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Assessment of Imaging Protocol and Patients Radiation Exposure in Computed Tomography Colonography

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Abstract: In the screening and identifying of colon and rectum malignancy, computed tomography colonography (CTC) is a highly effective imaging technique, albeit patients receiving a significant effective dose. Accordingly, patient dose evaluation is an important need, seeking to ensure benefits outweigh the projected cancer risk. Objective: For CTC procedures carried out in the Radiology Department, Medical Imaging Operation Services, King Fahad Medical City (KFMC), evaluation is done using the current American College of Radiology (ACR) imaging protocol and concomitant patient-effective doses. Study is carried out on a sample size of 55 CTC procedures, involving 25 males (45%) and 30 females (55%). The patients were classified as follows: two groups based on CT machine; four groups based on the applied protocol; and three groups based on the procedure results. All procedures were carried out using two machines, the products of two different vendors (a GE Healthcare DISCOVERY CT 750 HD 64 slices dual-energy scanner and a Philips Brilliance CT 64 slices scanner). The overall mean, standard deviation (SD), median, and range of the effective dose (in mSv) were 11.57 ± 7.75, 9.25 (2.17–31.93). Automatic tube current modulation (ATCM) shows a significant increase in $CTDI_{vol}$ up to 69% and effective dose (mSv) up to 95% than the manual tube current (mA) compared to the standard protocol. The CT protocol variation results in a three-fold variation in patient-effective dose. The technologist role is crucial in selecting a noise reference based on patient weight and adjusting tube current per slice to avoid overexposure during ATCM protocol.

Keywords: CT colonoscopy; effective dose; radiation dose; imaging protocol

1. Introduction

Colorectal cancer (CRC) is the second most common cancer among Saudi adults (12.2%), being the most prevalent cancer among males, ranking third for females (10.4%) [1]. CRC is responsible for a relatively high fraction of the worldwide cancer incidence, increasing in developed countries where it ranks as the third most common cancer (1.8 million new cases annually), and the second greatest cause of death (0.9 million annually) [2], in good part due to late diagnosis [3]. On the whole, CRC is a lifestyle disease with greater prevalence in men than women, increasing with age, obesity, alcohol consumption, low quality diet involving unhealthy food, and smoking [4]. It has been estimated that up to 40% of CRC cases are due to heritable factors [5]. In the USA and Western Europe, as a result of preventive measures and effective treatment, the incidence and mortality from CRC has decreased by 3% annually [6,7]. In Saudi Arabia, Alsanea et al. [8] have reported the prevailing percentages for the different CRC stages: localized disease 22.2%, regional disease 47.4%, distant disease 25.9%, and unknown 4.6%, the five-year survival rate being 63.3% for localized disease, 50.2% for the regional stage, and 14.7% for the distant stage. Thus, in Saudi Arabia as found elsewhere, it is both evident and unsurprising that early CRC detection increases the opportunity for improved outcome from treatment [8]. The Saudi Arabian Ministry of Health (MOH) actively encourages those of over 50 years of age to participate in CRC screening tests, to be repeated every 5 to 10 years. One of the options available for average-risk cancer individuals is the low radiation dose computed tomography colonography (CTC) technique [9]. CRC screening methods consist of invasive techniques such as colonoscopy and flexible sigmoidoscopy (FS). In contrast, the non-invasive procedures consist mainly of imaging procedures such as barium enema, CTC, and capsule endoscopy. CTC, also called CT enema, virtual colonoscopy, or CT pneumocolon, can identify colon and rectum malignancy (colorectal polyps) and other diagnostic findings in symptomatic and asymptomatic individuals [9,10]. de Haan et al. [11] have provided estimated sensitivity and specificity values for CTC versus colonoscopy procedures, specifically for the detection of polyps or adenomas: ($\geq$6 mm lesion) sensitivity of 75.9% versus 82.9%, specificity 94.6% versus 91.4%; ($\geq$10 mm lesion) sensitivity of 83.3% versus 87.9%, specificity 98.7% versus 97.6%. An extensive study of 1233 individuals shows CTC and colonoscopy sensitivities for detecting polyps of 10 mm or more of 94% and 88% respectively [12], while another study, using an ultra-low dose protocol (10 mAs) for CTC, shows sensitivity and specificity for detection of $\geq$5 mm polyps of 94% and 84% respectively [13]. Radiation dose to patients during radiographic procedures is one of the public concerns. Therefore, there is a need for providing accurate information regarding patient dose and associated risk. Moreover, cancer risk is overwhelmingly estimated based on study of population survival in the aftermath of the August 1945 atomic bombings of Hiroshima and Nagasaki [14]. The Saudi Arabia government is seeking to provide diagnostic reference levels (DRL) for radiation doses arising from medical imaging [15]. CTC radiation dose can be one-half of that from the conventional abdomen-pelvis CT, with high natural contrast deference between the colonic soft tissue, gas, tagged feces, and fluids. The American College of Radiology (ACR) has recommended that the adult relative radiation level (RRL) for CTC should not exceed 10 mSv per procedure while for an average weight patient of 70 to 90 kg. The American Association of Physicists in Medicine (AAPM) note that the volume computed tomography dose index ($CTDI_{vol}$) range should be 3 to 6 mGy [12,16]. The CTC procedure is considered a frequent screening program, for asymptomatic diagnostic purpose, follow-up, or surveillance tool after surgical resection of CRC [17]. Therefore, as a low radiation dose protocol (screening protocol) the exposure factors needs to be optimized and justified according to the patient situation [18,19]. A study shows that an optimized screening protocol can reduce the effective dose significantly compared to a general daily practice protocol, with a life-time cancer risk of 0.14% being estimated for a 50-year-old individual exposed to CTC radiation dose [20]. Today, manufacturers provided many options to reduce the radiation dose to the patient, automatic tube current modulation (ATCM) being one such example, justifying the number of photons (mA) according to patient size [18]. Iterative reconstruction technique (IRT) is yet another technique to reduce the tube current, providing less image noise and a more extended threshold without degrading the image quality [21]. Good professional practice is also a leading factor in reducing radiation dose without constraining optimum coverage of the CTC procedure [22]. Previous studies of patient-effective dose during CTC have shown patient doses ranging from 2.3 to 9.8 mSv per procedure [18,19,23], the wide variation pointing to the likelihood that patients might be subject to unnecessary radiation risk. Thus it is crucial that investigation be made of patient exposure to ensure the procedure is optimized. This study evaluates the current imaging protocol at King Fahad Medical City (KFMC) and radiation dose, following guidance of the American College of Radiology (ACR).

