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Effectiveness of Tube Potential Reduction and Scan Range in Dose Reduction in Computed Tomography (CT): A Systematic Review

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ABSTRACT

Computed Tomography (CT) is one of the most used imaging modalities. As CT continues to expand its usage, public has raised questions regarding the adverse effect due to radiation in CT. Dose reduction techniques without affecting good quality image useful for diagnosis remains a major concern in healthcare. However, limited studies that focuses on the effectiveness of reducing tube potential or adjustments of scan range on CT dose reduction can be identified in recent years. The objective of this study is to systematically review the effectiveness of reducing tube potential and scan range in dose reduction in CT. Literature search was conducted via PubMed and Google Scholar within a span of 15 years from 2008 to 2023 with the use of phrases and keywords that are specific. Studies that are duplicated or contain insufficient data are excluded. A single reviewer conducted the screening of the title, abstract, objectives methods and results of the studies. 25 studies from a total of 486 studies was included in this review after adhering to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram. 16 of the studies achieved radiation dose reduction by decreasing the tube potential while nine other studies achieved radiation dose reduction by implementing a reduced scan range protocol. The dose reduction percentage by tube potential reduction ranges from 6.5% to 63%, whereas the dose reduction by reducing scan range ranges from 11% to 71%. The efficiency of tube potential reduction and optimised scan range in lowering radiation doses in CT has been shown by this systematic review where reduced tube potential protocol can effectively reduce patients' radiation dose without sacrificing image quality, while decreasing scan range can also decrease radiation dose received by patient without missed diagnosis of disease. Both of these protocols are recommended to be use in future clinical practices.

1. Introduction

Medical Imaging is essential in healthcare as it provides images that corresponds to actual human anatomy that aids physicians in the diagnosis of diseases. Computed Tomography (CT) has become one of the most common imaging modalities in radiology as its usage has increased over time in recent years as it offers important anatomical information essential for efficient disease diagnosis

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and treatment planning. Despite the advantages of CT scans, people have started to raise questions regarding the adverse effects accompanied by the radiation due to possessing the potential risks of causing cancer [1]. Thus, as CT continues expand its usage, dose reduction techniques without affecting good quality image useful for diagnosis remains a major concern in healthcare.

CT scanning has gained global attention since its invention due to it being one of the imaging modalities that implements the use of high volume of ionizing radiation doses to produce diagnostic images. The CT scan usage worldwide is estimated to be 403 million examinations from the year 2008 to 2019, where 55 people is found to have undergone a CT examination in 1000. This is nearly double the amount of CT scans done in 2006. The most frequent CT scan procedure is head CT procedure that includes skull, facial bones, soft tissue and brain, contributing around 26.3% of the total scans, followed by chest (12.2%) and abdomen (11.9%) CT.

CT procedures use ionizing radiation that can directly or indirectly cause damage to the cells of a living bring by breaking the chemical bonds of the cells due to the ionization activity with the cells by the free radicals in the radiation. It can produce deterministic effects and stochastic effects. The first effect produced by the ionizing radiation in CT is deterministic effect. Deterministic effects lead to cell necrosis in tissues or organs, causing impairments and injuries [2]. This happens when the damage to cells passes a threshold beyond the body's repair capacity. The effects usually surface within hours or weeks, and the dose threshold to trigger direct damage is less than 2 Gy (Gray). Examples include skin injuries, infertility, and cataract formation. For complicated CT-guided interventions, stochastic effects may occur at doses slightly above 1 Gy even though the deterministic threshold for skin is 2 Gy.

The ionizing radiation produced during a CT procedure is more likely to produce stochastic effects while irradiating the patient [3]. The ionizing radiation causes changes in the DNA such as damages directly by ejected electrons or damages indirectly via free radical production, mainly hydroxyl radicals from water, prevalent with x-rays [1]. Severe damage to DNA causing double-strand breaks may induce cell necrosis. If necrosis does not occur or single-strand breaks are repaired incorrectly, DNA mutations will occur which occasionally results in malignancy. Radiation-induced malignancies may only emerge decades later after the exposure, unlike the acute effects that will manifest after hours or days. According to Food and Drug Administration (FDA), the severity of malignancy is unaffected by dose whereas the occurrence is greater with higher dose as stochastic effects has no threshold, which is called a “linear non-threshold” model. Thus, while stochastic effects are concerning, deterministic effects emphasize the importance of careful dose management in CT especially for interventional procedures that necessitates repeated exposures.

CT exposure can be influenced by a few parameters including tube current, tube potential, scan range, pitch and scan time. To reduce the exposure during a CT procedure, adjustments of CT parameters play a vital role. Radiation dose optimization in CT is critical because of the increased utilization in diagnostic purposes and treatment planning. It has been proven that radiation from CT scanners has the tendency to elevate the risks of developing cancer in patients [3]. Additionally, studies by Hemaya *et al.,* [4] and Power *et al.,* [5] has further demonstrated that patient has limited knowledge regarding the radiation emitted from CT. With the occasional exaggerated reports by the media, patients have the tendency to decline treatment with the usage of CT due to concern of developing cancer. Therefore, studies in this field are practical to develop evidence-based CT guidelines and protocols to improve patient safety. This research enhances clinical practice, fosters patient education and promotes informed decision-making regarding CT imaging procedures by examining the efficacy of dose reduction strategies.

However, there has been limited studies that focuses on the effectiveness of reducing tube potential or adjustments of scan range on CT dose reduction in recent years. Thus, this study strives to systematically review the impact of adjusting dose reduction techniques, particularly focusing on reducing tube potential or scan range, to minimize patient's radiation dose in CT examination. Adjustment of tube potential is achieved by modifying the voltage sent to the x-ray tube to reduce the amount of radiation radiated by the patient, whereas reduction of the scan range is achieved by restricting the area scanned by the CT machine. The effectiveness of these dose reduction strategies is evaluated via a comprehensive narrative analysis. The objective of this research is to systematically review the effectiveness of reducing tube potential and scan range in dose reduction in CT and to systematically associate different tube potential and scan range with dose reduction percentage in computed tomography.

This review aims to provide detailed insights regarding the optimal techniques utilized to reduce radiation dose in CT by synthesising the outcomes from different studies, which promotes the patient safety and decision-making skills in health personnels.

2. Methodology

The study design of this research is systematic review. This research is conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement, which is a revised version of the 2009 version that contains newest guidelines in reporting the details and progress in the methods to identify, choose, evaluate and incorporate the studies [6].

2.1 Location and Sampling

An advanced electronic search using article platforms search as PubMed and Google Scholar was conducted using the keywords including "Computed Tomography", "radiation dose reduction", "tube potential", "kVp" and "scan range" or "scan length" or "z-axis". All the literatures included must be published in English language. The literatures included were selected within the time stamp of 15 years from 2008 to 2023 and the amount was determined according to the inclusion and exclusion criteria. The location is not essential as this research is conducted in a systematic review design. The titles, methods and abstracts of full text articles were thoroughly reviewed before it was included in the research.

