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Quantification of Imaging Doses from Cone Beam Computed Tomography System at Steve Biko Academic Hospital

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Abstract

Introduction: In radiotherapy, to effectively treat tumours, a high level of precision, accuracy, and reproducibility is necessary. This guarantees that a sufficiently high dose reaches the tumour while preventing radiation exposure of the surrounding healthy tissues. Cone Beam Computed Tomography (CBCT) is an image guidance technique used by the Steve Biko Academic Hospital (SBAH) radiation therapy department to ensure accurate patient setup and position verification before treatment delivery. CBCT patient verification offers valuable insights into internal anatomical structures but involves the use of ionizing radiation. Consequently, the verification process using CBCT may deliver significant additional radiation doses beyond the prescribed treatment dose due to its frequent use. In radiotherapy, during position verification before treatment, it is vital to employ an imaging modality that allows visualization of both soft tissue and bony anatomy to ensure accurate patient positioning while keeping the dose as low as reasonably possible. To this end, this study seeks to quantify doses associated with setup positioning verification without compromising image quality and to develop recommendations to avoid stochastic effects arising from unnecessary doses. This was achieved by computed tomography dose index (CTDI) measurements, from which the dose-length product (DLP) was calculated, which was then converted to the effective dose.
Materials and Methods: The study was conducted at SBAH in the radiation oncology department. The University of Pretoria Research Ethics Committee approved this research (Ethics Reference No.: 2220/2022). To ensure that the CBCT system met the required image quality, the Catphan model 503 (Salem, NY, USA) imaging phantom was used. CTDI measurements were performed using head and body phantoms, an ionization chamber, and an electrometer.

The CTDI dose was measured for different cancer treatment setup verification imaging protocols, including head-and-neck, pelvis, and prostate protocols. Measurements were conducted for 100 and 120 kV. The CTDI dose was measured based on different parameter settings in the setup imaging protocols, including frame, field of view, collimator, and filter. The measured CTDI and calculated DLP were used to quantify imaging doses. The DLP values were converted to effective doses using factors from the American Association of Physicists in Medicine (AAPM) report 96. **Results:** The image quality test findings matched the South African Standards for Quality Assurance in Radiotherapy (SASQART) and the manufacturer's tolerances. In adults, the CTDI dose for head and neck ranges from 0.23 to 0.52 mGy, for the pelvis from 3.1 to 6.44 mGy, and for the prostate from 3.9 to 13.46 mGy per imaging protocol. For paediatric protocols, the CTDI dose ranges from 0.19 to 0.40 mGy for head and neck, 6.00 to 12.10 mGy for pelvis, and 6.00 to 24.00 mGy for the abdomen per imaging protocol. **Conclusion:** This study has revealed that the doses of CBCT radiation used during verification procedures are generally low in areas such as the head and neck. However, for pelvic sites such as the prostate, where detailed visualization of soft tissue is necessary, the doses tend to be relatively high. The results showed that, per fraction, a maximum CTDIvol of approximately 24 mGy can be delivered to paediatric patients. This is noteworthy because repeated imaging during treatment may pose significant risks related to the stochastic effects of radiation.

Subject Areas

Radiology & Medical Imaging

Keywords

Imaging Doses, Radiation Exposure, Stochastic Effects

1. Introduction

Image-guided radiotherapy (IGRT) is a critical process in radiotherapy, in which patient alignment is meticulously verified using both kilo-voltage (kV) and megavoltage (MV) X-ray imaging systems throughout the treatment course. These IGRT techniques encompass planar imaging (two-dimensional, or 2D) and volumetric imaging (three-dimensional, or 3D) [1]. One noteworthy example of a contemporary linear accelerator (Linac) used for external radiation therapy is the Elekta Versa HD. These Linac units have been designed to integrate both kV and MV X-ray imaging systems, enabling cone-beam computed tomography (CBCT) imaging, mainly for IGRT [2]. It is noteworthy to emphasize that among these imaging technologies, the kV-CBCT is important for IGRT verification. This prominence is attributed to the heightened soft-tissue contrast achieved through the photoelectric effect in images produced by the kV imaging system, in contrast to the diminished contrast observed in MV imaging due to Compton scatter [3]

