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Impact of Noise-Suppression Strength and Exposure Reduction on Contrast–Detail in Image-Guided Radiation Therapy with High-Performance CBCT

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ABSTRACT

Purpose: To evaluate how varying the noise-suppression level and adjusting the imaging exposure affects contrast-detail performance and spatial resolution in high-performance CBCT-guided radiation therapy.

Methods: A CATPhan 604 image-quality phantom was scanned on a C-arm linac equipped with high-performance CBCT using three imaging modes (head, thorax, and pelvis). For each mode, factory-default acquisition and reconstruction settings were tested as well as three reduced exposure settings and four additional iterative reconstruction noise-suppression levels. Image-quality metrics, including spatial resolution, noise, and low-contrast detectability were assessed to determine the potential for CBCT dose reduction. Contrast-detail (CD) curves were generated, and the smallest detectable object size was evaluated using the Rose criterion at 1% and 0.5% contrast. CD curves acquired with CBCT were compared to CD curves for the same phantom scanned on a CT simulator with corresponding imaging protocols.

Results: Spatial resolution, quantified by MTF (10%), was unaffected by changes to the noise-suppression level but decreased by up to 8% when exposure was lowered to 25% of the default settings. Noise decreased linearly with the strength of the noise suppression setting. The relationship between squared noise and exposure followed a power-law, showing diminishing improvements at higher exposures. The CD curves showed that reducing exposure to 50% of the default values increased the smallest detectable low-contrast object size by only 1-2 mm. Increasing the noise-suppression by one level improved detectable low-contrast object size by a comparable amount (1-3 mm). Comparable CD sensitivity was found between CT data and CBCT data for varied CTDI levels.

Conclusion: This phantom study suggests that imaging dose in image-guided radiation therapy using a high-performance CBCT system may be reduced by up to 50% from factory-default settings when combined with a moderate increase in noise-suppression strength without substantially compromising low-contrast detectability. Validation with clinical image data is needed to confirm these findings.

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INTRODUCTION

- HyperSight is an advanced imaging system available on Varian TrueBeam linear accelerators, including both hardware and software improvements.
- HyperSight employs iterative reconstruction and advanced scatter reduction for improved CBCT image quality. Unlike filtered back-projection, the relationship between exposure and image quality in iterative reconstruction is not easily determined.[1]
- The level of noise suppression is one of the reconstruction parameters adjustable by the user, but it may impact other image quality metrics.

Purpose:

1. **This study provides data on the performance of HyperSight on TrueBeam CBCT systems and is one of the first studies to use contrast-detail (CD) curves to quantitatively evaluate low-contrast resolution beyond minimum detectable object size.**
2. **This study also investigates dose levels needed to match corresponding CD curves from a CT simulator.**

METHODS AND MATERIALS

- A Catphan 604 phantom was scanned on a Varian TrueBeam linear accelerator with HyperSight.
- Three different CBCT imaging modes were used:
  - Head – 100 kVp, 2 mm slice thickness, full fan
  - Thorax – 125 kVp, 2 mm slice thickness, half fan
  - Pelvis – 125 kVp, 2 mm slice thickness, half fan
- Four exposure levels and five noise-suppression settings (*Very Low*, *Low*, *Medium*, *High*, and *Very High*) were evaluated using an automated analysis tools (TotalQA[2]). Exposure levels and corresponding CTDI values are listed in Table 1.
- The frequency at which the modulation transfer function (MTF) drops to 10% quantified the effects on spatial resolution for the exposure and noise-suppression levels used.
- CD curves were generated for all imaging modes, noise-suppression strengths, and exposure levels.
- The phantom was also scanned on a Siemens go.Open Pro CT simulator to determine the dose at which HyperSight CBCT and CT CD curves matched, using typical clinical exposure settings.

Table 1. CBCT imaging modes and their corresponding exposure levels and CTDI values. Underlined values are the manufacturer's default.

