# Creative Imaging Solutions for HDR Brachytherapy Planning Using Linac-Integrated Hypersight CBCT

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## ABSTRACT

**Purpose:** Mobile CT and CBCT systems improve flexibility and reduce patient transport burden in HDR gynecologic brachytherapy. However, competition for imaging resources remains a practical limitation. This work evaluates the Varian Ethos linear accelerator equipped with HyperSight iCBCT for applicator implantation verification and treatment planning without reliance on a dedicated CT simulator.

**Methods:** Two applicator configurations were studied in a gynecologic phantom with a silicone uterus and vaginal canal embedded in synthetic medical gel with added layers of folded bolus: (1) Varian Fletcher-Suit-Delclos-style tandem-and-ovoids (T&O) applicator set with two titanium interstitial needles. (2) Varian Universal Interstitial Cylinder (UIC) with five plastic interstitial needles inserted through the central channel and posterior half of the UIC. The phantom was imaged using a dedicated brachytherapy CT scanner (Brainlab Airo CT) with 1 mm slice thickness and the Ethos system (5.6-second iCBCT with 2 mm slice thickness). 40-cm x 40-cm field of view was used for both systems. The applicators were digitized on both image-sets using Varian BrachyVision. Image quality was compared using Catphan scans.

**Results:** HyperSight iCBCT accurately visualized all the intracavitary applicators and coded marker strands required for interstitial needle reconstruction. Measured tandem full width at half maximum values were closer to the nominal 3 mm diameter with HyperSight than Airo CT. Catphan analysis showed comparable or improved HyperSight performance for spatial resolution, low-contrast detectability, HU constancy, uniformity, and noise. Three feasible gynecological HDR brachytherapy workflows using HyperSight were proposed for centers with limited CT simulation capacity.

**Conclusion:** This work demonstrates, for the first time, the feasibility of using Ethos HyperSight iCBCT for HDR gynecologic brachytherapy planning with hybrid applicators. HyperSight iCBCT offers an efficient imaging option that may significantly improve workflow flexibility at centers with limited CT availability, while maintaining clinically acceptable image quality.

## CONTACT

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## INTRODUCTION

Institutional workflow and infrastructure may prioritize CT for diagnostic imaging or external beam radiation therapy planning, thereby limiting brachytherapy implementation. This study proposes using Varian Ethos HyperSight iterative reconstruction CBCT (iCBCT) for CT-independent gynecological (GYN) brachytherapy and provides an image quality comparison with a dedicated Airo Helical CT brachytherapy scanner.

## METHODS AND MATERIALS

**The Imaging Systems:**

**Airo CT → [19.6 Second Scan]**
Fan beam helical scan with filtered back projection reconstruction + metal artifact reduction algorithm (MAR), 1mm slice thickness and 107cm bore diameter. 1.92s rotation time with 1.415 pitch.

**Ethos HyperSight iCBCT → [5.9 Second Scan)**
iCBCT scan with iterative reconstruction + MAR, 2mm slice thickness and 100cm bore diameter. Cesium iodide scintillator detector with scatter reducing grid.

**The GYN Phantom Study (Treatment Planning Feasibility):**

GYN phantom with a silicone uterus surrounded by folded layers of bolus to simulate realistic scatter/attenuation conditions[1]. Two Varian HDR applicator configurations tested:

**1.) T&O with two titanium interstitial needles**

**2.) UIC with five plastic interstitial needles**

HyperSight treatment planning fidelity quantified using:

- **Geometric Accuracy:** FWHM of line profiles across the 3 mm diameter intra-uterine tandem were compared using a custom MATLAB 2025a code.
- **Needle Identification:** Line profiles along needle channels with coded marker strands were compared.
- **Metal Artifacts:** CT number histogram was generated in a 2 x 2 cm region of interest in the phantom uterus. Histogram standard deviation was used as a surrogate for local uniformity and artifact-related intensity variation.
- **DRR Quality:** Image quality of DRRs was compared for both applicator configurations to assess whether marker strand geometry remained interpretable in 2D images.