[4]. Nowadays, kV and MV CBCT systems are used for routine treatment to identify the treatment target and volumes of organs at risk, ensuring precise and accurate treatment setup [5]. While CBCT provides valuable information about internal anatomical structures, it has the drawback of using ionizing radiation. To address this concern, the International Commission on Radiological Protection (ICRP 103) has issued guidelines to protect against the dangers associated with ionizing radiation. These guidelines emphasize keeping medical and public radiation exposures as low as reasonably achievable (ALARA principle) [6]. Patients must remain in the same position during radiotherapy pre-treatment and during treatment delivery. These guarantee that radiotherapy treatment is directed to the tumour while sparing healthy tissues or organs at risk [7]. This is because treating organs at risk can cause detrimental effects later. These CBCT techniques deliver excessive doses to patients; hence, it is vital to know the magnitude of these doses to minimize their effects. Minimizing imaging dose is important, as it may affect image quality. Methods of minimizing imaging dose may include adjusting clinical imaging protocols for a particular acquisition.

At Steve Biko Academic Hospital (SBAH), the radiotherapy centre uses CBCT for patient setup and position verification before treatment delivery. These CBCT techniques may deliver a significant additional radiation dose to the prescribed treatment dose due to their frequent use. With setup imaging being done numerous times during treatment, these doses may increase significantly. The increase in radiation dose may contribute to an elevated risk of late radiation effects, including the potential development of radiation-induced secondary malignancies [8] [9]. Optimized dose assessments will provide a clearer insight of the radiation doses being delivered, particularly in paediatric patients, which remains a major concern at SBAH. Due to the ongoing development of children's organs and tissues, exposure to radiation at a young age may lead to damage and, in the long term, result in the potential development of radiation-induced cancer many years down the road [6]. It is therefore vital to quantify the doses for each CBCT protocol in radiation therapy, which helps optimize imaging protocols for verifying patient positioning and delivering the minimum imaging dose possible. The study investigated the doses received by patients during treatment setup imaging for each protocol.

2. Materials and Methods

2.1. Preparation of the Scanning

The study was conducted in the radiation oncology at SBAH. Research Ethics Committee at the University of Pretoria granted ethical clearance to conduct the study (Ethics Reference No.: 2220/2022). The investigation was conducted using phantoms scanned with a CT scanner, after which the image sets were transferred to the treatment planning system (TPS). Treatment plans were then generated based on these scans and sent to the Elekta Versa HD linear accelerator via the record-and-verify system (Mosaiq) for image quality assessment and dose meas-

urements. The study evaluated different imaging protocol settings for the head-and-neck, pelvis, and prostate regions. Additionally, CTDI measurements were performed, and the effective doses for the various clinical protocols were calculated.

This study focused on quantifying doses for each clinical protocol without compromising image quality. Therefore, the evaluation was conducted on two fronts: image quality evaluation and dose measurements. Image quality was assessed using the Catphan 503 (Salem, NY, USA) to ensure the system met the required quality standards. For dose assessment, a head-and-body phantom with slots for inserting a calibrated pencil ionization chamber connected to an electrometer was used to measure dose for different imaging protocols, including treatment areas such as the head, pelvis, and prostate.

2.2. KV Image Quality

The Catphan 503 phantom was used to evaluate XVI CBCT image quality. The phantom was placed in its box using the dedicated alignment marks and positioned on the treatment couch, as shown in Figure 1. It was then aligned to the treatment isocenter using a three-dimensional laser system consisting of anterior, left, and right lateral lasers. The alignment was verified by ensuring that the lasers intersected precisely at the white reference markers indicated on the phantom. Measurements were performed using manufacturer-standard protocol settings, including an S10 collimator cassette (used to define the X-ray beam size and shape) and an F0 filter cassette (a standard beam filtration setting). The imaging was conducted at 120 kV, with the kV imaging panel configured to the small field-of-view position for image acquisition. Volume view images were acquired for uniformity, high resolution, geometric consistency, and low-contrast visibility on the XVI system.