	Exposure Levels (mAs)	CTDI (mGy)
Head	50, 84, 109, <u>149</u>, 298, 598, 898, 1187	1.1, 1.8, 2.3, <u>3.2</u>, 6.4, 12.8, 19.3, 25.5
Thorax	88, 177, <u>265</u>, 619	1.3, 2.6, <u>3.9</u>, 9.1
Pelvis	88, 260, 530, <u>1062</u>	1.3, 3.8, 7.8, <u>15.7</u>

RESULTS

- MTF(10%) demonstrated only slight dependence on noise suppression levels, with a 6% change on average between *Very Low* and *Very High* noise suppression. (Figure 1).
- Noise-squared as a function of exposure obeyed a power law relationship (Figure 2).
- Figure 3 is a plot of the CD curves for the pelvis imaging mode as a function of noise-suppression strength.
- CD curves for all imaging modes as a function of exposure are shown in Figure 4. Minimum detectable object size decreased as exposure increased.
- Similar CD sensitivity between CT and CBCT data were observed at different exposure levels for different imaging modes:
  - Head – CBCT exposure increased by a factor of 8 from default (2.5x lower CTDI than CT)
  - Thorax – CBCT exposure increased by a factor of 2.3 from default (4.5x higher CTDI than CT)
  - Pelvis – Similar CD sensitivity using default values (5.5x higher CTDI than CT)

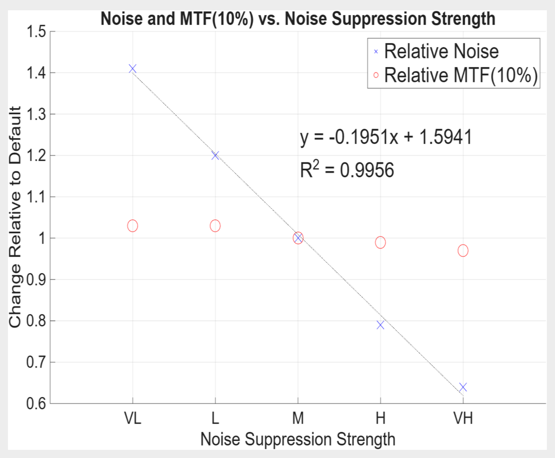

Figure 1. Average relative change in MTF(10%) and noise with respect to noise-suppression strength.

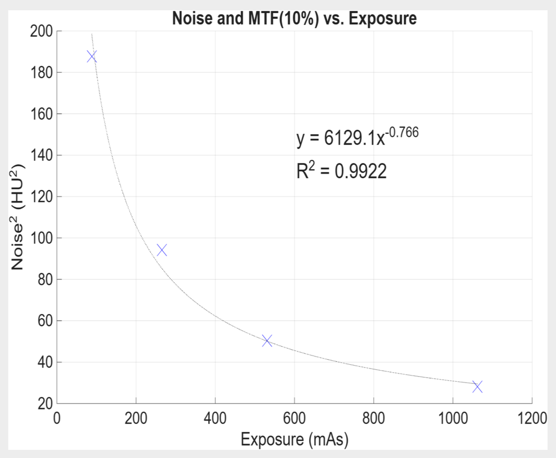

Figure 2. Noise squared as a function of exposure for the Pelvis CBCT mode.