The studies included must be eligible for the inclusion criteria of the research. The inclusion criteria are: (1) articles related to dose reduction in computed tomography, (2) articles describing the parameters in reducing the radiation dose in CT, (3) the parameters included in the articles must be tube potential or scan range, (4) articles that provide accurate statement of the radiation dose of the patient after applying the parameters, and (5) articles that describes the total dose reduction in percentage.

The exclusion criteria of this research include (1) articles not related to CT or involving other imaging modalities, (2) articles not related to radiation dose reduction in CT, (3) articles related to radiation dose reduction in CT but do not include reduction in tube potential or kVp and scan range, and (4) articles related to CT dose reduction via reduction of tube potential or adjustment of scan range in addition to tin filtration.

2.2 Material and Data Collection

The literatures obtained were sorted and duplicated studies are removed using Microsoft Excel and the app Zotero. Zotero is a software developed for management of open-source references. It assists users in collecting, organizing and citing materials used in research and bibliography databases by filtering the sources according to their authors, date of publication and title. It also allows user with offline access to some sources. With Zotero, duplicated sources were made visible and could be removed before it was included in the research.

To ensure the studies are relevant to the research, the title, objectives, methodology and results were reviewed and screened by a single reviewer. The data that were extracted include: (1) author name, (2) publication year, (3) study design, (4) study aim, (5) number of subjects, (6) CT modality, (7) protocols of study, (8) radiation dose and (9) dose reduction percentage.

2.3 Data Analysis

A narrative synthesis was conducted instead of meta-analysis in this systematic review. The results were then compiled into tables and descriptive explanations were made.

2.4 Risk of Bias Assessment

Bias is a factor that influences research as it is described as errors of methodology causing skewing of measurements which in turns interferes with the study investigations and results. To eliminate this risk, a risk of bias assessment must be done by reviewing the analysis, conduct and design affecting the results of study [7]. The quality and the risk of bias of each study included in this research is ascertained by using of risk of bias assessment tool, “Rob 2”, which is a second version of assessment tool for bias risk in random controlled trials published in “Robvis” [8]. The tool is published in accordance with the guidelines of Cochrane Reviews and emphasizes on the multiple aspects of the research, such as design of trial, ways of conducting and writing report, by identifying the information that are pertinent to a few different domains of bias. After assessing the bias for each study, the results are compiled in a Microsoft Excel spreadsheet and converted into a traffic-light plot using the “Robvis” tool.

2.5 Parametric for Radiation Dose Reduction Calculation

Researchers from the studies included had implemented various parameters to approximately quantify the amount of radiation dose of the patients. Some of the values including $CTDI_{vol}$, DLP, effective dose and size specific dose estimation (SSDE) is absent and is manually calculated by the author. The parameters included would be explained as follows:

2.5.1 Volume weighted CT Dose Index ($CTDI_{vol}$)

$CTDI_{vol}$ is a value that is used and displayed by CT scanners used in the modern. It uses mGy as a unit of quantification. The scanner calculates $CTDI_{vol}$ according to the resultant radiation after a patient has undergone a scan. This value is varied from different patients as radiation yield is spontaneously regulated by the scanners depending on the patient’s body mass index (BMI). Eq. (1) is used to define $CTDI_{vol}$ [2].

$$CTDI_{vol} = CTDI_w \cdot \frac{NT}{I} = \frac{CTDI_w}{pitch\ factor} \tag{1}$$

where:
$CTDI_w$ = weighted CTDI
NT = total width of nominal collimation
I = distance travelled by the table for one rotation during helical scan

2.5.2 Dose Length Product (DLP)

DLP is used to term the calculation for the radiation dose received by the patient after completing a scan in the unit mGy·cm. Eq. (2) is used to define DLP [2].

$$DLP = \sum_{i=1}^{N} (CTDI_{vol})_i \cdot L_i \tag{2}$$

where:
N = number of slices
i = individual scans of examination
L_i = length of anatomy of patient

2.5.3 Effective dose

Effective dose, E, is a term applied for quantification of adverse biological effect from a partial radiation exposure to the body, allowing the potential risks to be determined. The unit used is mSv and the equation is described as in Eq. (3) [2].

$$E = \sum_{i=1}^{N} k_i DLP_i \tag{3}$$

where:
N = number of slices
i = number of individual scans
k_i = conversion factor depending on anatomy and type of examination
DLP_i = DLP resulting from each individual scans

2.5.4 Size Specific Dose Estimation (SSDE)

Size specific dose estimation (SSDE) is used to estimate the amount radiation dose irradiated by the patient which takes account of the patient's size. It does not a considered a measure of effective dose as it does not include the consideration of the organs field of view during a CT scan. It can be defined with the Eq. (4).

$$SSDE = CTDI_{vol} \times f \tag{4}$$

where:
f = conversion factor related to effective and water equivalent diameter reduction in DLP for scan length

2.5.5 Dose reduction percentage

Dose reduction percentage is calculated by the percentage of the difference between the total dose for control group and intervention group divided by the dose of the total dose for control group, which is shown in Eq. (5).

$$\text{Reduction Percentage} = \frac{ED_{control}/SSDE_{control} - ED_{intervention}/SSDE_{intervention}}{ED_{control}/SSDE_{control}} \times 100\% \tag{5}$$

2.6 Ethical Considerations

This study does not require ethical approval as it involves reviewing of literatures and no patients were directly involved. However, it still requires the ethical approval from MAHSA University.

3. Results

3.1 Literature Search

A thorough search in the electronic database such as PubMed and Google Scholar produced 486 studies. The obtained studies have undergone selection by adhering to the flow diagram of PRISMA before they were included in this systematic review. Following the selection process, 461 studies that did not meet the inclusion criteria were excluded, which includes four studies that were duplicated. A total of 25 studies that met the inclusion criteria of this review had passed the final selection and were selected (refer to Figure 1).

