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SECONDARY CANCER RISK ASSESSMENT OF PELVIC CONE BEAM COMPUTED TOMOGRAPHY IMAGING PROTOCOLS

Introduction. ***This study evaluates the secondary cancer risks associated with low-dose ionizing radiation from pelvic cone beam computed tomography (CBCT) imaging protocols in the context of image-guided radiotherapy (IGRT).***

Methods. ***The research identifies that effective dose varies significantly with protocol choice and field size; larger fields result in higher doses, emphasizing the need for optimization to balance diagnostic accuracy with safety.***

Results. ***Protocols such as Pelvis Fast, characterized by reduced default mAs and shorter scan times, demonstrate substantially lower effective doses compared to alternatives like Pelvis Large, translating to a decreased excess absolute risk (EAR) for secondary cancer development. Utilizing the BEIR VII model for risk assessment, the study underscores the importance of selecting imaging protocols with lower EAR values to mitigate secondary cancer risks effectively.***

Conclutions. ***These findings highlight the critical role of protocol selection in reducing radiation exposure while maintaining high image quality, providing valuable guidance for enhancing patient safety in medical imaging practices.***

Keywords: ***low doses, risk assessment, linear accelerator, anthropomorphic phantom.***

Introduction

In image-guided radiotherapy (IGRT), cone-beam computed tomography (CBCT) plays a pivotal role in ensuring accurate patient positioning and treatment verification. As a key component of radiation therapy, CBCT has significantly improved the precision of delivering prescribed doses to targeted treatment sites. Although the radiation dose associated with CBCT is lower than therapeutic doses, the cumulative effect and potential long-term consequences warrant careful consideration (Iliopoulos et al., 2023). The additional radiation exposure from CBCT raises concerns about potential risks, such as the development of secondary cancers. Therefore, optimizing

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CBCT protocols to deliver the lowest possible imaging dose while maintaining image quality is essential for accurate verification (Khan et al., 2022). Balancing dosage is critical; lower dosages might risk cancer recurrence, while higher dosages increase potential damage to healthy tissues (Simonetto et al., 2021). Currently, assessing cancer risks from low-level carcinogen exposure relies on uncertain extrapolations from bioassay data, subjective human judgment, and the controversial linear no-threshold (LNT) dose-response model for estimating cancer risks at low doses (Lau et al., 2021). This study aims to calculate and evaluate the potential secondary cancer risk associated with various pelvic CBCT imaging protocols.

Methods

In this study, image-guided radiotherapy was conducted using a Halcyon 3.0 linear accelerator, which integrates advanced imaging technology to enhance treatment planning and delivery for oncology patients. Cone beam computed tomography (CBCT) with full 360° rotational scanning was employed at a fixed field of view of 49.2 cm, ensuring high-resolution images with a matrix size of 512 × 512 pixels and a slice thickness of 2.0 mm.

An anthropomorphic phantom (801-P-A; CIRS, Norfolk, VA), the Virtual Human Male Pelvis Phantom Sectional without holes, was used. The experimental setup involved the alignment of the anthropomorphic phantom with the built-in lasers and positioning of the phantom at the isocentre following standard alignment procedures at the Halcyon facility (Fig. 1).

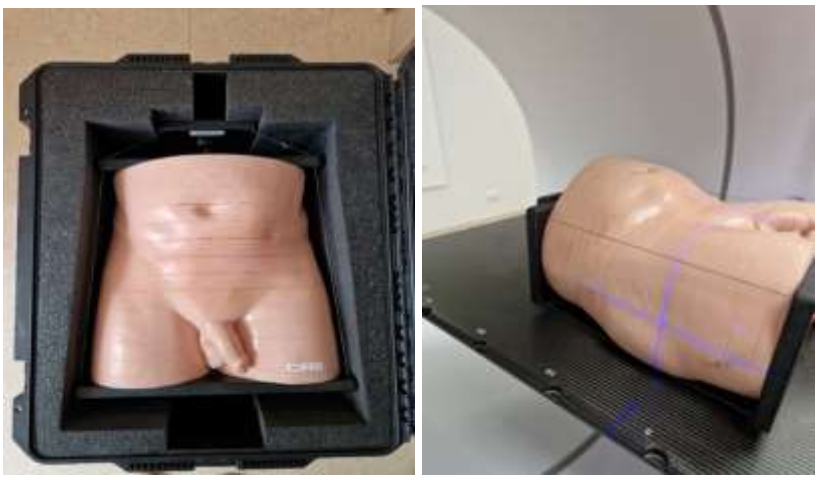


Fig. 1. An anthropomorphic phantom in the left alignment of the laser beam

Various field of view sizes FOV (3.3 × 3.3 cm², 5 × 5 cm², 10 × 10 cm², and 14 × 14 cm²) were systematically assessed to investigate their influence on dose distribution across multiple CBCT imaging protocols (Fig. 2 and Table 1). All measurements were conducted in QA mode



