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Impact of High Pitch and Tube Starting Angle on Pediatric CT k-Factor Variability A Monte Carlo Study

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ABSTRACT

Purpose: Monte Carlo simulations are widely used to derive effective dose conversion factors (k-factors) for CT; however, acquisition parameters such as helical pitch and tube starting angle are often randomly selected. The impact of these parameters on the variability of k-factor estimates, especially in high pitch scans, has not been systematically evaluated. This study investigated how tube starting angle and pitch influence *k*-factor variability in pediatric chest-abdomen-pelvis (CAP) CT across clinically relevant pitch settings.

Methods: Monte Carlo simulations of CAP CT examinations were performed using ICRP-reference pediatric extended cardiac-torso (XCAT) phantoms representing ages of newborn, 1, 5, 10, and 15 years. CT scanner (SOMATOM Force, Siemens Healthineers) simulated helical dual-source acquisitions using 120 kV across pitches of 0.5 to 3 in increments of 0.5. For each age and pitch, simulations were repeated for 12 tube starting angles uniformly distributed over 360°. Organ doses and their respective ICRP-103 tissue weighting factors were used to calculate effective dose. Pediatric *k*-factors were calculated by dividing the resulting effective dose by scanner-reported DLP. Angle-averaged mean *k*-factors and variability metrics, including coefficient of variation (CV) and peak-to-peak percent range, were evaluated.

Results: Across all age groups, the angle-averaged mean k-factor was nearly constant with pitch, indicating that pitch does not systematically bias mean k-factor estimates for CAP CT. As expected, k-factor variability across tube starting angles increased with pitch. For pitch ≤ 1, CV ranged from 0.2–1.2%, whereas for pitch values > 1, CV increased to as high as 6.5%, with peak-to-peak percent range reaching 17.3%.

Conclusion: While *k*-factors remain stable in their mean values across pitch, higher pitch increases sensitivity to tube starting angle. This work defines practical limits on *k*-factor precision and has implications for Monte Carlo dose modeling and interpretation of effective dose estimates in high-pitch pediatric CT.

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INTRODUCTION

Background
Effective dose conversion factors are generally assumed to be independent of helical pitch because DLP inherently accounts for pitch. However, this assumption has not been systematically evaluated for high-pitch FLASH CT acquisitions.

Purpose
Evaluate the impact of helical pitch and tube starting angle on the stability of effective dose conversion factors.

METHODS AND MATERIALS

CT Monte Carlo Model
- Previously validated Monte Carlo model of a dual-source CT scanner (SOMATOM Force)
- Included FLASH acquisition geometry and tin spectral filtration
- CTDI validation demonstrated agreement within 5% of measurements

Reference Patient Phantoms
- ICRP-89–reference XCAT male and female phantoms
- Ages:
  - Newborn
  - 1 year
  - 5 years
  - 10 years
  - 15 years

Simulated FLASH CT Examinations
- Clinical exams:
  - Chest-Abdomen-Pelvis (CAP)
- Spectrum:
  - 120 kV
- Pitch Values
  - 0.5, 1.0, 1.5, 2.0, 2.5, 3.0
- Twelve tube starting angles per simulation

Effective dose normalized to DLP to derive k-factors ($mSv \cdot mGy^{-1} \cdot cm^{-1}$)

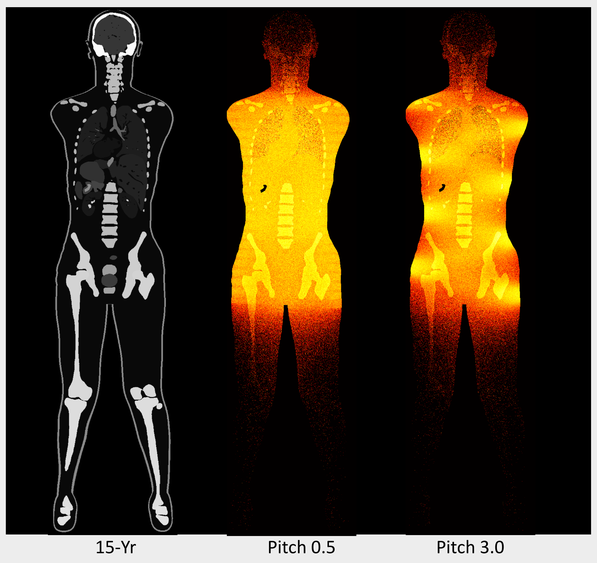

Figure 1. Dose distribution in 15-year-old phantom at pitch 0.5 and 3.0, showing sparser dose sampling in higher helical pitch acquisition.