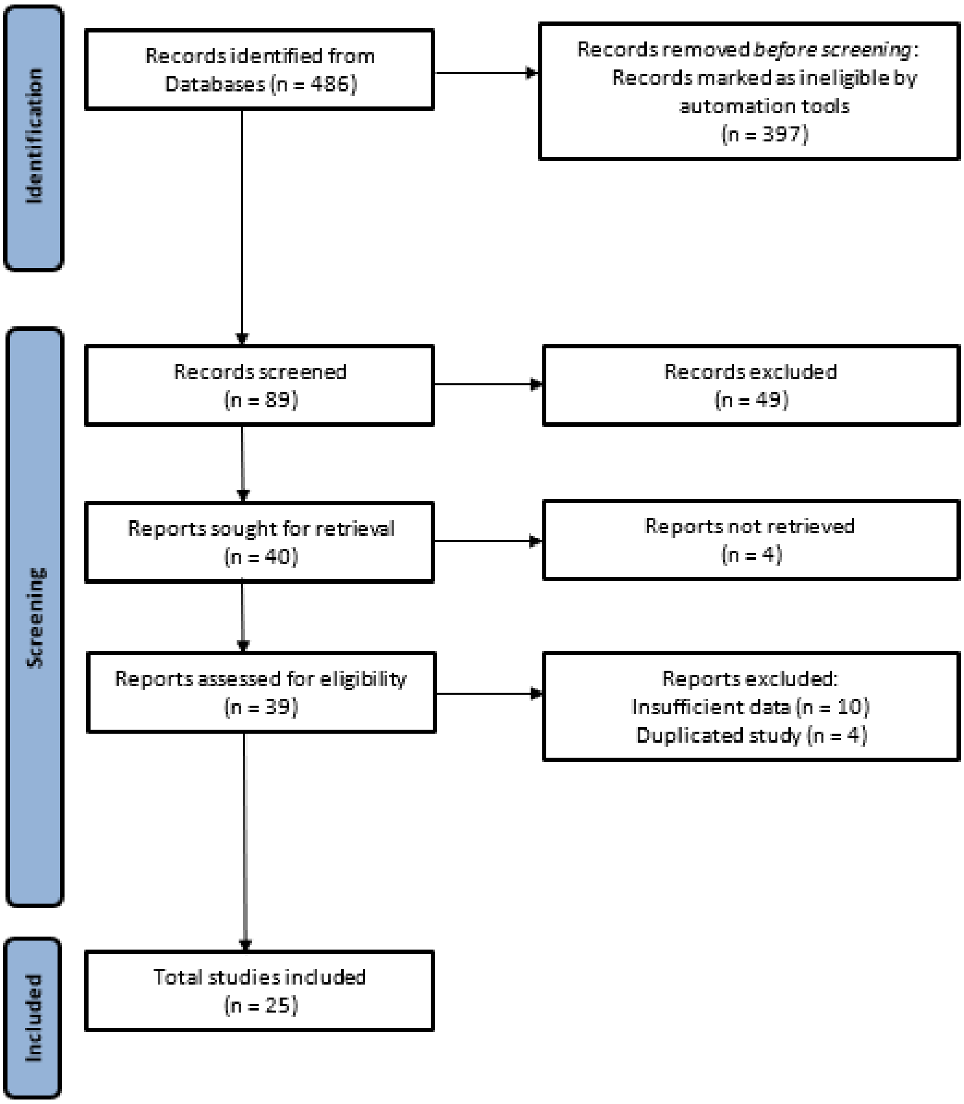

Fig. 1. PRISMA flow diagram used in the process for systematic search

3.2 Characteristics of Included Studies

All 25 studies are patient studies. 16 of the studies are retrospective studies, six studies are prospective studies, one study is observational prospective study, one study is comparative retrospective study and one study is a combination of prospective and retrospective study, as referred to Figure 2. The studies included were conducted within the span of the year 2009 to 2023. The number of samples, study design and the aim for each of all 25 studies were compiled and stated in Table 1.

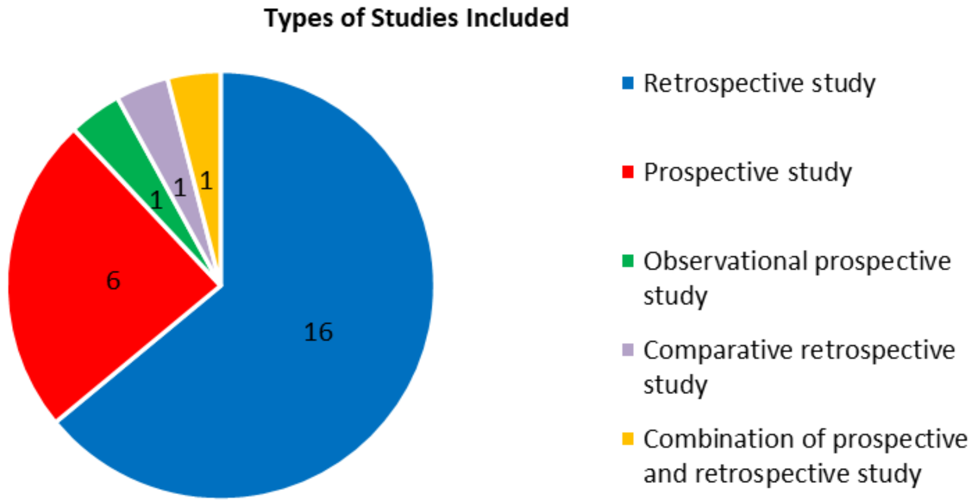

Fig. 2. Characteristics of studies included

Table 1
The aim and the design of studies included in this descriptive analysis

Authors	Year	Sample Size	Study Design and Aim
Khan *et al.,* [9]	2013	78	• Prospective study • To evaluate the effect of reducing tube voltage from 120 to 100 kVp using prospective gating 320 row multi-detector computed tomography angiography on image quality and reduction in radiation dose
Qi *et al.,* [10]	2014	62	• Retrospective study • To compare the image quality and radiation dose of lower extremity CTA at 70 kVp using a dual-source CT system with an integrated circuit detector to similar studies at 120 kVp
Park *et al.,* [11]	2017	30	• Retrospective study • To assess the image quality and radiation dose of non-enhanced brain CT scans acquired at 80 kilo-voltage peak (kVp) compared to those at 120 kVp in children
Fanous *et al.,* [12]	2012	32	• Retrospective study • To compare image quality and radiation dose of pulmonary CT angiography (CTA) performed in the same patient cohort using tube potentials of 100 and 120 kVp
Fang *et al.,* [13]	2016	100	• Prospective, observational study • To evaluate image quality and diagnostic accuracy for acute infarct detection and radiation dose of 70 kVp whole brain CT perfusion (CTP) and CT angiography (CTA) reconstructed from CTP source data.