Fig. 2. Visual representation of the pelvis in varying positions during the CBCT examination on the right, with the field size selection process during the CBCT on the left

Table 1

Predetermined configurations for the Halcyon 3.0 kV CBCT protocols

Protocol	Energy, keV	Default, mAs	Scan time, s	CTDIvol, mGy	Field size, cm x cm	DLP, mGy*cm
Pelvis	125	1074	36.7	21.48	14×14	599.9
					10×10	429.5
					5×5	215.2
					3.3×3.3	140.5
Pelvis fast	125	592	21.2	11.84	14×14	330.7
					10×10	236.9
					5×5	119.5
					3.3×3.3	77.5
Pelvis large	140	1456	40.6	38.44	14×14	1037.6
					10×10	766.4
					5×5	383.8
					3.3×3.3	252.3
Pelvis large fast	140	698	24	18.43	14×14	514.6
					10×10	368
					5×5	185.3
					3.3×3.3	123.4

The effective doses calculated from dose length product (DLP) using equation (1) from AAPM report 96 (Altergot et al., 2023), are shown below:

$$E_{eff} = k \cdot DLP, \quad (1)$$

where k for pelvis = 0.015 (Buxi et al., 2014). The excess absolute risk (EAR) was calculated using the Biological Effects of Ionizing Radiation (BEIR VII) model:

$$EAR = \beta_s D \exp(\gamma e^*)(\frac{a}{60})^n, \quad (2)$$

where D is the dose (Sv), e is the age at exposure (years), e^* is the attained age (years), βs stands for the excess relative risk per sievert (ERR/Sv), γ and η being associated parameters for ERR/Sv. The age of exposure was standardized at 30 years

($e = 30$), and the age attained was set at 60 years ($a = 60$) as a conservative assumption. By setting e^* to 0 when e equals 30 (Altergot et al., 2023). The adjustment function in equation (2) is eliminated, leading to a simplified equation for calculating the EAR:

$$EAR = \beta_S D . \quad (3)$$

In the BEIR VII report (National Research Council (U.S.). Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, 2006), the relevant model parameters for prostate secondary cancer are provided in Table 2. These parameter values are used to calculate the excess absolute risk for prostate secondary cancer.

Table 2

Parameters in (BEIR VII model – Phase 2, table 12-2) for prostate secondary cancer

Model parameter	Male
β_s	0.11
Γ	-0.41
η	2.8

Results

An analysis of kV-CBCT pelvis region protocols revealed significant variations in effective dose and EAR values across different protocols and field sizes. Table 3 summarizes the calculated effective doses and EARs for each protocol and field size combination (Fig. 3). Protocols with higher default mAs and longer scan times resulted in higher effective doses and EARs. The Pelvis Fast protocol demonstrated lower effective doses and EARs compared to the Pelvis protocol. Increasing the field size consistently led to higher effective doses and EARs.

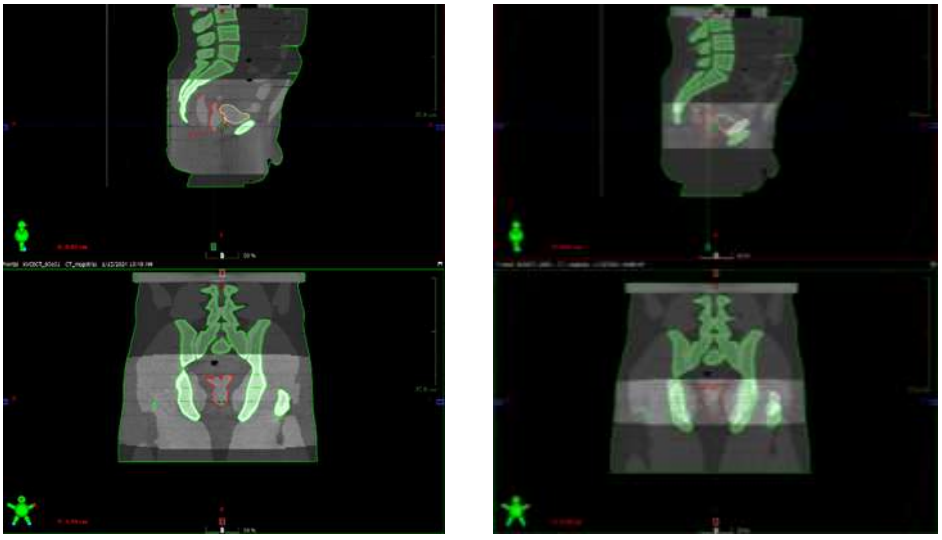


Fig. 3. Visualizing the impact of field size on pelvic CBCT Imaging
A Comparison of 5 cm x 5 cm(right) and 10 cm x 10 cm(left) Field Sizes