2. Materials and Methods

2.1. Population

In this study, conducted over the period January 2017 to June 2019, all CTC procedures were reviewed retrospectively (via the hospital information system, HIS, the radiological information system, RIS, and the picture archiving and communication system, PACS). The study sample size is 55 procedures, 25 males (45%), and 30 females (55%). The mean, standard deviation, and range of the patient age (years) were 57.96 ± 13.6 (24–83), 16.3% of the cohort being below 50 years of age. The mean ± sd and range of patient weight (kg) is 76 ± 22 (50–120). The patients in this study were classified in several ways: (i) into two groups based on the CT machine; (ii) four groups based on the applied protocol, and; (iii) three groups based on the procedure results. The researchers obtained Institutional Review Board (IRB) approval from the ethics and research committee at KFMC (No: FWA00018774). The patients in this study, all adults, were referred to the radiology department as a result of the usual clinical criteria. The CTC procedure clinical indications are screening, limited colonoscopy, colonoscopy contraindication, or known cancer/follow up.

2.2. CT Equipment

The CTC procedures were carried out at KFMC, in carrying out each procedure using one of two machines, each the product of a different vendor (specifically, a GE Healthcare DISCOVERY CT 750 HD 64 slices dual-energy scanner and a Philips Brilliance CT 64 slices scanner). KFMC is a significant medical entity in Saudi Arabia, the estimated annual number of in- and out-patients being 30,000 and 500,000 respectively (KFMC statistics, 2019). ACR criteria were followed in evaluating the protocol and patient safety measures. The CT machine features are presented in Table 1.

Table 1. Image acquisition parameters during CTC procedure.

Parameters	Philips	GE
Scan type	Helical	Helical
kVp *	120	120
mA *	100	120
Collimation (mm)	40 (64 * 0.625)	40 (64 * 0.625)
Rotation time (s)	0.5	0.5
Pitch	1.375	1.375
SFOV	Large	Large
Coverage	Diaphragm to ischium	Diaphragm to ischium
IRT	40% ASIR	50% ASIR

* For standard size patient (70–90 kg); SFOV: scan field of view; IRT: iterative reconstruction technique; GE: General Electric.

2.3. CTC Protocol

Patients with a justified request form for CTC procedures were included in this study, being instructed to follow the preparation procedure, including: avoiding all high-fiber food for at least 72 h before the procedure and taking 100 mL of Gastrografin with water on the day before the CTC procedure. On the CT scan day, the specialist will check the patient precaution points and provide a clear explanation about the procedure. The patient should then remove any metallic object. At the CT table, the patient colon will be adequately inflated through the rectum by room air or carbon dioxide (CO_2). The CTC scan is carried out in the supine and prone position during which time the patient is requested to hold their breath. The CTC imaging acquisition parameters are provided in Table 1, with the GE manufacturer recommendations according to the guidance of the AAPM [16].

