Monte Carlo Assessment of Pediatric Patient Dose in Tin-Filtered High-Pitch CT

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ABSTRACT

Purpose: High-pitch dual-source acquisition ("FLASH") with tin spectral filtration has substantially reduced radiation dose while minimizing patient motion, both of which are particularly important for pediatric imaging. However, in adults, tin-filtered spectra have been shown to yield higher radiation dose conversion coefficients compared with conventional spectra. The purpose of this study was to use Monte Carlo simulation to quantify pediatric organ and effective doses in tin-filtered FLASH CT protocols across common anatomic regions.

Methods: A previously validated Monte Carlo framework modeling a dual-source CT system (SOMATOM Force, Siemens Healthineers) was used to simulate CT examinations using ICRP reference pediatric extended cardiac–torso (XCAT) phantoms representing ages of newborn, 1, 5, 10, and 15 years. High-pitch FLASH acquisitions (pitch = 3) were simulated using conventional spectra (100 kV and 120 kV) and tin-filtered spectra (100Sn and 150Sn) for head, neck, head-neck, chest, abdomen-pelvis, pelvis, and chest-abdomen-pelvis examinations. To reduce angular bias, each scan was repeated with 12 uniformly-distributed tube starting angles. Angle-averaged $CTDI_{vol}$-normalized organ doses (*h*-factor) and DLP-normalized effective doses (*k*-factor) were compared across the different spectra.

Results: Across all anatomic regions, pediatric *k*-factors decreased with increasing age, with reductions of 26.2%–41.5% between successive age groups. The dependence of *k*-factors on beam hardness was age dependent: *k*-factors decreased with increasing beam hardness (100 kV, 120 kV, 100Sn, 150Sn) for newborn, were relatively insensitive to beam hardness for 1-year, and increased with increasing beam hardness for 5-, 10-, and 15-year. Pediatric *h*-factors demonstrated similar age- and beam-hardness–dependent behavior, with most organs exhibiting a crossover in beam-hardness dependence near the 1-year phantom. Breast tissue showed increasing *h*-factors with beam hardness across all ages, whereas bone surface showed decreasing *h*-factors.

Conclusion: Radiation dose conversion coefficients for tin-filtered FLASH CT are strongly age dependent in pediatric imaging, with trends differing from those reported in adult studies.

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INTRODUCTION

Background
FLASH CT and tin spectral filtration are increasingly used to reduce motion artifacts and improve dose efficiency in pediatric imaging. Effective dose is commonly estimated from dose-length product (DLP) using published conversion factors (*k*-factors), but these values were derived using conventional beam qualities and may not be applicable to tin-filtered acquisitions.

Purpose
Determine how effective dose conversion factors vary with patient age and beam spectrum in tin-filtered FLASH CT.

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–based XCAT male and female phantoms
- Ages:
  - Newborn
  - 1 year
  - 5 years
  - 10 years
  - 15 years
  - Adult

Simulated FLASH CT Examinations
- Clinical exams:
  - Head
  - Neck
  - Head-Neck
  - Chest
  - Abdomen-pelvis
  - Pelvis
  - Chest-Abdomen-Pelvis (CAP)
- Spectra:
  - 100 kV
  - 120 kV
  - 100Sn
  - 150Sn
- Twelve tube starting angles per simulation and averaged

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

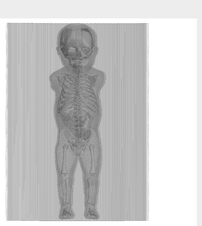

Figure 1. Example of Peds Reference Phantom (newborn)

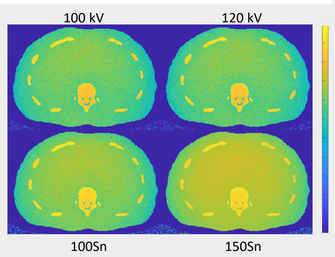

Figure 2. Normalized dose distribution due to different spectra

RESULTS

Finding 1: *k*-factors decrease with age
- Observed across all examination types
- Reductions between adjacent age groups ranged from approximately 26–42%
- Highest values observed in chest examinations
- Lowest values observed in head examinations