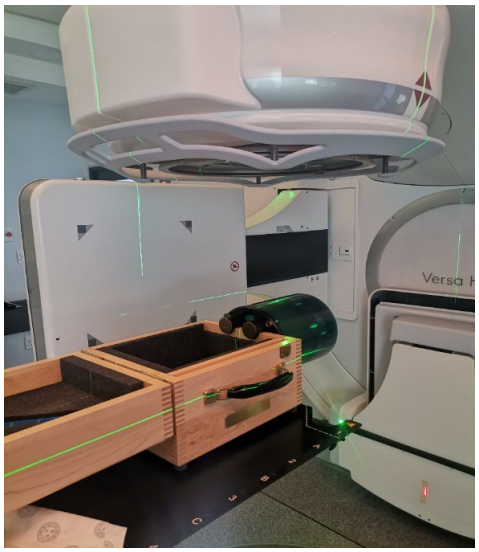
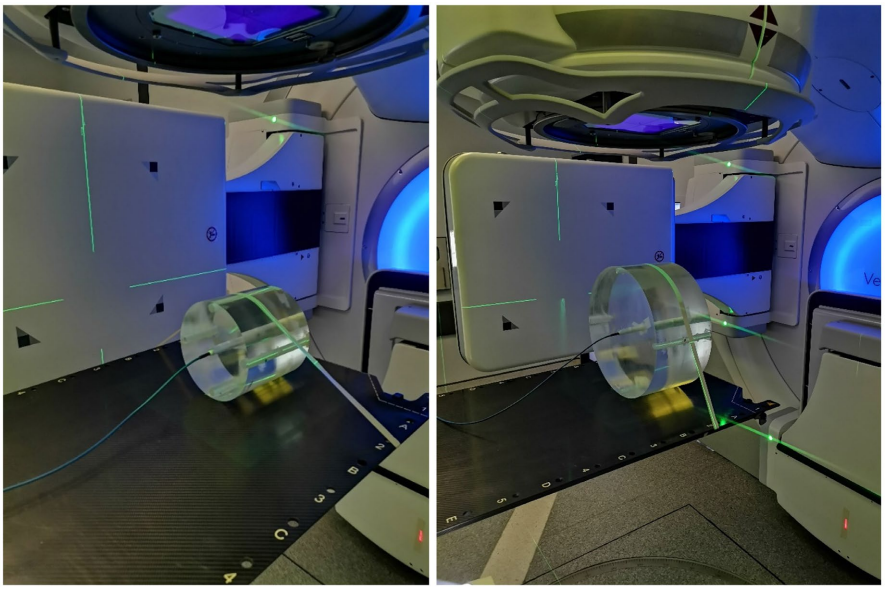


Figure 1. A Catphan 503 phantom setup using room lasers (Courtesy of Steve Biko Academic Hospital).

2.3. Dose Measurement during CBCT Imaging

Measurements of the delivered doses were conducted by employing a CTDI body and head phantom combined with a 100 mm PTW pencil ionization chamber linked to a PTW Unidos Freiburg electrometer. Both these phantoms are 15 cm in length. Both acrylic cylindrical phantoms have five holes for inserting the 100 mm long cylindrical pencil ionization chamber for center and peripheral CTDI measurements.

The Head and body CTDI phantoms were set up separately at the Linac by positioning them on the treatment couch, as in a CT scanner, using lasers, as shown in Figure 2(a) and Figure 2(b), respectively. Before the CBCT measurement, the CTDI scan image from the Monaco TPS was first loaded on the XVI software as the reference image. Then, CBCT was acquired to assess setup accuracy by superimposing the CT image onto the CBCT. Three electrometer charge readings were collected in each of the five measurement positions in the CTDI phantom.