2.4. Radiation Dosimetry

Medical physics tests of the radiation dose report system in the CT console have been made, ensuring the accuracy of the reported radiation dose values. In this study, the radiation dose is evaluated per procedure, obtaining the dose-length product (DLP) (in mGy.cm), and per slice by the volume computed tomography dose index, $CTDI_{vol}$ (in mGy). The total effective dose was calculated according to the International Commission on Radiological Protection (ICRP) by multiplying the DLP by the abdominal and pelvis conversion factor f to obtain a value in $mSv.mGy^{-1}.cm^{-1}$ [24], as follows:

$$E\ (\text{mSv}) = DLP(mGy.cm) \times f \quad (1)$$

The cancer risk for the entire CTC procedure is calculated by multiplying the effective dose by the cancer risk factor (5.5×10^{-2} Sv^{-1}) [24].

3. Results and Discussion

CTC dose was assessed for 55 patients presenting with a range of clinical indications, using two helical scanners and varying imaging protocols, as in Table 1. Similar exposure parameters were used for the CT machines, with slight change in the tube current-time product (mAs) and use of the adaptive statistical iterative reconstruction technique (ISRT). Both parameters (mAs and ISRT) impact the dose reduction during CT imaging while maintaining diagnosable images. The dose reduction is considered to be important, with radiogenic risk from the imaging procedure conservatively assumed to be linearly related with the dose received, other influencing factors being held constant (age, dose per procedure, organ sensitivity). CTC was performed for different clinical indications using four imaging protocols: supine and one decubitus, supine, two decubiti, auto tube current, and routine (manual), as illustrated in Table 2. The mean ± SD, median, and range of (tube current (in mA) and ($CTDI_{vol}$ (in mGy) radiation dose has been calculated for two decubiti according to the imaging protocol. This variation in CT protocol results in an up to three-fold variation in patient-effective dose (Table 2).

Table 2. Mean ± standard deviation (minimum − maximum) of (tube current (mA) and ($CTDI_{vol}$ (mGy) radiation dose is calculated for two decubitus according to the protocol.

Protocol	Tube Current (mA)		$CTDI_{VOL}$ (mGy)		Effective Dose (MSV)
	Supine	Prone/Decubitus	Supine	Prone/Decubitus	
Supine and one decubitus	266.6 ± 144 (100–350)	266.6 ± 144 (100–350)	7.5 ± 4 (2.8–9.8)	7.5 ± 4 (2.8–9.8)	13 ± 5.9 (6.1–16.8)
Supine and two decubitus	375 ± 106 (300–450)	375 ± 106 (300–450)	13.4 ± 1 (12.6–14.2)	12.2 ± 0.57 (11.8–12.6)	31.6 ± 0.38 (31.3–31.9)
Auto tube current (mA)	253.1 ± 63 (150–325)	256.2 ± 59 (150–325)	11.2 ± 5.2 (2.2–18.3)	10.5 ± 4.7 (2.1–16.5)	18.7 ± 9.9 (3.06–31.9)
Routine (manual)	203 ± 96.3 (100–440)	202.2 ± 96 (100–440)	6.4 ± 3.3 (2.7–15.5)	6.51 ± 3.9 (2.8–19.7)	9.6 ± 6 (2.1–26.7)

The effective dose from supine and two decubitus protocol CRC give the greatest value (31.6 mSv), exceeding that of the routine protocol (9.6 mSv). The effective dose in supine and two decubitus protocols are attributed to the high tube current used in this protocol, ranging from 300 to 450 mA per CTC procedure compared to the other three imaging protocols. The median and mean values for all patients groups are closely similar, suggesting asymmetrical distribution of the dose values for supine and two decubitus and routine CTC protocols. Conversely, for supine and one decubitus and auto tube current (mA) protocols, the dose values are skewed, with many $CTDI_{vol}$ (mGy) values at the higher end. Table 3 shows the image acquisition parameter and radiation dose values according to the manufacturer and the tube current mode. Automatic tube current modulation (ATCM) shows a significant increase in $CTDI_{vol}$ (mGy) (69%) and effective dose (mSv) (95%) than the manual tube current (Table 3). ATCM is established on the basis of attenuation of the radiation during image acquisition in order to adjust for disparities in patient anatomy while maintaining the image quality, reducing unnecessary exposure. In contrast, patient dose resulting from the application of ATCM are two times that of the standard protocol (Table 3). Söderberg and Gunnarsson [25] have reported that ATCM may reduce the dose during CT procedures by up to 60% while maintaining image quality.