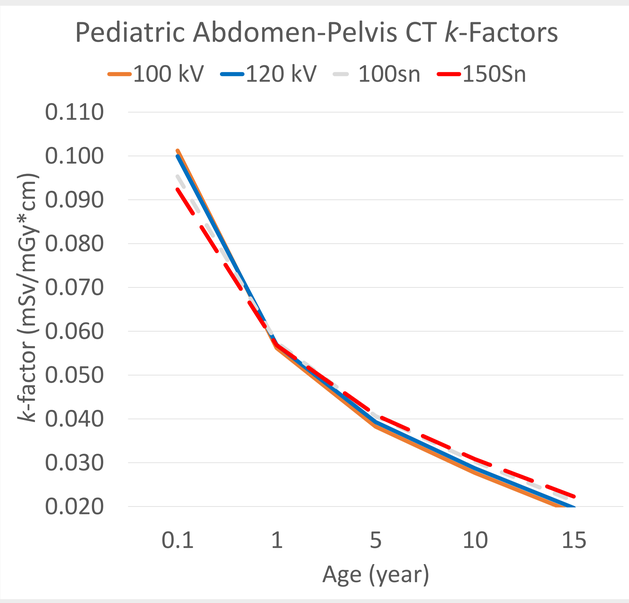

Chart 1. *k*-factor decreases with patient age.

Finding 2: Spectral dependence reverses with age
For body examinations:
- Newborns:
  - Tin filtration decreased *k*-factors
  - Up to −11.4% for 150Sn pelvis
- 1-year-old:
  - Minimal spectral dependence
- Older pediatric phantoms:
  - Tin filtration increased *k*-factors
  - Up to +34.8% for 15-yo pelvis

Key observation: The effect of tin filtration changes direction between newborn and older patients.

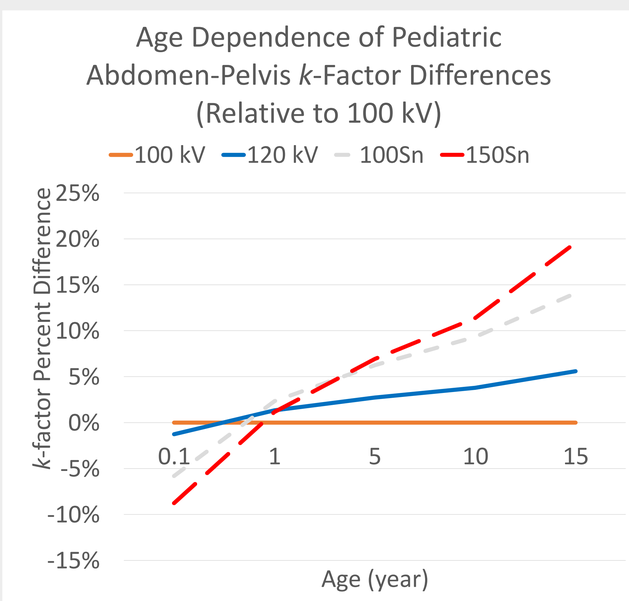

Chart 2. Differences in *k*-factor magnitude depend on patient age and spectra, with largest differences observed with tin spectra.

DISCUSSION

Clinical Significance

1. Spectral Effects Are Not Constant Across Age
The impact of tin filtration on effective dose conversion factors was highly age dependent. While tin-filtered spectra reduced *k*-factors in newborn body examinations, the same spectra increased *k*-factors in older pediatric and adult phantoms. This finding demonstrates that spectral effects observed in adults cannot be directly extrapolated to pediatric patients and highlights the importance of considering patient size when evaluating dose metrics in tin-filtered CT.

2. Conventional *k*-Factors May Misestimate Effective Dose in Tin-Filtered CT
Current clinical estimates of effective dose are commonly derived by multiplying DLP by published conversion factors developed using conventional beam qualities. However, the present study demonstrated spectrum-dependent differences exceeding 30% for some examinations. Consequently, use of conventional *k*-factors may overestimate or underestimate effective dose when applied to tin-filtered FLASH CT protocols. Age- and spectrum-specific conversion factors may therefore improve protocol evaluation, dose monitoring, and inter-institutional comparisons.

Key Message
Effective dose conversion factors in tin-filtered FLASH CT depend on both patient age and beam spectrum. A single *k*-factor is insufficient for all patient sizes, and conventional conversion factors may not accurately represent effective dose in tin-filtered protocols.

CONCLUSIONS

Tin-filtered FLASH CT demonstrates strong age-dependent spectral effects on effective dose conversion factors. Body examinations showed a reversal in spectral dependence between newborn and older patients, while head examinations demonstrated consistently positive spectral dependence.

Age- and spectrum-specific *k*-factors are therefore needed for accurate DLP-based effective dose estimation.

REFERENCES

1. Fong G, Herts B, Primak A, Segars P, Li X. Effect of tin spectral filtration on organ and effective dose in CT colonography and CT lung cancer screening. Med Phys. 2024;51:103–112. https://doi.org/10.1002/mp.16836

DISCLOSURES

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