(a) (b)

Figure 2. (a) CTDI head phantom setup shown. (b) CTDI body phantom setup shown (Courtesy of Steve Biko Academic Hospital).

The CBCT dose was measured using various manufacturer-standard XVI clinical protocols. The clinical protocols investigated in this study, together with the associated setup parameters—including kilovoltage (kV), milliampere-seconds (mAs), field of view (FOV), filter, frames and the computed tomography dose index measured in both clockwise (CW) and counterclockwise (CCW) directions—are presented in Table 1.

2.4. Computed Tomography Dose Index (CTDI) Calculations

$CTDI_{100}$ was measured at all five positions, and the mean peripheral $CTDI_{100}$ was obtained by averaging the four peripheral measurements. Subsequently, the

Table 1. Displays the manufacturer-standard XVI clinical protocols with the exposure parameters.

Clinical protocol	kV	mAs projected	FOV	Filter	Collimator	Frames	CTDI projected (mGy)
Head & neck cw S10	100	36.6	small	F0	S10	366	1.0
Head & neck ccw S10	100	36.6	small	F0	S10	366	1.0
Head & neck cw S20	100	36.6	small	F0	S20	366	0.5
Head & neck ccw S20	100	36.6	small	F0	S20	366	0.5
Fast head & neck cw S20	100	18.3	small	F0	S20	183	0.5
Fast head & neck ccw S20	100	18.3	small	F0	S20	183	0.5
Pelvis M15 cw	120	1056.0	Medium	F1	M15	660	15.3
Pelvis M15 ccw	120	1056.0	Medium	F1	M15	660	15.3
Pelvis M20 cw	120	1056.0	Medium	F1	M20	660	15.5
Pelvis M20 ccw	120	1056.0	Medium	F1	M20	660	15.5
Pelvis fast M20 enhanced cw	120	422.4	Medium	F1	M20	330	15.5
Pelvis fast M20 enhanced ccw	120	422.4	Medium	F1	M20	330	15.5
Pelvis L20 cw	120	844.8	Large	F1	L20	330	18.8
Pelvis L20 ccw	120	844.8	Large	F1	L20	330	18.8
Prostate M10 cw	120	1689.6	Medium	F1	M10	660	24.5
Prostate M10 ccw	120	1689.6	Medium	F1	M10	660	2.5
Prostate M15 cw	120	1689.6	Medium	F1	M15	660	24.2
Prostate M15 ccw	120	1689.6	Medium	F1	M15	660	24.2
Prostate fast M20 enhanced cw	120	844.8	Medium	F1	M20	330	24.2
Prostate fast M20 enhanced ccw	120	844.8	Medium	F1	M20	330	24.2
Prostate fast M20 low dose cw	120	422.4	Medium	F1	M20	330	15.5
Prostate fast M20 low dose ccw	120	422.4	Medium	F1	M20	330	15.5

weighted CTDI ($CTDI_w$) was determined using Equation (2), where one-third of the central $CTDI_{100}$ and two-thirds of the average peripheral $CTDI_{100}$ were combined. The $CTDI_{vol}$ was then calculated by dividing $CTDI_w$ by the pitch factor (Equation (3)). The DLP was obtained by multiplying $CTDI_{vol}$ by the scan length (Equation (4)). Finally, the effective dose was estimated by multiplying the DLP by the appropriate anatomical-region conversion coefficient (k-factor) (Equation (5)). The final reported dose values were calculated as the average of the measurements obtained from the CW and CCW acquisitions.

The CTDI was calculated as follows:

$$\mathrm{CTDI} = \frac{1}{N \times T} \int_{-L/2}^{+L/2} D(z)\,\mathrm{d}z \tag{1}$$

where $D(z)$ is the dose profile along the scan direction, N is the number of tomo-

graphic slices acquired, T is the slice width, the product NT is the nominal beam width, $\pm L/2$ represents integration limits (L shows the length of the active detector volume) and $D(z)$ represents dose integral [10].