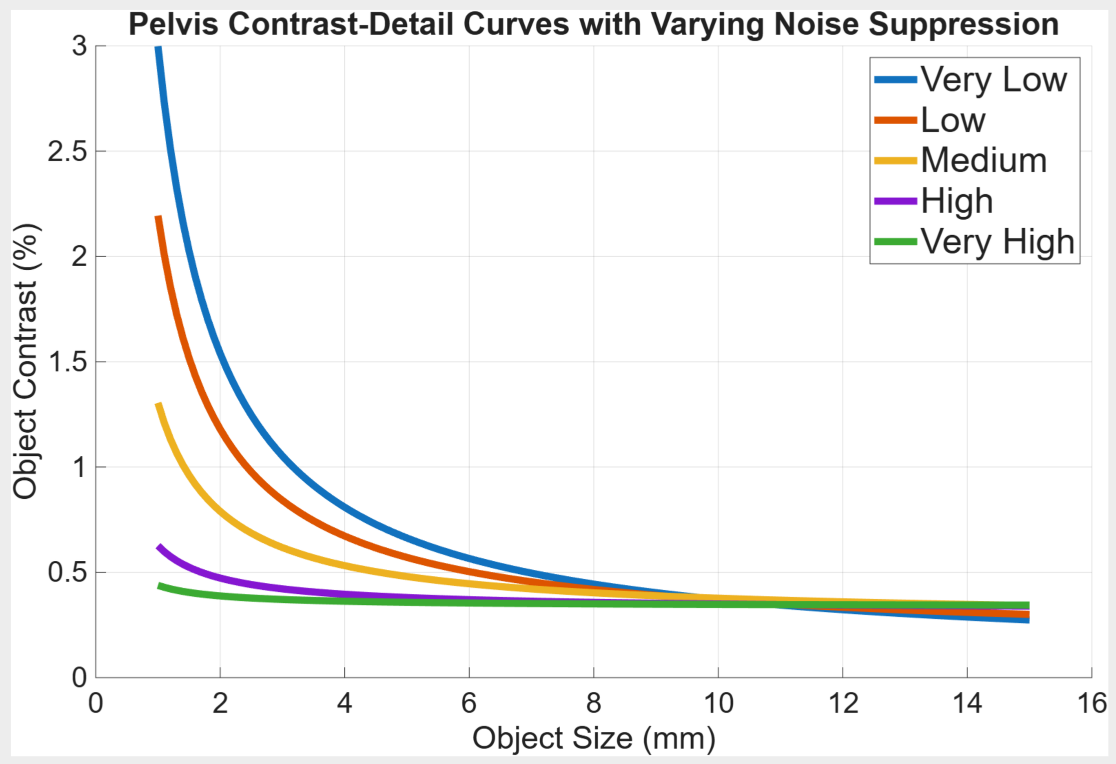

Figure 3. CD curves for the Pelvis imaging mode with varied noise-suppression strengths.

DISCUSSION

- A substantial decrease in noise can be achieved without significant reduction in spatial resolution.

  For example, changing noise-suppression strength from *Medium* to *Very High* reduced noise by 36% on average, with only a 3% decrease in MTF(10%).
- Low-contrast detectability depends strongly on exposure and noise-suppression strength.
- A similar level of CD sensitivity compared to the default settings could be achieved by increasing the noise suppression from *Medium* to *High* and reducing the exposure by half.
- Very high exposure levels did not necessarily result in a further improvement in low-contrast detectability for the Head and Thorax imaging modes.
- CD curves similar to those from a CT scanner would yield CTDI values that are approximately five times higher for the thorax and pelvis modes and 2.5 times lower for the head mode.

CONCLUSIONS

- **This phantom study suggests that imaging dose in image-guided radiation therapy using the HyperSight CBCT system may be reduced by up to 50% from factory-default settings when combined with a moderate increase in noise-suppression strength without substantially compromising low-contrast detectability or spatial resolution.**
- **Matching CD curves from a CT scanner would generally require an increase in dose to the phantom (CTDI).**
- Validation with clinical image data is needed to confirm these findings.

REFERENCES

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DISCLOSURES

This study was funded by Siemens Healthineers.

The authors have no other disclosures.

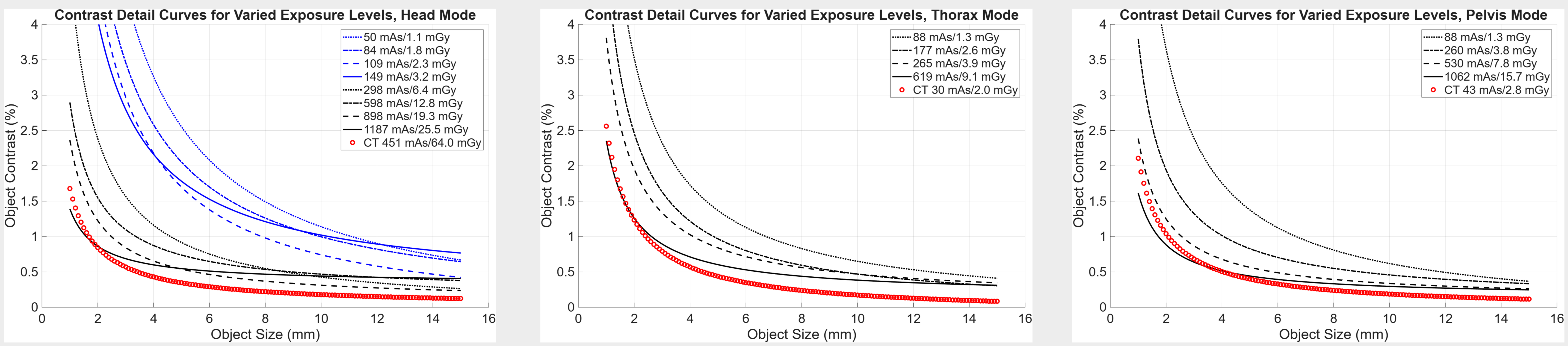

Figure 4. CD curves for all imaging modes with varied exposure levels. Head mode (left), thorax mode (center), pelvis mode (right). The legends include exposure levels (mAs) and CTDI (mGy).

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