However, the potential dose reduction depends on the proper choice of imaging factors and images' standard quality [26]. In the Philips CT machine, the noise level can be adjusted to obtain image contrast based on patient size. ATCM is activated using Dose Right, automatic current selection (ACS), to get acceptable image quality by variation in tube current around the patient, and the z-direction. For this, technologist intervention is necessary.

Table 3. (**A**): Mean ± standard deviation (minimum − maximum) of the image acquisition parameter and radiation dose values according to the manufacturer and the tube current mode. * fixed values. (**B**): Mean ± standard deviation (minimum − maximum) radiation dose values according to the manufacturer and the tube current mode.

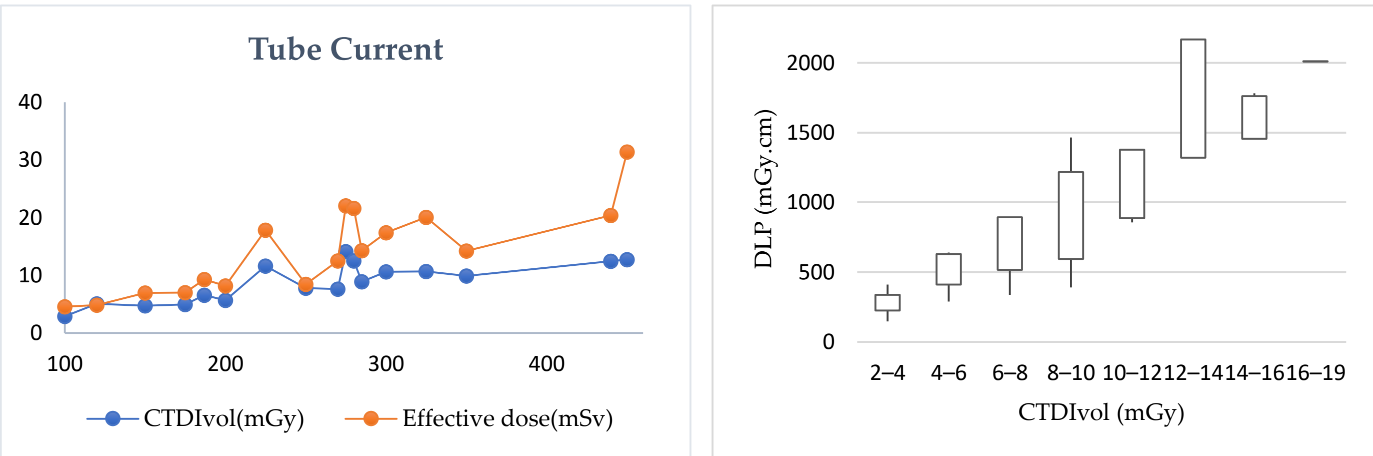
(A)

Mode	Tube Voltage (kVp)	Tube current (mA)		Rotation Time (s)	Pitch	Slice Thickness (mm)
		Supine	Prone			
Auto mA (Philips)	120	287.5 ± 17 (275–300)	287.5 ± 17 (275–300)	0.85 ± 0.02 (0.84–0.87)	0.9 *	0.67 *
Auto mA (GE)	116.6 ± 8.1 (100–120)	241.6 ± 70 (150–325)	245.8 ± 65.9 (150–325)	0.5 ± 0.1 (0.4–0.7)	1.1 ± 0.2 (0.98–1.37)	0.62 *
Manual mA (GE)	120	212.3 ± 104 (100–450)	213.2 ± 105.5 (100–450)	0.52 ± 0.06 (0.5–0.7)	1.32 ± 0.1 (0.98–1.37)	0.62 *

(B)

Mode	$CTDI_{vol}$ (mGy)		DLP (mGy.cm)	Effective Dose (mSv)
	Supine	Prone		
Auto mA (Philips)	16.2 ± 2.9 (14.2–18.3)	14.6 ± 2.6 (12.7–16.5)	1702.8 ± 436.7 (1394–2011.6)	25.5 ± 6.5 (20.9–30.1)
Auto mA (GE)	9.6 ± 4.8 (2.2–14.5)	9.1 ± 4.6 (2.2–15)	1098.1 ± 686.5 (204–2128.8)	16.4 ± 10.2 (3.06–31.9)
Manual mA (GE)	6.6 ± 3.4 (2.7–15.5)	6.7 ± 3.9 (2.8–19.7)	690.1 ± 447.3 (145.2–2092.9)	10.3 ± 6.7 (2.1–31.3)