The weighted CTDI ($CTDI_w$) was calculated by using the center and peripheral measurements with 1/3 and 2/3 weighting, respectively [11]. Weighted CTDI is expressed as follows:

$$CTDI_w = \frac{1}{3}CTDI_{100,center} + \frac{2}{3}CTDI_{100,periphery} \quad (2)$$

The volume CTDI (CTDIvol) was subsequently determined by dividing CTDIw by the pitch factor as

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad (3)$$

The dose-length product (DLP) was calculated by multiplying $CTDI_{vol}$ by the scan length [11].

$$DLP = CTDI_{vol} \times L \quad (4)$$

Effective dose (ED) was estimated from the DLP using the appropriate anatomical-region conversion coefficient (k-factor),

$$ED = DLP \times k \quad (5)$$

3. Results

3.1. CBCT Results for 100 KV & 120 KV Adult Patients

The CBCT findings were measured while utilizing the manufacturer's default settings XVI clinical protocols. The measurements were conducted at 100 kV and 120 kV for adult patients, involving both a 16 cm diameter head & neck phantom and a 32 cm diameter body phantom. Each scan was performed on three separate occasions to ensure consistency.

Table 2 presents the experimental mean dose measurements for the clinical protocols used to estimate the effective dose. DLP was determined from the measured CTDIvol and calculated by multiplying the CTDIvol by the scanned length of 10 cm. Effective dose was subsequently calculated by multiplying the DLP values by conversion factors for adult patients from AAPM report 96 [12]. Conversion coefficients of 0.0031 $mSv \cdot mGy^{-1} \cdot cm^{-1}$ and 0.015 $mSv \cdot mGy^{-1} \cdot cm^{-1}$ were used for head-and-neck and pelvis/prostate examinations, respectively [12].

Table 2. Experimental mean dose measurements for the clinical protocols using an adult-sized phantom.

Clinical protocol	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective dose (mSv)
Head & neck	0.33 ± 0.11	3.24 ± 1.15	0.01 ± 0.00
Pelvis	4.63 ± 1.15	46.34 ± 11.53	0.70 ± 0.17
Prostate	8.43 ± 3.54	84.34 ± 35.44	1.26 ± 0.53

The CTDIvol for the head and neck ranged from 0.23 to 0.52 mGy, with a mean

value of 0.33 ± 0.11 mGy at a 95% confidence interval. For the pelvis, CTDIvol values ranged from 3.1 to 6.44 mGy, with a mean of 4.63 ± 1.15 mGy at a 95% confidence interval. In the prostate region, CTDIvol ranged from 3.9 to 13.46 mGy, with a mean of 8.43 ± 3.54 mGy at a 95% confidence interval. The effective dose for the head and neck ranged from 0.01 to 0.02 mSv, with a mean of 0.01 ± 0.00 mSv. For the pelvis, the effective dose varies between 0.47 and 0.97 mSv, with a mean of 0.70 ± 0.17 mSv. In the prostate region, the effective dose ranges from 0.58 to 2.02 mSv, with a mean value of 1.26 ± 0.53 mSv. Figure 3 illustrates the mean effective doses in mSv for clinical protocols.