Maruyama *et al.,* [14]	2020	90	• Retrospective study • To assess the utility of 70 kVp contrast-enhanced computed tomography (CECT) for visualization and identification of the right adrenal vein (RAV) in comparison with that of conventional 120 kVp CECT
Nakaura *et al.,* [15]	2014	157	• Prospective study • To evaluate the radiation dose, image quality, and influence on visual contrast of low tube voltage abdominal computed tomography (CT) and the effects of display setting optimization
Zaehringer *et al.,* [16]	2016	80	• Prospective study • To assess image quality and radiation dose in patients with body weights ≤75 kg undergoing abdominal computed tomography (CT) with a tube voltage of either 120 or 100 kVp
Masuda *et al.,* [17]	2018a	100	• Retrospective study • To compare the radiation dose and diagnostic accuracy on 120- and 100-kVp coronary computed tomography angiography (CCTA) scans whose contrast-to-noise ratio (CNR) was the same.
Chang *et al.,* [18]	2013	63	• Retrospective study • To assess the effect of a decrease in tube voltage from 120 kVp to 100 kVp on dose, contrast-to-noise ratio (CNR), three-dimensional (3D) image quality in patients undergoing computed tomographic (CT) colonography and to determine how these changes are affected by patient size.
Masuda *et al.,* [19]	2019	116	• Retrospective study • To compare the diagnostic performance of 100- and 120-kVp coronary computed tomography angiography (CCTA) scans for the identification of coronary plaque components.
Masuda *et al.,* [20]	2021	140	• Retrospective study • To compare the radiation dose, diagnostic accuracy, and the resultant ablation procedures • using 80 and 120-kVp cardiac computed tomography angiography (CCTA) protocols with the same contrast-to-noise ratio in patients scheduled for atrial fibrillation (AF) ablation
Park *et al.,* [21]	2009	185	• Retrospective study • To assess the feasibility of performing 100-kVp electrocardiogram (ECG)-gated coronary CT angiography, as compared to 120-kVp ECG-gated coronary CT angiography.
Hu *et al.,* [22]	2014	89	• Prospective study • To assess image quality and radiation dose of multidetector computed tomography (CT) examination using a standard protocol and a low-voltage protocol.
Feuchtner *et al.,* [23]	2010	103	• Retrospective comparative study • To evaluate a 100-kilovoltage (kV) tube voltage protocol regarding radiation dose and image quality, in comparison with the standard 120 kV setting in cardiac computed tomography angiography (CCTA).
Masuda *et al.,* [24]	2018b	100	• Retrospective and prospective study • To evaluate the radiation dose and image quality at low tube-voltage paediatric chest computed tomographic angiography (CTA) that applies the same contrast-to-noise ratio (CNR) index as the standard tube voltage technique.

Michalakis *et al.,* [25]	2013	247	• Prospective study • To investigate the effect of a two-third reduction of the scanned length (i.e. 10 cm) on diagnosis of both pulmonary embolism (PE) and alternative diseases
Weiss *et al.,* [26]	2017	51	• Retrospective study • To evaluate the effect of reduced z-axis scan coverage on diagnostic performance and radiation dose of neck CT in patients with suspected cervical abscess.
Shahir *et al.,* [27]	2013	200	• Retrospective study • To determine whether reduced scan range (z axis) computed tomography pulmonary angiography (CTPA) technique in 18- to 40-year age group can accurately detect pulmonary embolism (PE) and other important conditions and to quantify the resulting dose reduction.
Zinsser *et al.,* [28]	2019	90	• Retrospective study • To evaluate a reduced range CT protocol in patients with suspected acute appendicitis as compared to standard abdominal CT regarding diagnostic performance, effective radiation dose and organ doses.
Badawy *et al.,* [29]	2018	102	• Retrospective study • To assess the incidence, length of overscan and radiation dose in the pre-awareness period, to present data as to the extent of this issue at a large tertiary hospital
Leschka *et al.,* [30]	2010	125	• Prospective study • To prospectively investigate the effect of adjusting the scan length of CT coronary angiography using the calcium scoring images instead of the scout view with regard to radiation dose.
Shahir *et al.,* [31]	2015	36	• Retrospective study • To determine the feasibility of using reduced scan range CT pulmonary angiography technique in pregnancy for pulmonary embolism (PE) and to quantify resulting dose reduction
Dowhanik *et al.,* [32]	2021	531	• Retrospective study • To compare the diagnostic performance and radiation dose of reduced vs. standard scan range CT in diagnosing appendicitis.
Corwin *et al.,* [33]	2014	235	• Retrospective study • To determine the accuracy and radiation dose reduction of a limited abdominopelvic CT from the bottom of T10 to the top of the pubic symphysis in patients with suspected acute appendicitis.

3.3 Risk of Bias Assessment

The results of the risk of bias assessment are compiled into a “traffic light” plot, demonstrated in Figure 3. There are 10 studies that has low risk of bias overall as no evaluated domains demonstrate concerns of bias, whereas 15 studies demonstrated some concern of bias overall due to having one or two evaluated domains demonstrating some concerns of bias. There is no bias identified for the domain 3, a domain that discerns bias due to missing data; domain 2, a domain that discerns bias due to deviation from intended intervention; and domain 5, a domain that discerns bias in selection of the reported results. Some concerns for bias are frequently encountered in domain 1, domain that identify bias from randomization process and domain 4, domain that describes bias in measurement of outcome.

Risk of bias domains

Study	D1	D2	D3	D4	D5	Overall
Khan et al., 2013	-	+	+	+	+	-
Qi et al., 2014	+	+	+	+	+	+
Park et al., 2017	+	+	+	+	+	+
Fanous et al., 2013	-	+	+	-	+	-
Fang et al., 2016	+	+	+	-	+	-
Maruyama et al., 2020	+	+	+	+	+	+
Nakaura et al., 2014	+	+	+	+	+	+
Zaehringer et al., 2016	+	+	+	+	+	+
Masuda et al., 2018a	-	+	+	-	+	-
Chang et al., 2013	+	+	+	+	+	+
Masuda et al., 2019	-	+	+	-	+	-
Masuda et al., 2021	+	+	+	-	+	-
Park et al. 2009	-	+	+	+	+	-
Hu et al., 2014	+	+	+	+	+	+
Feuchtner et al., 2010	-	+	+	-	+	-
Masuda et al., 2018b	+	+	+	-	+	-
Michalakis et al., 2013	-	+	+	+	+	-
Weiss et al., 2017	+	+	+	-	+	-
Shahir et al., 2013	+	+	+	-	+	-
Zinsser et al., 2019	+	+	+	-	+	-
Badawy et al., 2018	+	+	+	+	+	+
Leschka et al., 2010	+	+	+	-	+	-
Shahir et al., 2015	+	+	+	+	+	+
Dowhanik et al., 2021	-	+	+	+	+	-
Corwin et al., 2014	+	+	+	+	+	+

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
- Some concern
+ Low

Fig. 3. Overall risk of bias for included studies

3.4 Radiation Dose Reduction Result by Reduction of Tube Potential

There are 16 of the totals of 25 studies reduced the radiation dose by adjusting lower tube potential. The protocol of the studies included for this parameter include five studies of coronary CT angiography, three studies of CT abdomen, one studies of electrocardiogram-gated (ECG) coronary CT angiography, CT angiography of lower extremity, CT pulmonary angiography, CT brain, CT brain perfusion, CT colonoscopy, CT thorax and contrast enhanced CT venous sampling each respectively (refer to Figure 4 and Table 2).