The mAs per CT slice need proper adjustment since drift from the initial setting overtime is expected [26,27]. In comparison with the GE CT machine, the ATCM sustains a similar noise level during image acquisition. A reference image from a standard phantom is needed, using GE AutomA 3D has *z*-axis (AutomA) and angular modulation (SmartmA), with the mA being changed for each quadrant during every rotation [28]. To avoid overexposure the technologist role is crucial in selecting a noise reference based on patient weight [29]. From the results presented in Table 3A,B, the ATCM may not be adjusted by the technologist, which leads to a higher radiation dose. Figure 1A shows direct relationship between tube current (mA) and the $CTDI_{vol}$ (mGy) and effective dose (mSv). $CTDI_{vol}$ and effective dose increase with tube current value. According to the ACR recommendation, the standard effective dose per procedure is 10 mSv. The American Association of Physicist in Medicine (AAPM) recommends a 3.0 to 6.0 mGy range of $CTDI_{vol}$ for an average sized patient (70–90 kg) (AAPM, 2011). The AAPM recommended the $CTDI_{vol}$ value of 2–4 mGy and 5–9 mGy according to patient weight ranges, 50–70 kg and 90–120 kg, respectively. Figure 1B shows the relation between the CTIDvol (mGy) and the DLP (mGy.cm) per CTC procedure. Wide variation is observed in DLP (mGy.cm) value as $CTDI_{vol}$ increases (mGy). Both dose descriptors are patient dose indices that calculate patient dose per slice volume and per procedure, respectively. Although patient doses differ according to patient size, in agreement with current study, previous studies have shown that patient dose can fluctuate by as much as a factor of two through patient size for a similar type of CT procedure to obtain radiographic images of comparable quality. Smith-Bindman and Miglioretti [30] reported a variation in patients' doses ranging from 10 to 100 fold variances in DLP (mGy.cm) for CT procedures acquired for the typical clinical indication. In fact, after accounting for patient weight and body mass index, a profound—and unacceptable—variation in these measures remained. Most of the dose variation is due to variation in the adoption of multiphase protocols, larger scanning regions, or higher dose settings without awareness of the resulting dose burden these choices create. Thus, without considering patient weight, we can greatly improve the way of conducting CT simply by assessing $CTDI_{vol}$ and DLP. Figure 1B: The relation between the $CTDI_{vol}$ (mGy) and the DLP (mGy.cm), wide variation in DLP value as $CTDI_{vol}$ increases. (According to AAPM the $CTDI_{vol}$ (mGy) value according to the patient weight is 2–4 mGy for (50–70 kg), 3–6 mGy for (70–90 kg) and 5–9 mGy for (90–120 kg) [31]. In seeking to optimize patient dose consistent with sufficient image quality and with DLP depending proportionally on scan length, precise selection of scan length is important. Figure 2 illustrates the patient-effective dose (mSv) and $CTDI_{vol}$ (mGy) using the same parameter factors for patients in the supine position. The steps for the first three patients were found to provide optimum anatomical coverage while conversely the anatomical range situation for the last patients four and five was less favorable, the latter registering greater effective doses due to an associated need for wider variation in exposure parameters. As expected, compared to those of average body mass index (BMI, kg/m^2) of 18–24.9, patient doses are greater for obese patients [32]. Figure 3A,B, show for two patients with the same scan parameters a 16.5% difference in effective doses, a matter arising from anatomical coverage, the yellow line indicating scan coverage, the green line delineating the upper part of the colon, and the red line the lower level. Figure 3A shows optimum anatomical coverage while Figure 3B indicates poor choice of anatomical coverage. An increase of scan length due to the extension of the anatomical coverage beyond necessary increases the dose per procedure (DLP, mGy.cm), also the $CTDI_{vol}$ (mGy).



(**A**) (**B**)

Figure 1. (**A**): Direct relation between tube current (mA), the $CTDI_{vol}$ (mGy) and effective dose (mSv). $CTDI_{vol}$ (mGy) and effective dose (mSv) increase with tube current value. (ACR recommendation for the effective dose is 10 mSv) (According to AAPM, the range of $CTDI_{vol}$ for average patient size is 3–6 mGy). (**B**): The relationship between CTDIvol (mGy) and DLP (mGy.cm), a wide variation being seen in DLP value as $CTDI_{vol}$ increases. (According to AAPM, the $CTDI_{vol}$ value is 2–4 mGy for 50–70 kg, 3–6 mGy for 70–90 kg, and 5–9 mGy for 90–120 kg patients.