Table 3

Presents the predetermined configurations for the Halcyon 3.0 kV CBCT protocols

Protocol	Energy (keV)	Default (mAs)	Scan time (s)	CTDIvol (mGy)	Field size (cmxcm)	DLP (mGy*cm)	Effective dose (mSv)	EAR
Pelvis	125	1074	36.7	21.48	14×14	599.9	9.00	0.99
					10×10	429.5	6.44	0.71
					5×5	215.2	3.22	0.35
					3.3×3.3	140.5	2.10	0.23
Pelvis fast	125	592	21.2	11.84	14×14	330.7	4.97	0.55
					10×10	236.9	3.56	0.39
					5×5	119.5	1.80	0.20
					3.3×3.3	77.5	1.16	0.13
Pelvis large	140	1456	40.6	38.44	14×14	1037.6	16.11	1.77
					10×10	766.4	11.94	1.31
					5×5	383.8	5.76	0.63
					3.3×3.3	252.3	3.78	0.41
Pelvis large fast	140	698	25	18.43	14×14	514.6	7.73	0.85
					10×10	368	5.52	0.61
					5×5	185.3	2.78	0.31
					3.3×3.3	123.4	1.85	0.20

It was observed that increased field sizes are associated with higher effective dose values (Fig. 4), whereas reduced field sizes correspond to decreased doses. This emphasizes the significance of adjusting the dimensions of the field to achieve a balance between diagnostic requirements and ensuring radiation safety. Healthcare providers can reduce patient radiation exposure by using lower (Iliopoulos et al., 2023) field sizes wherever feasible, without affecting the quality of imaging. Optimal modifications to the size of the field in CBCT imaging for pelvic examinations are essential maintaining the delicate balance between accuracy in diagnosis and patient safety.

A clear positive correlation exists between effective dose and EAR (Fig. 5). As the effective dose increases, the EAR for cancer development also shows a corresponding increase. This underscores the importance of minimizing radiation exposure during medical imaging procedures to reduce the associated cancer risks.

The significant variations in excess absolute risk (EAR) values across different pelvic CBCT protocols and field sizes. Notably, the Pelvis Fast protocol demonstrated a substantially lower EAR of 0.55 compared to the Pelvis protocol's 0.99, reflecting a 44 % reduction in cancer risk associated with the lower effective dose (4.97 mSv vs. 9.00 mSv). This finding highlights the importance of selecting appropriate protocols to minimize the risk of radiation-induced secondary cancers in patients undergoing pelvic imaging. While higher effective doses can offer benefits in terms of enhanced image quality and diagnostic accuracy, they also lead to increased cancer risks. Therefore, healthcare providers must carefully balance these competing factors. For patients where high-quality imaging is crucial, alternative imaging modalities with lower radiation doses should be explored whenever possible.

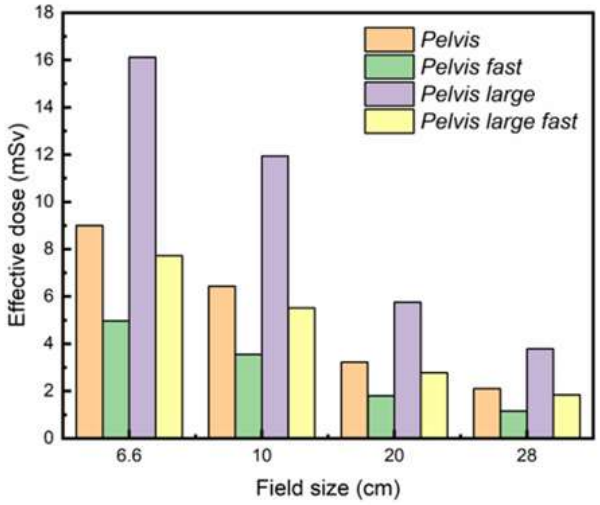


Fig. 4. Correlation between field size and effective dose in halcyon 3.0 kV CBCT protocols for pelvis imaging

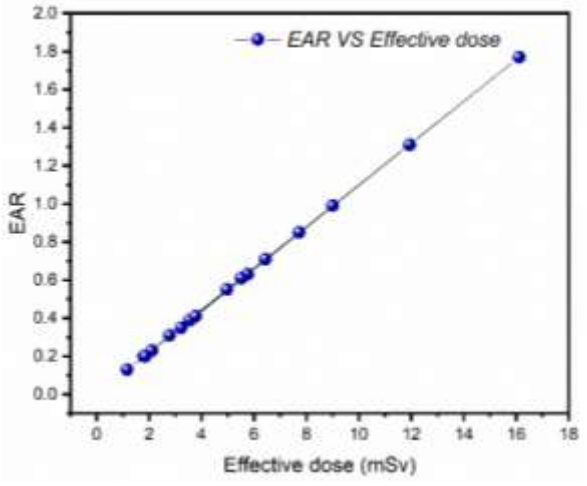


Fig. 5. Correlation between effective and excess absolute risk (EAR) in different pelvic CBCT protocols

This study emphasizes the importance of implementing several optimization strategies to minimize radiation exposure during CBCT imaging. These include:

• Lowering mAs settings: Reducing mAs settings can significantly decrease effective dose and EAR. For example, switching from the 1456 mAs default in the Pelvis Large protocol to the 698 mAs in the Pelvis Large Fast protocol resulted in a 63 % reduction in effective dose (from 38.44 mSv to 18.43 mSv) and a corresponding decrease in EAR.