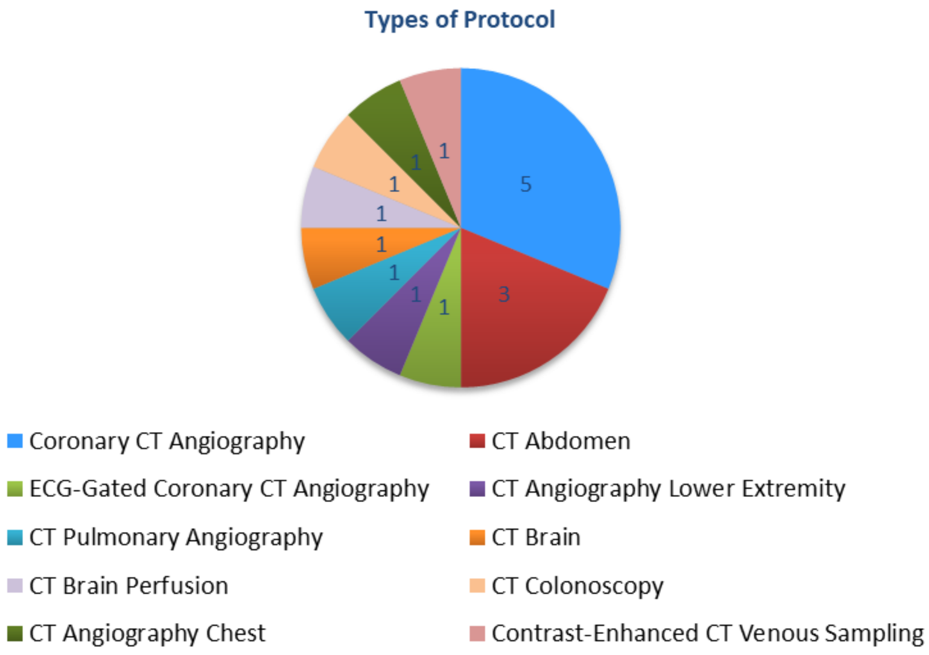

Fig. 4. Types of protocols of the studies for tube potential reduction

Table 2
Study protocol for tube potential reduction

Authors	Year	Study Protocol
Khan *et al.,* [9]	2013	Coronary CT Angiography
Qi *et al.,* [10]	2014	CT Angiography Lower Extremity
Park *et al.,* [11]	2017	CT Brain
Fanous *et al.,* [12]	2012	CT Pulmonary Angiography
Fang *et al.,* [13]	2016	CT Brain Perfusion
Maruyama *et al.,* [14]	2020	Contrast Enhanced CT Venous Sampling
Nakaura *et al.,* [15]	2014	CT Abdomen
Zaehringer *et al.,* [16]	2016	CT Abdomen
Masuda *et al.,* [17]	2018a	Coronary CT Angiography
Chang *et al.,* [18]	2013	CT Colonography
Masuda *et al.,* [19]	2019	Coronary CT Angiography
Masuda *et al.,* [20]	2021	Coronary CT Angiography
Park *et al.,* [21]	2009	Coronary CT Angiography
Hu *et al.,* [22]	2014	CT Abdomen
Feuchtner *et al.,* [23]	2010	Electro-Cardiogram (ECG) Gated Coronary CT Angiography
Masuda *et al.,* [24]	2018b	CT Angiography Chest

The protocols and modality of CT machines used for each study were identified and compiled into Table 3. For the standard tube potential protocol for in each study, the kVp (kilovoltage peak) was represented as “g1”, whereas the reduced tube potential protocol was represented as “g2”.

The mean CTDI$_{vol}$, mean DLP, mean SSDE (if applicable), mean effective dose and dose reduction percentage is analysed and compiled into Table 4. There is one study by Nakaura *et al.,* [15] that included three groups of results. For this study, the protocols were labelled “g1”, “g2” and “g3”. Only the highest dose reduction percentage from the three groups is obtained. The dose reduction percentage is calculated by using the effective doses for each parameter. For the studies by Maruyama *et al.,* [14] and Zaehringer *et al.,* [16] the percentage of reduction for SSDE is obtained instead of effective dose. The dose reduction percentage ranges from 6.5% to 63%.

Table 3
Characteristics of study for radiation dose reduction by kVp reduction

Authors	Year	Modality of CT Machine Used	Kilovoltage peak (kVp) Used
Khan *et al.,* [9]	2013	320-row scanner (Aquilion ONE, Toshiba, Tokyo, Japan).	g1: 120 g2: 100
Qi *et al.,* [10]	2014	• 120kvp: first generation dual-source CT (Somatom Definition; Siemens Medical Solutions, Erlangen, Germany) • 70kvp: second generation dual-source CT system with an integrated circuit detector (Definition Flash, Siemens Medical Solutions, Forchheim, Germany)	g1: 120 g2: 70
Park *et al.,* [11]	2017	A 128-slice, second generation dual-source multidetector row CT scanner (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany)	g1: 120 kVp, 220 mAs g2: 80 kVp, 700 mAs
Fanous *et al.,* [12]	2012	64 × 0.5 mm MDCT scanners (Aquilion 64, Toshiba Medical Systems).	g1: 120 g2: 100
Fang *et al.,* [13]	2016	Dual-source CT system (Somatom Definition FLASH, Siemens Healthcare, Forchheim, Germany)	g1: 80 kVp, 100 mAs g2: 70 kVp, 120 mAs
Maruyama *et al.,* [14]	2020	• 120: a 64- or 320- detector-row CT scanner (Aquilion 64 or Aquilion ONE; Canon Medical Systems, Otawara, Japan) • 70: a 192-slice CT scanner (SOMATOM Force; Siemens Healthcare, Forchheim, Germany)	g1: 120 g2: 70
Nakaura *et al.,* [15]	2014	A 256-section MDCT system (Brilliance iCT, Philips Healthcare, Cleveland, OH, USA)	g1: 120 g2: 100 g3: 80
Zaehringer *et al.,* [16]	2016	Two 128- section multidetector-row CT systems (Somatom Definition Flash and Somatom Definition, Siemens, Forchheim, Germany)	g1: 120 kVp, 150 mAs g2: 100 kVp, 180 mAs
Masuda *et al.,* [17]	2018a	A 64-detector row CT scanner (Lightspeed VCT, GE Healthcare, Milwaukee, WI).	g1: 120 g2: 100
Chang *et al.,* [18]	2013	Two 64-detector multidetector CT scanners with identical hardware and software (Lightspeed VCT; GE Healthcare, Milwaukee, Wis)	g1: 120 g2: 100
Masuda *et al.,* [19]	2019	A 64-detector-row CT scanner (Lightspeed VCT; GE Healthcare, Milwaukee, Wis)	g1: 120 g2: 100
Masuda *et al.,* [20]	2021	A 64-slice CT scanner (Lightspeed VCT; GE Healthcare, Milwaukee, WI)	g1: 120 g2: 80
Park *et al.,* [21]	2009	A 16-detector-row scanner (Somatom Sensation 16; Siemens Medical Solutions, Forchheim, Germany).	g1: 120 g2: 100
Hu *et al.,* [22]	2014	A 64-slice CT machine (Somatom Definition AS, Siemens Healthcare) equipped with CARE kV	g1: 120 g2: CARE kV
Feuchtner *et al.,* [23]	2010	A 32 × 0.6 mm detector row multi-slice computed tomography system and z-flying focus techniques with 64 × 0.6 mm slice acquisition, 0.33 s rotation time (Sensation 64TM, Siemens) and a pitch of 0.2.	g1: 120 g2: 100
Masuda *et al.,* [24]	2018b	A 64 detector-row CT scanner (Lightspeed VCT; GE Healthcare, Milwaukee, WI).	g1: 120 g2: 80