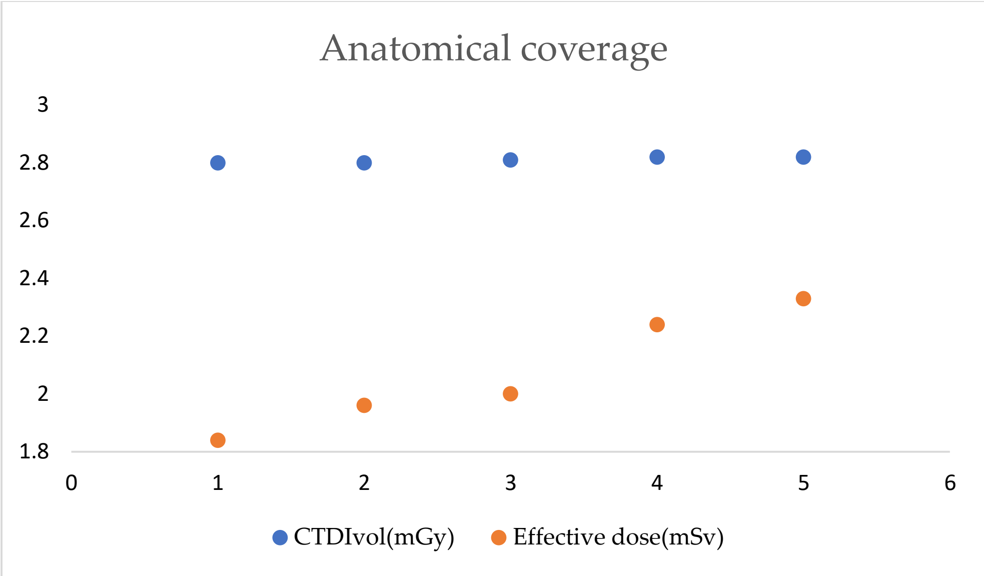


Figure 2. Patients with the same parameter factors in a supine position, the first three patients having optimum anatomical coverage while the last two patients less well indicated anatomical range coverage, accordingly registering greater effective dose.

(**A**) (**B**)

Gender	F	Age	77	Gender	F	Age	50
Protocol	Routine	mA mode	Manual	Protocol	Routine	mA mode	Manual
Parameters	kVp	mAs	Pitch	Parameters	kVp	mAs	Pitch
Values	120	50	1.37	Values	120	50	1.37
Position	$CTDI_{vol}$	DLP	Eff Dose	Position	$CTDI_{vol}$	DLP	Eff Dose
Supine	2.81	133.5	2	Supine	2.82	155.8	2.33
Outer margin	Upper	Lower	Total	Outer margin	Upper	Lower	Total
in cm	2.8	4.2	7	in cm	7.4	4.8	12.2

Figure 3. (**A**,**B**) Two female patients with the same scan parameters have a 16.5% difference in the effective dose due to anatomical coverage. The yellow line shows the scan coverage, the green line is the first part for the colon, and the red line shows the colon's last level. (**A**) is an optimum anatomical coverage and (**B**) is improper anatomical coverage.

Figures 4 and 5, show the relation between patient weight (kg) and CTDIvol (mGy) and effective dose (mSv) per procedure. The CTDIvol (mGy) is less dependent of patient weight. Other factors including tube output and scan length affect the patients' dose values.

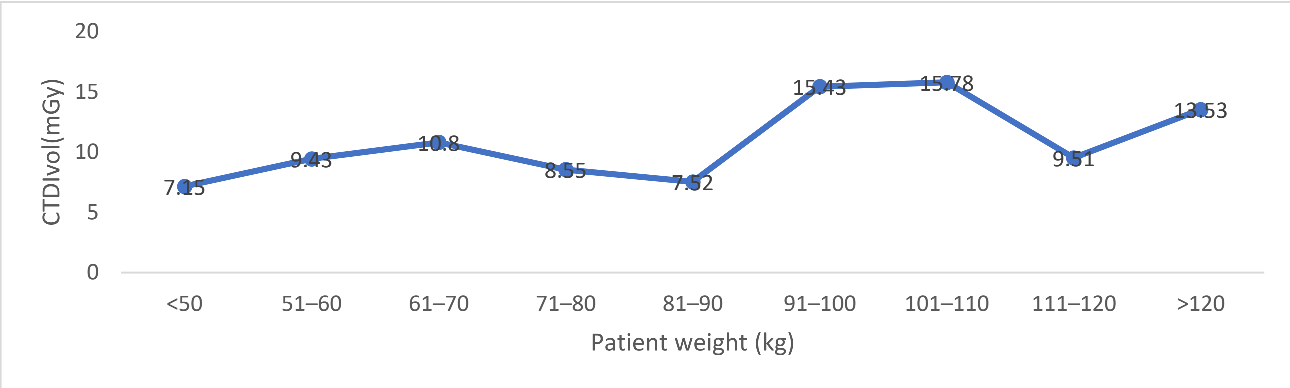


Figure 4. Patient weight versus CTDIvol (mGy).