**Image Quality Comparison:**

A Catphan 504 imaging phantom was scanned using both systems. Image quality analysis was performed using Total QA software and the open-source Pylinac Catphan QA module to determine contrast-detail performance, line spread function (LSF), modulation transfer function (MTF), and noise power spectrum (NPS).

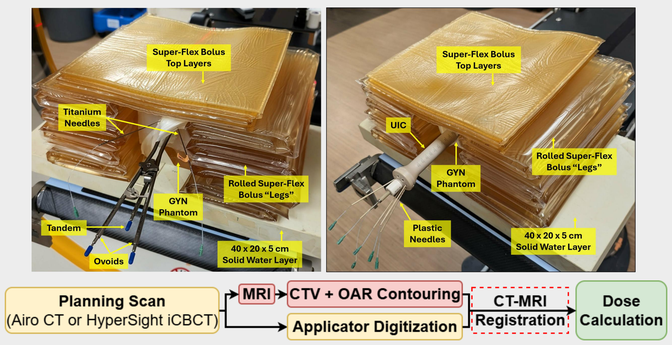


**Figure 1.** The custom GYN HDR brachytherapy phantoms with the T&O (Left) and UIC (Right) applicator configurations. (Bottom) Treatment planning workflow followed for both phantoms after applicator insertion.

## RESULTS & DISCUSSION

**The GYN Phantom Study (Treatment Planning Feasibility):**

- HyperSight was closer to the true physical dimensions of the intra-uterine tandem in both planes (Figure 2a). This suggests improved geometric accuracy over Airo CT.
- HyperSight line profiles through needle coded marker strands showed distinct marker peaks for needle identification (Figure 2b). Airo CT showed superior sharpness and reduced blooming inside the titanium needles (volume averaging may contribute due to the increased HyperSight 2mm slice thickness).
- Airo CT DRR showed sharper marker strand edges (Figure 2c). HyperSight DRRs still provided sufficient visualization to identify the marker seed trains.
- A 46% reduction in standard deviation in the uniform phantom uterus (Figure 2d) with HyperSight iCBCT MAR indicates a more effective metal artifact reduction compared to the Airo CT MAR algorithm.