Table 4
Results of radiation dose by reducing tube potential

Authors	Year	Mean $CTDI_{vol}$ (mGy)	Mean DLP (mGy·cm)	Mean SSDE (mGy)	Mean Effective Dose (mSv)	Dose Reduction Percentage (%)
Khan *et al.,* [9]	2013	• g1: 1.43 • g2: 0.99	• g1: 214.98 • g2: 150.20	Not Applicable	• g1: 5.31 • g2: 3.71	30
Qi *et al.,* [10]	2014	• g1: 3.8 • g2: 2.4	• g1: 412.4 • g2: 264.5	Not Applicable	• g1: 3.8 • g2: 2.4	36
Park *et al.,* [11]	2017	• g1: 24.7 • g2: 23.6	• g1: 479.8 • g2: 448.9	Not Applicable	• g1: 1.31 • g2: 1.23	6.5
Fanous *et al.,* [12]	2012	• g1: 19.9 • g2: 12.5	• g1: 604.46 g2: 379.26	Not Applicable	• g1: 15.84 • g2: 9.94	37
Fang *et al.,* [13]	2016	• g1: 55.5 • g2: 44.7	• g1: 859 • g2: 616	Not Applicable	• g1: 1.80 • g2: 1.29	28
Maruyama *et al.,* [14]	2020	• g1: 21.3 • g2: 12.5	• g1: 737.5 • g2: 424.1	• g1: 28.6 • g2: 15.9	Not Applicable	44
Nakaura *et al.,* [15]	2014	• g1: 17.9 • g2: 14.1 • g3: 11.4	• g1: 905.2 • g2: 705.0 • g3: 572.6	Not Applicable	• g1: 13.6 • g2: 10.6 • g3: 8.6	37
Zaehringer *et al.,* [16]	2016	• g1: 16.9 • g2: 15.3	• g1: 414.4 • g2: 347.4	• g1: 12.1 • g2: 9.8	• g1: 10.2 • g2: 7.4	19
Masuda *et al.,* [17]	2018a	Not Applicable	• g1: 603.4 • g2: 897.0	Not Applicable	• g1: 24.67 • g2: 16.59	33
Chang *et al.,* [18]	2013	• g1: 5.3 • g2: 4.1	• g1: 239 • g2: 197	Not Applicable	• g1: 3.59 • g2: 2.96	18
Masuda *et al.,* [19]	2019	Not Applicable	• g1: 819.1 • g2: 563.7	Not Applicable	• g1: 22.53 • g2: 15.50	31
Masuda *et al.,* [20]	2021	• g1: 52.88 • g2: 22.82	• g1: 1269.0 • g2: 559.0	Not Applicable	• g1: 34.90 • g2: 15.38	56
Park *et al.,* [21]	2009	• g1: 38.75 • g2: 30.50	• g1: 594.3 • g2: 456.4	Not Applicable	• g1: 10.1 • g2: 7.8	24
Hu *et al.,* [22]	2014	• g1: 11.2 • g2: 9.6	• g1: 497.9 • g2: 411.4	Not Applicable	• g1: 7.5 • g2: 6.2	17
Feuchtner *et al.,* [23]	2010	• g1: 47.2 • g2: 25.6	• g1: 785.8 • g2: 419.8	Not Applicable	• g1: 13.4 • g2: 7.1	47
Masuda *et al.,* [24]	2018b	• g1: 1.2 • g2: 0.5	• g1: 20.8 • g2: 7.8	Not Applicable	• g1: 0.57 • g2: 0.21	63

3.5 Radiation Dose Reduction Result by Reduction of Scan Range

There are nine out of the total 25 studies included in this parameter utilized two CT machines to modify the scan range. The type of protocols of the studies included are three CT pulmonary angiography, three CT abdomen pelvis, two CT neck and one coronary CT angiography, as shown in Figure 5 and Table 5.

The protocols and modality of CT machines used for each study were identified and compiled into Table 6. The term “S” was used to represent the standard scan range protocol whereas the term for reduced scan range protocol was represented as “R”.

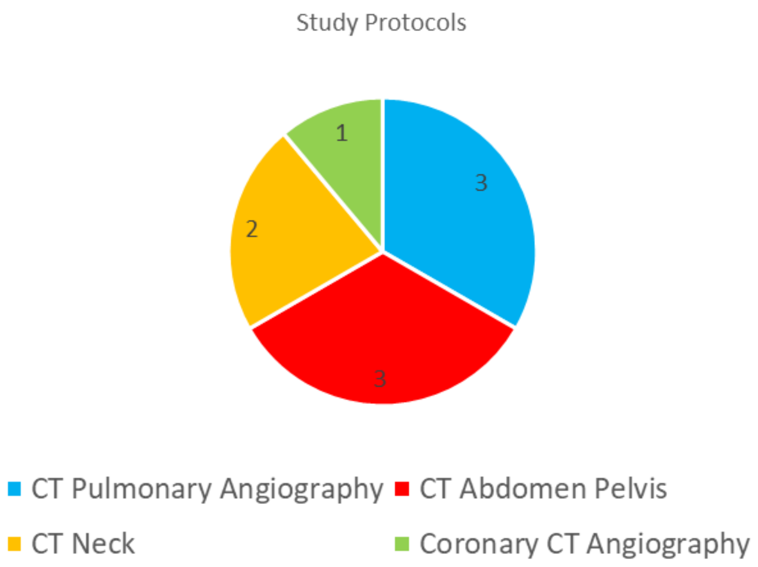

Fig. 5. Protocols for scan range reduction studies

Table 5
Study protocol for scan range reduction

Authors	Year	Study Protocol
Michalakis *et al.,* [25]	2013	CT Pulmonary Angiography
Weiss *et al.,* [26]	2017	CT Neck
Shahir *et al.,* [27]	2013	CT Pulmonary Angiography
Zinsser *et al.,* [28]	2019	CT Abdomen Pelvis
Badawy *et al.,* [29]	2018	CT Neck
Leschka *et al.,* [30]	2010	Coronary CT Angiography
Shahir *et al.,* [31]	2015	CT Pulmonary Angiography
Dowhanik *et al.,* [32]	2021	CT Abdomen Pelvis
Corwin *et al.,* [33]	2014	CT Abdomen Pelvis