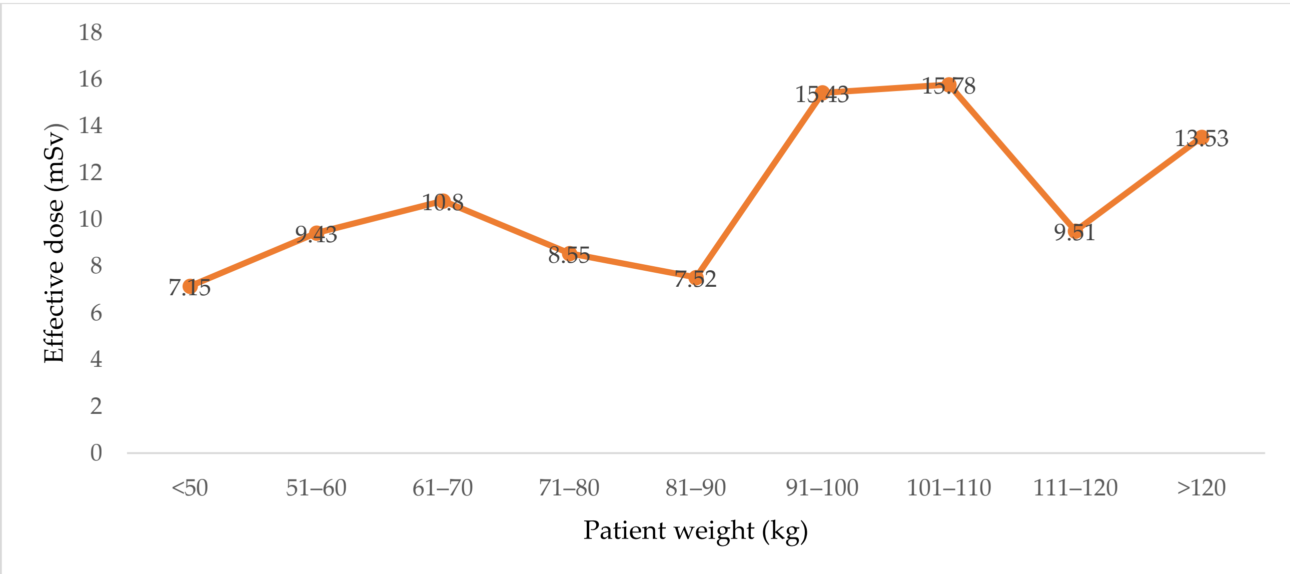


Figure 5. Patient weight versus the effective dose (mSv).

Fujii et al. [32] have reported a strong correlation between patient size and $CTDI_{vol}$ (mGy); the use of tube current modulation (TCM) caused an immediate increase in the value of the $CTDI_{vol}$ (mGy) for obese patients (i.e., of large BMI (kg/m^2). Table 4 shows the mean, standard deviation (SD), median, and range of the effective dose (mGy.cm) according to patient gender. Comparable mean effective doses were obtained for males (10.30 mSv) and females (10.99 mSv) per procedure with a mean percentage difference (PD) $\leq$ 6.5%. The overall mean, standard deviation (SD), median, and range of the effective dose (mSv) was 11.57 $\pm$ 7.75, 9.25 (2.17–31.93), the overall mean exceeding the maximum ACR recommendation (10.0 mSv) by 16%, the $CTDI_{vol}$ (mGy) exceeding the AAPM recommendation for average patients, of weight (70–90 kg), by 22% [31]. The entire CTC procedure results were: 20% positive, 27% negative, and 53% limited diagnostic value. The patient dose per procedure in terms of $CTDI_{vol}$ (mGy), DLP (mGy.cm), and effective dose is greater than the previous studies (Table 5). CTC has a superior advantage on CRC diagnosis, including asymptomatic patients. The main drawback is the use of ionizing radiation, which may increase the probability of cancer risk. Recently, the use of ultra-low-dose CTC (ULD-CTC) with ATCM up to 63% and a 66% for effective dose (mSv) and $CTDI_{vol}$ (mGy), respectively, in comparison with the low-dose CTC (LD-CTC) without significant deterioration in image quality and polyp detection was seen. In addition to that, the use of sinogram-affirmed iterative reconstruction (SAFIRE) and ATCM can reduce the patient doses below 1.0 mSv, while maintaining the diagnostic quality of CT image [18,19,23,33,34] (Table 5). Furthermore, Chang et al. [35] reported a reduction of CTDIvol (mGy) up to 20% by reducing the tube potential (kVP) from 120 to 100 irrespective of the patient size with a slight decrease in image quality. The available dose reduction techniques can significantly reduce the risk of CRC procedure. However, it requires awareness and a skillful technologist.