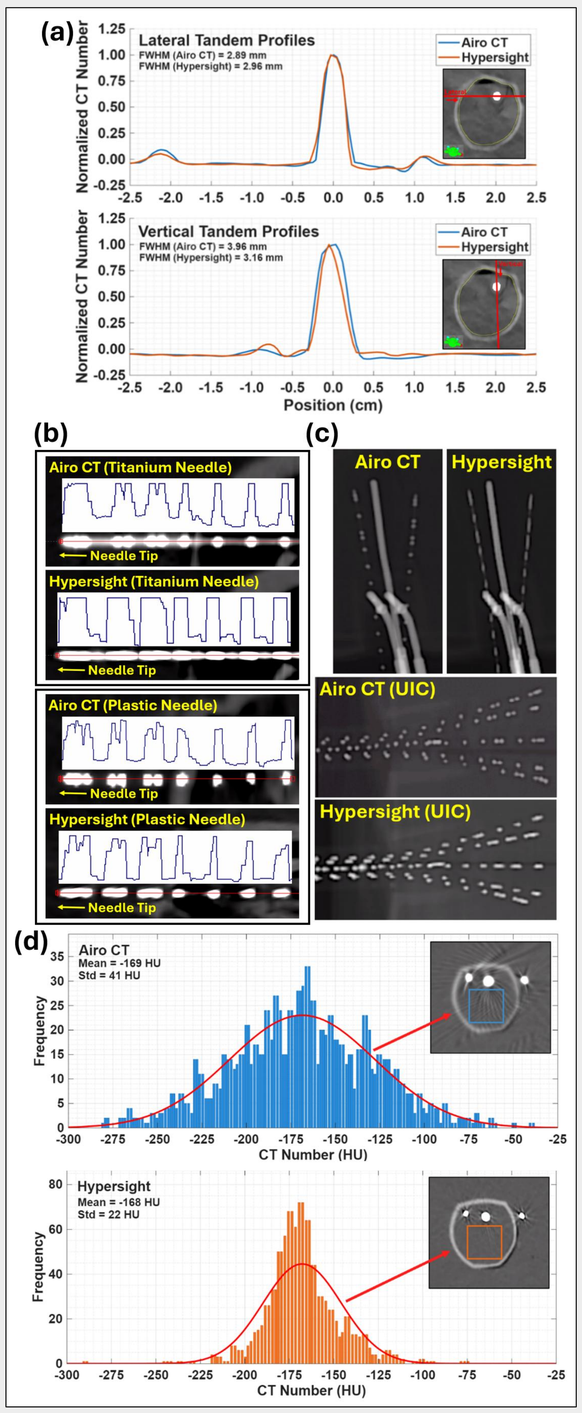


**Figure 2.** (a) Line profiles through the tandem. (b) Line profiles through the titanium (left) and plastic (right) needles with marker strands inserted. (c) DRRs for the T&O configuration (top) and UIC configuration (bottom). (d) Histograms for the uniform phantom uterus with the T&O applicator configuration with a Gaussian fit.

**Image Quality Comparison:**

- Narrower HyperSight LSF suggests HyperSight was better at reproducing the sharp edges of the Catphan high contrast beads with less blurring than the Airo CT.
- The MTF for HyperSight lost resolution at a reduced rate compared to Airo CT, suggesting reduced blurring and improved ability to transmit spatial frequency information of the object being imaged.
- HyperSight contrast detail curve is lower than the Airo CT curve for the entire range of Catphan targets, suggesting improved detection of smaller objects at lower contrast levels than the Airo CT.
- Reduction in low frequency noise magnitude in the HyperSight NPS compared to the Airo CT suggests that the iCBCT MAR scan was able to produce comparably less noisy images using the pelvis imaging protocol.

**Table 1.** Measured image quality metrics for Airo CT and HyperSight iCBCT Catphan scans. Superior HyperSight metrics are highlighted.

| Quality Metric | Airo CT | HyperSight |
|---|---|---|
| Geometric Distortion (mm) | 0.02 | 0.08 |
| Spatial Resolution (lp/cm) | 4.55 | 6.03 |
| HU Constancy (HU) | 17 | 12 |
| Uniformity (HU) | 3.9 | 3.7 |
| Noise (HU) | 6.6 | 5.4 |
| Contrast (mm) | 4 | 3 |
| Low Contrast CNR | 8.46 | 8.17 |

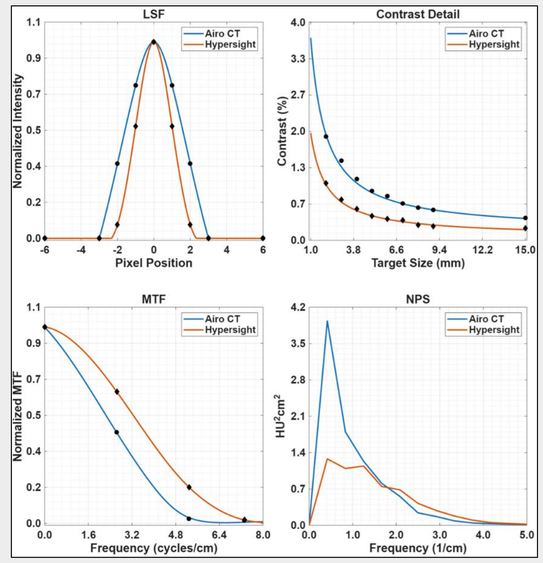


**Figure 3.** The LSF, contrast detail, MTF and NPS for both the Airo CT and HyperSight iCBCT scans of the Catphan phantom.

## CONCLUSIONS

- **HyperSight accurately reconstructed common brachytherapy applicators and differentiated coded marker strands for reconstruction.**
- **HyperSight iCBCT showed image quality comparable to or better than our Airo CT brachytherapy system.**
- **Findings support HyperSight as an imaging platform for HDR GYN brachytherapy.**

## REFERENCES

1. Eckroate B, Ayala-Peacock D, Venkataraman R, et al. A novel multi-modality imaging phantom for validating interstitial needle guidance for high dose rate gynecological brachytherapy. J Appl Clin Med Phys 2023;24:e14075. https://doi.org/10.1002/acm2.14075.