Table 6
Characteristics of study for radiation dose reduction by scan range reduction

Authors	Year	Modality of Machine Used	Scan Range
Michalakis *et al.,* [25]	2013	• 16-section MDCT scanner (Sensation 16; Siemens Healthcare, Forchheim, Germany) • 64- section MDCT scanners (Sensation 64, respectively; Siemens Healthcare, Forchheim, Germany)	• S: Entire thorax • R: From the bottom of the aortic arch to 10 cm more caudally
Weiss *et al.,* [26]	2017	• 2nd generation dual-source CT system (Somatom Flash, Siemens Healthineers, Forchheim, Germany) • 3rd generation dual-source CT system (Somatom Force, Siemens Healthineers, Forchheim, Germany)	• S: Aortic arch and included the frontal sinuses completely • R: Starting at the aortic arch but terminating just below the orbital floor
Shahir *et al.,* [27]	2013	• 16-row multidetector CT system (Lightspeed Xtra; GE Healthcare, Waukesha, Wis) • 64-row multidetector CT system (Lightspeed VCT; GE Healthcare)	• S: Extending from the level of the lung apex (frontal scout) to the level just at the posterior

			costophrenic angle (lateral scout) • R: From the top of the aortic arch and below the level of the heart using the scout image and reference lines
Zinsser *et al.,* [28]	2019	• Two dual-energy (SOMATOM Force and SOMATOM Definition Flash) • Two single-energy scanners (SOMATOM Sensation 64 and SOMATOM Definition AS+, all Siemens Healthineers, Forchheim, Germany).	• S: Soft body convolution kernel • R: Superior endplate of L1 to inferior edge of symphysis pubis
Badawy *et al.,* [29]	2018	• GE VCT • Two GE Revolution Evo • Toshiba Aquilion Prime	• p1: Precampaign overscan length • p2: Post-campaign overscan length • p3: Post 1-month overscan length
Leschka *et al.,* [30]	2010	A dual-source CT scanner (Somatom Definition, Siemens Healthcare)	• S: CT Coronary Angiography Using the Calcium Scoring– Derived Scan Length • R: CT Coronary Angiography Using the Scout View–Derived Scan Length
Shahir *et al.,* [31]	2015	• 16-row multidetector CT system (Light speed Xtra, GE health care) • 64-row multidetector CT system (Light speed VCT, GE healthcare)	• S: Level of the lung apex (frontal scout) to the level just at the posterior • Costophrenic angle (lateral scout) • R: Top of the aortic arch and below the level of the heart
Dowhanik *et al.,* [32]	2021	• Siemens SOMATOM Definition Flash • Sensation 64 scanners (Siemens Healthineers)	• S: The top of the diaphragm (including the lung bases) to the ischial tuberosities • R: Upper L2 vertebral body to the upper border of the symphysis pubis.
Corwin *et al.,* [33]	2014	Two GE 64-detector row scanners (VCT, GE Medical Systems, Milwaukee, WI).	• S: From top of diaphragm to bony ischium • R: Bottom of T10 to top of symphysis pubis

The mean $CTDI_{vol}$, mean DLP, mean SSDE (if applicable), mean effective dose and dose reduction percentage for this parameter is described as in Table 7. The study groups for the study by Badawy *et al.,* [29] were categorized into “p1”, “p2” and “p3”. All of the dose reduction percentage is obtained by calculating the difference between effective dose of the control and intervention group. The highest percentage is 71%, while the lowest is 11%. The reduced scan range protocol should cover at least the anatomy of interest.

Table 7
Results of radiation dose by reducing scan range

Authors	Year	Mean $CTDI_{vol}$ (mGy)	Mean DLP (mGy·cm)	Mean SSDE (mGy)	Mean Effective Dose (mSv)	Dose Reduction Percentage (%)
Michalakis *et al.,* [25]	2013	• S: 5.2 • R: Not Applicable	• S: 167.3 • R: 52.0	Not Applicable	• S: 2.8 • R: 0.9	69
Weiss *et al.,* [26]	2017	Not Applicable	• S: 397.4 • R: 309.4	Not Applicable	• S: 3.9 • R: 3.5	11
Shahir *et al.,* [27]	2013	Not Applicable	• S: 557 • R: 172	Not Applicable	• S: 15.32 • R: 4.73	69
Zinsser *et al.,* [28]	2019	Not Applicable	• S: 493.33 • R: 300.00	Not Applicable	• S: 7.4 • R: 4.5	39
Badawy *et al.,* [29]	2018	• p1: 16 • p2: 16 • p3: 14	• p1: 474 • p2: 392 • p3: 374	Not Applicable	• p1: 2.8 • p2: 2.3 • p3: 2.2	20
Leschka *et al.,* [30]	2010	• S: 45.3 • R: 45.5	• S: 629 • R: 531	Not Applicable	• S: 10.7 • R: 9.0	16
Shahir *et al.,* [31]	2015	Not Applicable	• S: 490 • R: 142	Not Applicable	• S: 8.33 • R: 2.41	71
Dowhanik *et al.,* [32]	2021	Not Applicable	• S: 633 • R: 363	Not Applicable	• S: 9.50 • R: 5.45	43
Corwin *et al.,* [33]	2014	Not Applicable	• S: 786.67 • R: 606.67	Not Applicable	• S: 11.8 • R: 9.1	23

4. Discussion

4.1 Radiation Dose Reduction by Reducing Tube Potential

All of the studies included has demonstrated a decrease in radiation dose after applying lower tube potential when compared to the original tube potential used in the control group [9-24]. A 10 kVp decrease in tube potential resulted in a 28% decrease in the patient’s radiation dose, as demonstrated in the study by Fang *et al.,* [13]. When the tube potential is reduced by 20 kVp, the dose was reduced for 18% to 47%. For a decrease of 40 kVp in tube potential, the greatest reduction in radiation dose was identified, with a reduction of 6.5%, 56% and 63% respectively by Park *et al.,* (2017) [11] and two studies by Masuda *et al.,* [20,24]. However, greater reduction in tube potential did not necessarily produce a greater reduction in radiation dose. Qi *et al.,* [10] and Maruyama *et al.,* [14] only achieved 36% and 44% decreased dose respectively while implementing a protocol that reduces tube potential from 120 kVp to 70 kVp, which was lower than that achieved by the 120-80 kVp protocol. Overall, greater dose reduction is shown by protocols involving CT angiography, this because imaging of the blood vessels involves higher radiation dose, as concurred by Smith-Bindman *et al.,* [34].