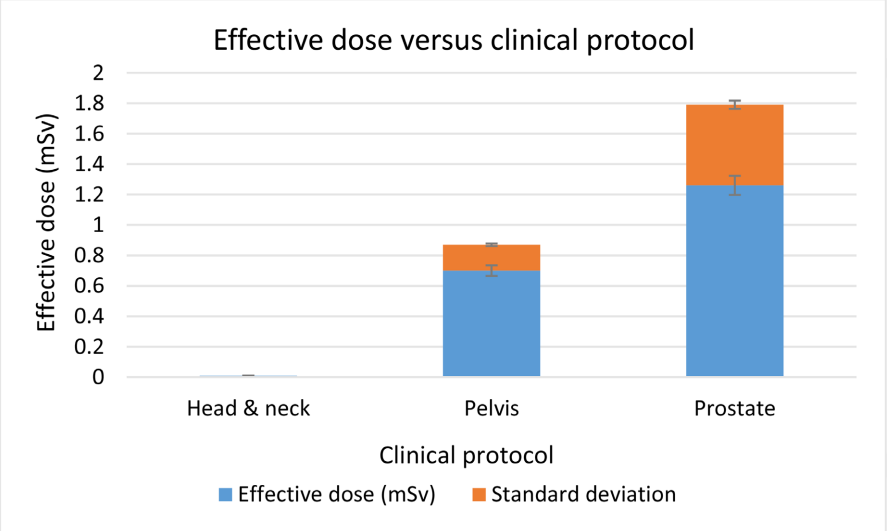


Figure 3. Mean effective dose (mSv) measured for clinical CBCT imaging protocols using both a 16 cm diameter head & neck phantom and a 32 cm diameter body phantom on the Elekta XVI system.

3.2. Cone Beam Computed Tomography Doses Findings for Paediatric Patients

The paediatric dosage outcomes were obtained using a 16 cm diameter head and neck phantom, while a 16 cm diameter phantom was also used for the body. The 16 cm diameter phantom was selected to represent paediatric body measurements, as it better reflects smaller body dimensions. Effective dose calculations were performed using conversion coefficients for a 5-year-old patient, considered representative of the midpoint of the selected paediatric age range (0 - 10 years), based on values extracted from the AAPM Report [12].

Table 3 presents the experimental mean dose measurements for the clinical protocols used to estimate the effective dose. The CTDIvol, DLP, and effective dose were obtained using the same procedures defined in Table 2. However, conversion coefficients of 0.0057 $mSv{\cdot}mGy^{-1}{\cdot}cm^{-1}$ and 0.020 $mSv{\cdot}mGy^{-1}{\cdot}cm^{-1}$ were applied for head-and-neck and pelvis/abdomen examinations, respectively.

The CTDIvol for the head and neck ranged from 0.19 to 0.40 mGy, with a mean of 0.26 ± 0.08 mGy at a 95% confidence interval. For the pelvis, CTDIvol values

Table 3. Experimental mean dose measurements for the clinical protocols using a Paediatric-sized phantom.

Clinical protocol	CTDIvol (mGy)	DLP (mGy·cm)	Effective dose (mSv)
Head & neck	0.26 ± 0.08	2.56 ± 0.80	0.01 ± 0.01
Pelvis	8.33 ± 2.40	83.28 ± 25.00	1.67 ± 0.45
Abdomen	14.77 ± 6.00	147.72 ± 70.00	2.95 ± 1.30

ranged from 6.00 to 12.10 mGy, with a mean of 8.33 ± 2.40 mGy at a 95% confidence interval. In the abdomen region, CTDIvol ranged between 6.00 and 24.00 mGy, with a mean of 14.77 ± 6.00 mGy at a 95% confidence interval. The effective dose for the head and neck ranges from 0.01 to 0.02 mSv, with a mean of 0.01 ± 0.01 mSv. For the pelvis, the effective dose varies between 1.20 and 2.50 mSv, with a mean of 1.67 ± 0.45 mSv. In the abdomen region, the effective dose ranges from 1.20 to 5.00 mSv, with a mean value of 2.95 ± 1.30 mSv. Figure 4 illustrates the mean effective doses in mSv for clinical protocols.