RESULTS

Finding 1: Mean *k*-factor is independent of pitch
- Mean *k*-factors remained essentially constant across all pitch values
- Variations were less than 1%
- Supports the conventional assumption that DLP-normalized effective dose is pitch independent

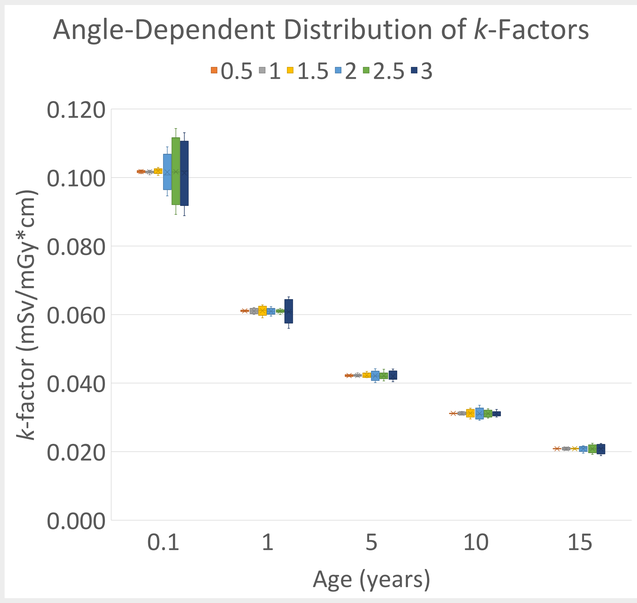

Chart 1. Mean *k*-factor is generally stable across pitch

Finding 2: Variability increases with pitch
At low pitch:
- CV generally below 1%

At high pitch:
- Variability increased substantially, especially for newborn patients
- Greater dependence on tube starting angle

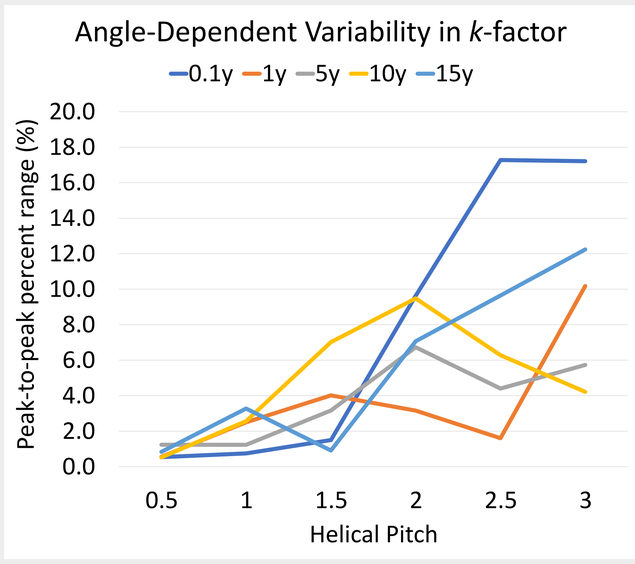

Chart 2. Peak-to-Peak variability generally increases with pitch

DISCUSSION

Practical Implications
Implication 1: *k*-Factors remain valid across pitch
Mean *k*-factors varied by less than 1% across pitch values from 0.5 to 3.0, indicating that DLP-normalized effective dose conversion factors remain essentially independent of helical pitch, even for high-pitch FLASH acquisitions. This supports the conventional assumption that effective dose conversion factors can be applied across a wide range of pitch settings without introducing systematic bias.

Implication 2: Single-angle Monte Carlo simulations may be insufficient
Although mean *k*-factors remained stable, variability associated with tube starting angle increased substantially at higher pitch values. Studies that rely on a single tube starting angle may therefore produce dose estimates that deviate from mean values

Implication 3: Angular Averaging Improves simulation-derived *k*-factors
At FLASH pitch values, tube starting angle becomes an increasingly important source of uncertainty. Averaging across multiple starting angles minimizes angular sampling bias and produces more reproducible estimates of organ dose and effective dose. Future Monte Carlo investigations of high-pitch CT should consider angular averaging as part of study design.

Key Message
FLASH pitch does not change the true *k*-factor, but it increases angle-dependent variability. Robust Monte Carlo dosimetry for high-pitch CT should therefore incorporate multiple tube starting angles to ensure stable dose estimates.

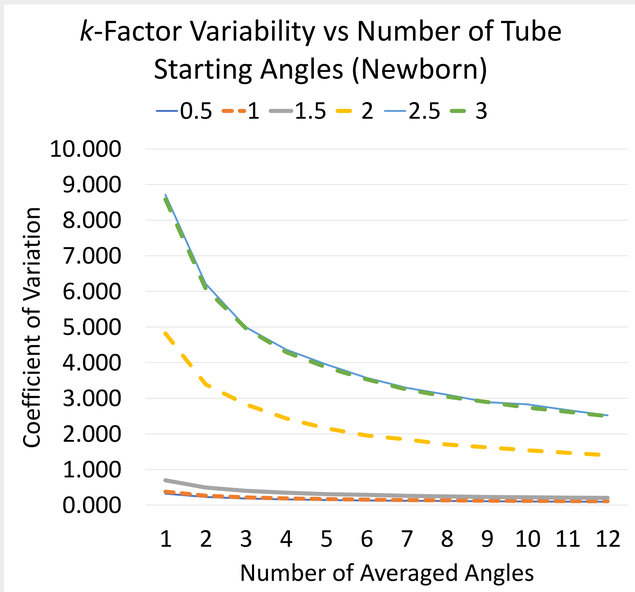

Chart 3. Improved mean *k*-factor precision with increasing number of tube starting angles

CONCLUSIONS

Helical pitch does not alter angle-averaged effective dose conversion factors in FLASH CT. However, higher pitch substantially increases variability associated with tube starting angle, emphasizing the importance of angular averaging when deriving *k*-factors using Monte Carlo methods.

DISCLOSURES

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