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Evaluation of CBCT Protocol Optimization Following Upgrade from CB4030 to HyperSight

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ABSTRACT

Purpose:
To quantitatively and qualitatively assess CBCT image quality and achievable mAs optimization following an upgrade from the CB4030 imaging system to HyperSight, including FDK and iCBCT reconstruction.

Methods:
Head, thorax, pelvis, large pelvis, and spotlight CBCT protocols were modified to achieve total mAs values ranging from 20–80% of default by varying mAs per projection and the number of projections. Protocol exposure was characterized using ion chamber air kerma measurements. Catphan 604 and anthropomorphic phantoms were imaged before and after the upgrade from CB4030 to HyperSight. Quantitative imaging metrics included HU constancy and uniformity, low contrast visibility, spatial resolution and spatial integrity. Anthropomorphic phantom images were qualitatively reviewed by physicists to determine appropriate image quality for patient alignment.

Results:
Low contrast visibility and integrated NPS demonstrated a strong and significant dependence on total mAs across all protocols ($r>0.86$, $p<0.02$).HU values and uniformity indices remained within a ±30 HU of baseline for all protocols with >20% relative exposure except for some low-dose CB large pelvis protocols, with HyperSight exhibiting modestly reduced variability compared to CB4030 that did not impact clinical acceptability. Spatial resolution and spatial integrity were insensitive to dose reduction. Qualitative assessment showed that protocols operating at 25–50% of default mAs maintained adequate image quality for alignment depending on anatomic site and reconstruction method. Compared with CB4030 FDK, HyperSight FDK permitted additional mAs reduction for the Spotlight and Thorax protocols, while HyperSight iCBCT permitted additional reduction for the Pelvis and Large Pelvis protocols. Projection number reduction introduced more pronounced aliasing artifacts than mAs/frame for both systems.

Conclusion:
Protocol mAs reductions of 50–75% were achieved across common IGRT protocols while maintaining clinically acceptable image quality for alignment. Low-contrast visibility and integrated NPS were the metrics most sensitive to mAs reduction. HyperSight FDK provided modest improvements relative to CB4030 FDK, while the largest gains and lowest acceptable mAs values were observed with iCBCT, indicating that reconstruction was the primary contributor.

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INTRODUCTION

- Cone-Beam Computed Tomography (CBCT) imaging is regularly used for patient alignment
- Imaging dose to healthy tissue may contribute significantly to stochastic and deterministic risk to patient. Repeated CBCT imaging should therefore be optimized to provide image quality appropriate for the clinical task with as low a dose as necessary.
- Our institution previously optimized CB4030 protocols by reducing mAs while preserving image quality sufficient for patient alignment [1].
- Following an upgrade to the HyperSight the optimization process was repeated using both FDK and iCBCT reconstruction where available.
- This study aimed to identify the lowest clinically acceptable mAs for each anatomic site and reconstruction method, compare CB4030 FDK with HyperSight FDK and iCBCT, and evaluate strategies for CBCT protocol optimization.

METHODS AND MATERIALS

- Protocol output was measured free in air with an ion chamber and compared with prior CB4030 measurements.
- CBCT protocols were generated at total mAs values ranging from 20–80% of default by varying either mAs per projection or the total number of projections. Seven protocols were evaluated for each anatomic site.
- Catphan and anthropomorphic phantom images were acquired for each site at every mAs level.
- HyperSight projection data was reconstructed with both FDK and iCBCT reconstruction algorithms for applicable protocols (Head, Pelvis, Large Pelvis).
- Catphan images were analyzed using pylinac to extract quantitative imaging metrics including HU accuracy and uniformity, low contrast visibility, modulation transfer function (MTF), noise power spectrum (NPS), and geometric accuracy.
- Associations between quantitative image-quality metrics and total mAs were assessed using Pearson correlation and regression analysis. Comparisons also considered imaging system and reconstruction method.
- Anthropomorphic phantom images were independently rated as “sufficient” or “not sufficient” for patient alignment.