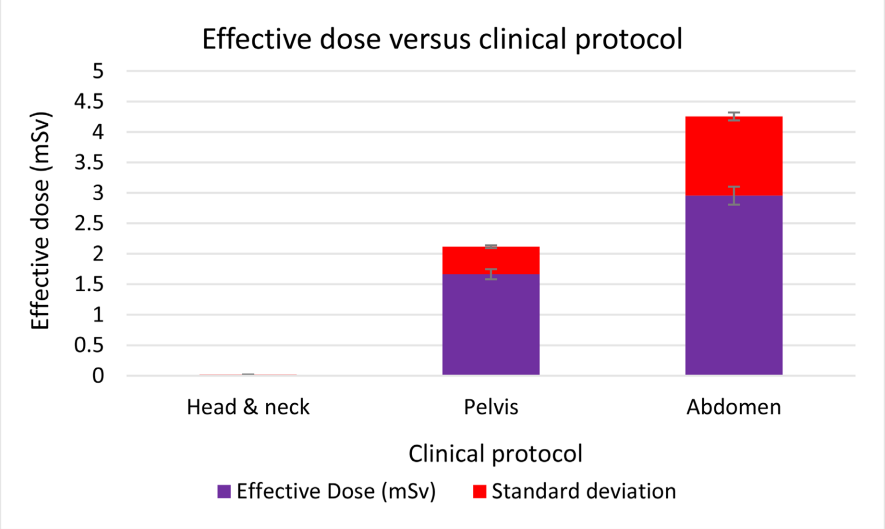


Figure 4. Effective dose (mSv) measured for clinical CBCT imaging protocols using a 16 cm diameter head and neck phantom, while a 16 cm diameter phantom was also used for the body on the Elekta XVI system.

4. Discussion

For kV imaging quality, regarding image uniformity, the calculation of the percentage difference for the average HU values across the five regions of interest (ROIs) produced a value of 0.33%, which was within the acceptable limit of 1.5% of the manufacturer and limit of 10% for SASQART. Spatial resolution exceeded 10 (lp/cm) by 12 lp/cm for both the manufacturer and SASQART. The low contrast visibility evaluation resulted in a percentage of 2.07%, well below the specified threshold of 3% for the manufacturer and 10% for SASQART. In terms of geometry, the measured vertical and horizontal distances between inserts were

116.70 mm and 116.70 mm, respectively, while the expected value was 117 mm. Both measurements displayed high accuracy, falling within the 1 mm tolerance range for the manufacturer and the 2 mm limit for SASQART. The results of the image quality tests presented here align with the specified tolerances outlined by both the manufacturer and SASQART.

Numerous studies have investigated CBCT dosimetry; however, most researchers [13]-[15] have based their assessments on the weighted computed tomography dose index (CTDIw) and have not extended their analyses to include conversion into effective dose. This study indicates that CTDIvol values (equal to CTDIw, since the pitch is 1) range from 0.1 to 14 mGy, with observed differences between the projected and delivered mAs. For the head-and-neck protocol, the machine was intended to deliver 36.6 mAs according to the manufacturer's default presets, but the actual measurements averaged 19 mAs. Similarly, the manufacturer's default presets set the intended mAs to 1056 for the pelvis protocol, but the actual measurements averaged 550 mAs. The manufacturer planned to deliver 1689.6 mAs for the prostate protocol, yet these measurements indicated an average delivery of 890 mAs. This study found that the manufacturer's default presets for the XVI clinical protocols delivered approximately half of the intended mAs and CTDI dose. If these mAs were delivering the entire mAs, the CTDIvol would be in the range of 0.8 to 24.6 mGy, a range similar to that reported by other researchers [13]-[15] and in line with the expected dose from the manufacturer's default settings for the XVI clinical protocols.

Song WY *et al.* (2008) have done a study using XVI acquisition default settings for all the clinical sites on an Elekta Synergy XVI system similar to ours, and dose measurements were conducted utilizing two cylindrical acrylic phantoms, one with an 18 cm diameter (head phantom) and the other with a 30 cm diameter (body phantom) [13]. They found that the average CBCT dose (CTDIw) ranged from 1 to 35 mGy, with total mAs of 36.1 for head and neck, 643 mAs for pelvis, and 1028.8 mAs for prostate. The body phantom recorded the highest measured dose under the prostate protocol [13]. Also, Isam MK *et al.* (2006) conducted measurements within the dose range of 1 - 23 mGy, while Spezi E *et al.* (2011) measured doses within the range of 0.1 - 30 mGy using Monte Carlo calculation, both utilizing similar XVI acquisition settings to ours using Elekta Synergy [14] [15].