Table 4. Mean ± sd, median and range of patient radiation dose values according to the patient gender.

Gender	Number	Age (Y)	$CTDI_{VOL}$ (mGy) Supine	$CTDI_{VOL}$ (mGy) Prone	Effective Dose (mSv)
M	25	58.64 ± 15.2, 58 (29–83)	6.7 ± 4.42, 5.63 (2.27–15.56)	6.5 ± 4.1, 5.6 (2.1–15.58)	10.3 ± 7.95, 6.92 (2.17–31.9)
F	30	57.4 ± 12.3, 55 (24–82)	7.84 ± 3.64, 8.02 (2.79–18.3)	8.06 ± 4.3, 7.61 (2.8–19.76)	12.6 ± 7.55, 10.99 (3.88–31.39)
Total	55	57.96 ± 13.6, 56 (24–83)	7.33 ± 4, 7.02 (2.2–18.3)	7.37 ± 4.3, 7.11 (2.2–19.7)	11.57 ± 7.75, 9.25 (2.17–31.93)

Table 5. Comparison of the average radiation dose values with six worldwide studies per series.

		Standard Imaging Protocol			Modified *		
Authors	Country	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective Dose (mSv)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective Dose (mSv)
Chang et al. [22]	USA	5.3	239	3.6	4.1	197	3.0
Nagata et al. [19]	Japan	2.37	118.8	1.78	1.22	47.4	0.9
Nagata et al. [19]	Japan	2.53	128.2	1.92	0.92	42.2	0.7
Nagata et al. [19]	Japan	2.63	130.4	1.96	0.77	36.4	0.6
Nagata et al. [19]	Japan	2.51	123.9	1.86	0.62	29	0.5
Cianci et al. [18]	Italy	3.87	179.3	2.69	1.32	65.3	1.0
Liedenbaum et al. [20]	The Netherlands	N/A	303.3	4.55	N/A	193.3	3.0
Millerd et al. [23]	USA	6.7	327.8	4.91	2.7	129.1	1.9
Current study	Saudi Arabia	7.3	385.5	5.7	7.3	385.5	5.7

* modified CTC imaging protocol.

With CTC performed for screening purposes, patients or individuals may be subject to repeat radiation exposures, contributing to additional cancer induction probability. With the current effective dose value (11.57 mSv), the additional expected cancer risk is six health detriments per 10,000 CTC procedures. Thus careful justification and optimization of CTC procedure are recommended, in particular to avoid unnecessary radiogenic risk, while maintaining the benefit of the CTC procedure. Artificial intelligence (AI) can considerably assist in the automation of image acquisition and reduce the human factors regarding experience in selecting optimal exposure parameters and scan range based on visual sensors and the imaging protocol [36]. Thus, the optimal scanning parameters can significantly improve the scanning efficiency and reduce the unnecessary radiation exposure. In addition to that, currently, computed aided diagnosis (CAD) is used widely to obtain an accurate diagnosis, prognosis, and tracking of CRC [37]. Patient dose reduction can be achieved by selecting optimum exposure parameters and the use of ATCM by well-trained technologists. The current study provided a rigorous assessment of patient dose during CTC at KFMC, Riyadh, Saudi Arabia. However, there is still a limitation regarding the sample size due to a multi-center study's access issues at a national level to derive the national diagnostic reference level (DRL) for patient dose optimization.

4. Conclusions

Patient dose during CTC has been assessed using two helical scanners, various imaging protocols, and CT machine settings. The variation in CT protocol results in an up to three-fold variation in patient-effective dose. The variation in the effective dose during CTC protocols is attributed to the high tube currents used in this protocol, ranging from 100 to 450 mA per CTC procedure. ATCM shows a significant increase in $CTDI_{vol}$ (mGy) (69%) and effective dose (mSv) (95%) compared to the manual tube current (mA) selection. This suggests the technologist's role to be invaluable and crucial in selecting a noise reference based on the patient weight and adjusting the tube current per slice to avoid the overexposure as seen in the use of ATCM protocol. The current patient-effective dose during CTC is greater compared to previously published studies. Individuals undergoing screening CTC have a greater risk of radiogenic cancer probability, arising from long-term repetitive exposures. Patient dose optimization is seen to be necessary in assuring patients receive the greatest benefit of the CTC procedure.

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