• Reducing scan times: Shorter scan times lead to lower radiation exposure. In our study, the Pelvis Fast protocol with a 21.2 s scan time achieved an effective dose of 4.97 mSv and an EAR of 0.55, significantly lower than the 36.7 s scan time in the Pelvis protocol which resulted in an effective dose of 9.00 mSv and an EAR of 0.99.

• Optimizing field size: As demonstrated by our findings, smaller field sizes significantly reduce radiation exposure. In the Pelvis Large Fast protocol, a 10 × 10 cm field size yielded an effective dose of 5.52 mSv and an EAR of 0.61, compared to 1.85 mSv and 0.20 respectively for a 3.3 × 3.3 cm field size. This represents a 67 % reduction in effective dose and a 68 % reduction in EAR, highlighting the substantial impact of field size optimization.

By adopting these optimization strategies, healthcare providers can effectively minimize radiation exposure during CBCT imaging, leading to a significant reduction in the risk of secondary cancers for their patients. This study provides valuable insights for optimizing CBCT protocols and ensuring safe and responsible medical imaging practices.

Discussions and conclusion

The study demonstrates a clear correlation between CBCT field size and effective dose: larger fields result in higher radiation exposure, highlighting the importance of optimizing field sizes to reduce risks. Specifically, the Pelvis Large Fast protocol's smaller field size (3.3 × 3.3 cm) yielded a significantly lower effective dose of 1.85 mSv compared to 5.52 mSv from a 10 × 10 cm field. Moreover, selecting the appropriate imaging protocol significantly impacts secondary cancer risk, as evidenced by the lower EAR of 0.55 in the Pelvis Fast protocol compared to 1.77 in the Pelvis Large protocol. These findings underscore the need for careful protocol selection and field size optimization to enhance patient safety by minimizing radiation exposure and associated cancer risks.

Authors' contribution: Sundus Osman Investigation, Formal analysis, Visualization, Writing – original draft preparation, Writing – review, and editing; Reda Venskauskaitė Methodology, Writing – original draft preparation; Reda Čerapaitė-Trušinskiene Formal analysis, Writing – review, and editing; Jurgita Laurikaitiene – Conceptualization, Visualization, Methodology, Resources, Writing – original draft preparation, Writing review, and editing.

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ОЦІНЮВАННЯ РИЗИКУ ВТОРИННОГО РАКУ ЗА ДОПОМОГОЮ ПРОТОКОЛІВ ВІЗУАЛІЗАЦІЇ ТАЗОВОЇ КОНІЧНОЇ ПРОМЕНЕВОЇ КОМП'ЮТЕРНОЇ ТОМОГРАФІЇ

Вступ. ***У цьому дослідженні оцінюються ризики вторинного раку, пов'язані з низькими дозами іонізуючого випромінювання, за допомогою протоколів візуалізації тазової конусно-променевої комп'ютерної томографії (КПКТ) у контексті променевої терапії з візуальним контролем (ПТВК).***

Методи. ***Дослідження виявило, що ефективна доза суттєво змінюється залежно від вибору протоколу та розміру поля; більші поля призводять до вищих доз, що вказує на необхідність оптимізації, щоб збалансувати точність діагностики та безпеку.***

Результати. ***Такі протоколи, як протокол для тазу Pelvis Fast, що характеризуються зниженням значення попередньо встановленого параметра міліампер-секунда і коротшим часом сканування, демонструють значно нижчі ефективні дози порівняно з такими альтернативами, як протокол для тазу Pelvis Large, що означає зниження значення надлишкового абсолютного ризику (НАР) розвитку вторинного раку.***

Висновки. ***Аналізуючи використання моделі BEIR VII для оцінювання ризику доходимо висновку про важливість вибору протоколів візуалізації з***

нижчими значеннями НАР для ефективного зниження ризиків вторинного раку. Зроблені висновки вказують на важливість значення вибору протоколу для зниження радіаційного опромінення при збереженні високої якості зображення та надають цінні рекомендації для підвищення безпеки пацієнтів під час отримання медичних зображень.

Ключові слова: ***малі дози, оцінка ризику, лінійний прискорювач, антропоморфний фантом.***

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