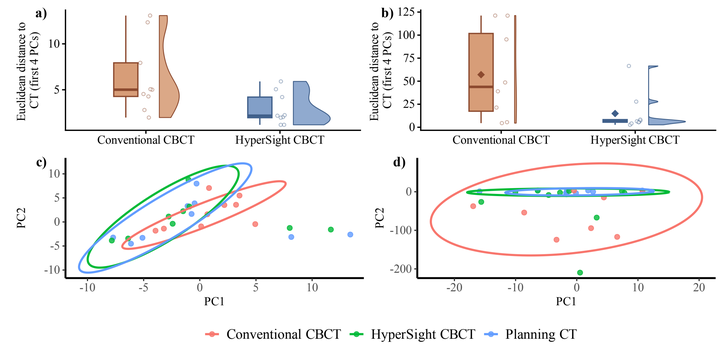

Figure 4. Preservation of the CT-defined multivariate radiomic structure. (a,b) Patient-level Euclidean distance to CT in a CT-trained PCA space (first 4 PCs), conventional CBCT vs HyperSight, for CTV and femur; smaller = closer to CT. (c,d) PC1-PC2 projections with robust covariance ellipses; HyperSight clusters near CT, conventional CBCT shifts and spreads, most notably in femur.

Results

- **Variance:** HyperSight more consistently preserved CT-like variance in both ROIs; conventional CBCT frequently distorted it, with pronounced inflation in the femur (**Figure** 2a-b).
- **Deviation:** normalized deviation from CT was lower for HyperSight across most features, with many FDR-significant gains in both ROIs (**Figure** 2c-d).
- **Agreement (ICC):** HyperSight improved ICC for 87/94 CTV (92.6%) and 70/93 femur features (75.3%); top-30 median ICC rose 0.773→0.951 (CTV), 0.586→0.878 (femur) (**Figure** 3, **Table** 1).
- **Multivariate (PCA):** HyperSight cut Euclidean distance to CT by 56.6% (CTV, 9/9 closer) and 90.5% (femur, 9/10 closer), with tighter PC1-PC2 clustering (**Figure** 4, **Table** 1).
- **Site:** gains were largest in the femur, the bony region where conventional CBCT artifacts are typically worst.

Table 1. Radiomic fidelity relative to planning CT. ICC is top-30 median [IQR]; PCA distance is median [IQR] over the first 4 PCs (≥90% CT variance); p from paired one-sided Wilcoxon tests. Better values in **bold**.

ROI	Modality	Top-30 median ICC ↑	PCA dist. to CT ↓
CTV	Conv. CBCT	0.773 [0.694, 0.869]	5.01 [4.27, 7.93]
	HyperSight	**0.951 [0.931, 0.969]**	**2.17 [1.96, 4.20]** (↓56.6%)
Femur	Conv. CBCT	0.586 [0.542, 0.665]	71.98 [25.79, 121.19]
	HyperSight	**0.878 [0.830, 0.922]**	**6.81 [5.52, 22.93]** (↓90.5%)

Features with improved ICC ($\Delta\text{ICC} > 0$): 87/94 (92.6%) CTV, 70/93 (75.3%) femur. $p = 0.001953$ (PCA, both ROIs).

Conclusion

- HyperSight CBCT preserves CT-derived radiomic biomarkers markedly better than conventional CBCT, at both the feature (ICC, deviation, variance) and multivariate (CT-PCA) levels.
- Gains were consistent in the CTV and femur, and largest in the femur, where conventional CBCT artifacts dominate.
- The three-endpoint plus PCA framework generalizes to benchmark any on-treatment modality against planning CT.
- Findings support HyperSight as a more reliable substrate for radiomics-driven adaptive radiotherapy (response assessment, toxicity prediction, longitudinal phenotyping) without additional CT acquisitions.

HyperSight CBCT → CT-faithful radiomics at the first fraction.