Differences between the selected settings and the actual delivered values highlight discrepancies in CTDI measurements compared with previous studies [13]-[15]. These variations are further influenced by factors such as phantom diameter, acquisition parameters, and the dosimetry methodologies used in previous studies, all of which impact the reported dose magnitude. Delivered mAs values from the Elekta Versa HD were consistently lower than the preset protocol values. This is due to the system's reporting methodology, whereby the displayed delivered mAs corresponds to the exposure recorded for the completed CBCT scan only.

The $CTDI_{vol}$ for the head and neck is generally much lower, while the prostate

protocol displays a higher dose than the pelvis protocol. This is mainly due to the prostate protocol's use of high mAs settings necessary to achieve better image quality. This is particularly crucial in areas such as the prostate, where detailed visualization of soft tissues is essential. If a prostate patient undergoes daily imaging, they may receive approximately 14 mGy over a 30-fraction treatment course. This results in a cumulative imaging dose of up to 420 mGy, which is relatively small compared with the treatment dose. Therefore, incorporating the cumulative imaging dose into the prescribed dose may not be necessary, particularly for adult patients.

The findings regarding $CTDI_{vol}$ within paediatric clinical protocols. Notably, the head and neck scans display lower doses than the pelvis and abdomen scans. The results indicated that, per fraction, paediatric patients in the abdominal region may receive a maximum $CTDI_{vol}$ of about 24 mGy. Over an average 25-fraction treatment course, this could accumulate to a total imaging dose of up to 600 mGy. This is significant, as repeated imaging throughout treatment may increase the risk of stochastic radiation effects. The fast M20 low dose CBCT preset evaluated in this study resulted in lower radiation dose and may be suitable for IGRT applications where reduced patient exposure is a priority. However, image quality was not assessed as part of this study, and some of the evaluated protocols are not routinely used clinically at our institution. Therefore, protocol selection should consider both radiation dose and the image quality requirements of the intended clinical application.

Figure 3 graphically presents the findings on effective doses for adult clinical protocols, while Figure 4 illustrates the effective dose findings for paediatric clinical protocols. Comparison of the graphical data between adult and paediatric clinical protocols shows that paediatric doses are higher than adult doses. The results also indicate a strong dependence on patient size, with a more pronounced increase in dose for smaller phantom sizes.

5. Conclusions

This study shows that CBCT doses used during verification procedures are generally low for regions such as the head and neck. However, for clinical protocols like the prostate, the doses are relatively higher, although still small compared with the treatment dose. Imaging dose increases with higher energy and mAs settings. The findings indicate that the modern linear accelerator, the Elekta Versa HD CBCT imaging system, reduces patient radiation exposure due to lowered mAs settings compared with the manufacturer's default presets, resulting in a lower delivered dose than originally intended.

For paediatric patients who require daily CBCT scans for precise treatment setup, additional precautions are essential. The findings show that significant radiation doses can be delivered to paediatric patients in the abdominal region, especially those with smaller bodies. This study concludes that there is a potential for a significant dose to be delivered to paediatric patients during image-guided

radiotherapy.

This study has several limitations. Due to resource constraints, doses from the CBCT systems were not measured directly using thermoluminescent dosimeters (TLDs). Instead, dose assessments were based on CTDI measurements obtained using standard CTDI phantoms, and effective doses were estimated using established conversion coefficients. Consequently, the reported CTDI and effective dose values do not represent patient-specific organ doses and do not account for variations in patient anatomy, size, age, or positioning. The calculated effective doses should therefore be considered standardized metrics for comparing imaging protocols rather than precise estimates of individual patient risk. Future studies incorporating direct TLD measurements, patient-specific dosimetry, or organ dose calculations would provide a more comprehensive assessment of radiation exposure and associated risks.

Conflicts of Interest

The authors declare no conflicts of interest.

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