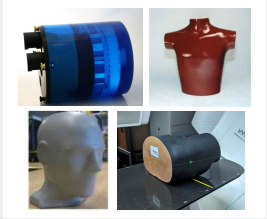
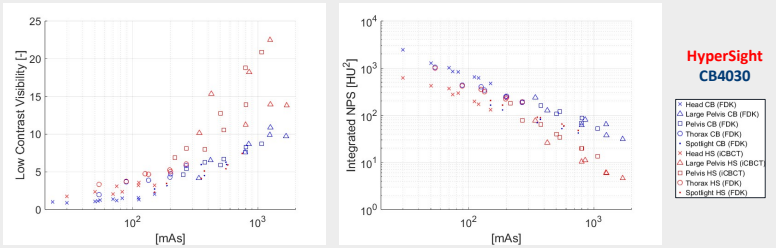


Figure 1. Anthropomorphic Phantoms used for image quality assessment

RESULTS

- Air Kerma measurements for HS CBCT protocols were verified to be consistent; within ±1% of measurements of CB panel.
- Low contrast visibility and Integrated NPS were the only quantitative metrics strongly and significantly associated with mAs across imaging sites ($|R| > 0.7$; $p < 0.05$, figures 2 and 3).
- Reducing number of projections to 50% and below of default introduced pronounced aliasing artifacts whereas comparable reductions achieved by lowering mAs per projection did not.
- Relative to CB4030 FDK, mean low-contrast visibility increased by 80% with HyperSight iCBCT but by only 2% with HyperSight FDK for default-mAs protocols.
- iCBCT shifted the NPS toward lower spatial frequencies, producing a more textured image appearance. For default Head, Pelvis, and Large Pelvis protocols, the mean NPS frequency decreased from 0.22 to 0.16 mm^{-1}, a 26% reduction.
- Qualitative review found that clinically acceptable alignment image quality was maintained at 25–50% of default mAs, corresponding to reductions of 50–75%, depending on site and reconstruction method (figure 4, table 1).



Figures 2 and 3. Low contrast visibility (left) and integrated NPS (right) as a function of mAs for all CB (red) and HS (blue) panels across all sites

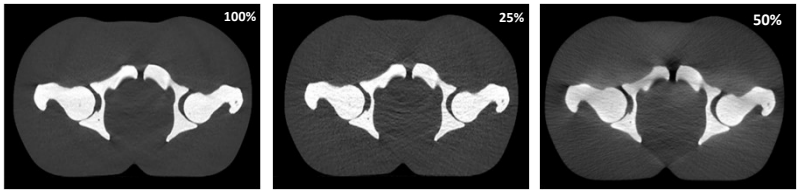


Figure 4. Pelvis phantom images demonstrating clinically acceptable image quality with HyperSight iCBCT at 25% of default mAs, compared with default HyperSight iCBCT and the optimized CB4030 FDK protocol at 50% of default mAs.

Table 1. Lowest clinically acceptable mAs, expressed as a percentage of the default protocol. iCBCT not available for Thorax and Spotlight protocols.

Site	CB4030 FDK	HyperSight FDK	HyperSight iCBCT
Head	33%	33%	33%
Large Pelvis	50%	50%	25%
Spotlight	75%	50%	N/A
Pelvis	50%	50%	25%
Thorax	50%	33%	N/A

CONCLUSIONS

- Clinically acceptable image quality for alignment was maintained at 25–50% of default mAs, depending on anatomic site and reconstruction method.
- Low-contrast visibility and integrated NPS were the quantitative metrics most sensitive to mAs reduction.
- Compared with CB4030 FDK, HyperSight FDK provided relatively modest improvements, whereas the largest gains in low-contrast visibility and the lowest acceptable mAs values were observed with iCBCT. This suggests that reconstruction was the primary contributor to the observed improvement.
- Reducing mAs per projection while maintaining the number of projections was preferable to reducing projection number
- No single quantitative metric clearly predicted the qualitatively selected minimum-mAs protocol for all protocols.
- Future work will include input from a larger interdisciplinary team and quantitative testing of alignment accuracy prior to clinical implementation.

References

1. S. Gros, J. Bian, H. Kang, J. Jackson, M. Delafuente, M. Mahesh, Proposal and Evaluation of a Practical CBCT Dose Optimization Method, Med. Phys. 50(6): p. e306. https://doi.org/10.1002/mp.16525 (2023)