One of the studies which is conducted by Hu *et al.,* [22] utilized CARE kV as the intervention group, producing a dose reduction of 17%. CARE kV is a feature that is automatically implemented to apply individual tube potential to each particular patient by taking into consideration the patient's size and length. In this study, CARE kV automatically applied 100 kVp for 45 patients and 80 kVp for five patients. For the tube current, it was automatically modulated by CARE Dose 4D, which is an automatic exposure control that selects tube current base on size of the patient [35].

Some of the studies included for tube potential reduction did not include the effective dose for both the control group and intervention group. Thus, the missing effective dose is manually calculated by the author by using the age specific k-factor published by published by International Commission on Radiological Protection (ICRP) [36]. However, Lyra *et al.,* [37] stated that if the SSDE for both groups are present, it was preferred over effective dose due to the fact that effective dose is highly dependent on phantoms that are standardized and has limited ability to properly identify the dose that are irradiated by the patient individually, whereas SSDE estimates the dose received by the patient by taking account of the parameters that has been input and the patient's specific dimension but ignoring the factors for weighing organ or tissue.

14 out of 16 of the studies included for this parameter provided a comparison of the image quality in terms of image noise. Most of the 14 studies demonstrated that the lower kVp protocol produces images with greater noise compared to higher kVp protocol, only one study has showed no significant difference in image noise [11]. However, the study by Maruyama *et al.,* [14] ruled out two sample due to unclear image of anatomy of interest caused by technical malfunction, leading to failure of catheterization. For signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), each study produced varies result due to differences in scanning parameters and machine.

The image noise is directly associated with tube potential. According to a similar study performed by Karmazyn *et al.,* [38] when kVp decreases, the radiation dose reduces but the noise increases in relation to the increasing size of phantom. Thus, to maintain the image quality without increasing noise level, two of the studies included in this review implemented automatic tube current modulation programme while three other studies calculated the tube current required based on the patient size. However, this may inadvertently contribute to patient's received radiation dose.

Moreover, only one out of the related 16 studies voided the use of contrast medium [11]. Mazloumi *et al.,* [39] confirmed that the use of contrast medium in a study contributes to the increase in radiation dose of the organ with the effect increases as the volume of contrast increases. In addition to that, four studies applied iterative reconstruction algorithms, which reduces the noise in images and increases the image resolution via reducing the artefacts and conserving the edges, leading to reduced tube potential and tube current [40]. These parameters have shown to reduce the radiation dose. Thus, the effective dose of these studies may not actually represent the actual absorbed dose by the patient.

4.1.1 Radiation dose reduction via tube potential reduction from 120 kVp to 100 kVp and 80 kVp

In the study by Nakaura *et al.,* [15] a comparison of the patient radiation dose was done between three different tube potential, which are 120 kVp, 100 kVp and 80 kVp. The overall reduction of dose is 37%. The mean SNR produced by the images in 80 kVp scan is similar to those of 120 kVp. This is because photoelectric effect had increased due to low tube potential, leading to better contrast of image compensating the noise produced in the image. However, significant difference in the SNR of fat, muscle and kidney in 80 kVp compared to 120 kVp can be observed. On the other hand, 100 kVp protocol had produced scans with increased attenuation of iodine compared to 80 kVp while similar image contrast can be seen as images from 120 kVp. This leads to authors believing that 100 kVp is the viable option for reduced tube potential protocols due to changes of contrast in visual unrelated to poor quality of image and is unfamiliarized by the radiologists in 80 kVp compared to 120 kVp and 100 kVp.

4.2 Radiation Dose Reduction by Reducing Scan Range

There are nine studies included that is related the reduction of scan range protocol and the respective dose has been determined [25-33]. All of these studies either employed a standard scan range that either follows the worldwide or institute protocol and a reduced scan range that covers the superior and inferior border of the anatomy of interest; or achieved the reduced scan range protocol by reconstructing the standard scan range image using reconstruction kernels.

Only six studies recorded the mean reduction of scan range [25-27,29,31,33]. Michalakis *et al.,* [25] achieved a dose reduction of 69% when the scan range was reduced from the including the entire thorax to including the bottom of the arch of aorta to 10 cm caudally with mean reduction of roughly one third of the scan length (296 ± 80 mm to 100 mm). Weiss *et al.,* [26] has a mean scan range reduction of 24%, but only achieving 11% in dose reduction, which is the lowest among the studies included. A 42.6% of mean scan range reduction resulted in a 69% decrease in patient dose Shahir *et al.,* [27]. Another study by Shahir *et al.,* [31] demonstrated the highest reduction in radiation dose (71%) but also achieving the same mean of scan range reduction (42.6%). Corvin *et al.,* [33] achieved the same in mean scan range reduction (24%) as Weiss *et al.,* [26] but produced a greater reduction in radiation dose, with a percentage of 23%. Similar to dose reduction via reducing tube potential, the type of CT protocol used plays a crucial role in affecting the amount of dose reduced, with CT pulmonary angiography, which is a vascular imaging procedure, showing better reduction in dose than other protocols used due to the high exposure required.

Missed diagnosis of disease has been observed in some of these studies. All of the studies have no missed findings of pertinent disease. Four of the studies reported missed findings of incidental or complementary disease [25,28,31,33]. The study by Michalakis *et al.,* [25] demonstrated inaccurate classification of the pulmonary embolism due to localization of clot outside the reduced scan range. Another two studies resulted in poor organ visualization due to organ not full included in the reduced scan range and one of them reported cases of patient's anatomy located above the superior border of the original scan range [30,33].

The patients' body mass index (BMI) contributes to the total patient absorbed dose, especially in protocol involving abdomen pelvis. Three of the included studies used CT abdomen pelvis protocol to rule in appendicitis but only one of the studies had taken patients weight into account [28,32,33]. Chan *et al.,* [41] found out that the effective dose will increase by 1.95 mSv for when the BMI has 5 kg/m^2 increase, which is further supported by a study done by Panakkal *et al.,* [42] that obese patients with greater circumference of abdomen and BMI will have greater effective dose. In addition to that, fat in obese patient may decrease image quality, leading to the necessity of increased parameters in comparison to patients with low BMI [43].

While patient undergoes a reduced scan range procedure, the organ of interest will be focused on. Thus, the specific dose received by the organ must be taken into account. However, each organ has different radiosensitivity and the absorption of radiation differs between organs. Principi *et al.,* [44] conducted a similar study and concluded that effect of dose reduction for organs varies due to their sensitivity to radiation, indicating that doses should be calculated based on tissues irradiated. Thus, SSDE is more preferrable to measure the radiation dose reduction for scan range reduction protocol as it provides better correlation with specific organ dose, as concluded by Moore and Brady [45].

4.2.1 Radiation dose reduction by reducing scan range for three groups

The study conducted by Badawy *et al.,* [29] implemented a different method of reducing the scan range. They retrospectively obtained and compared the over-scanned images of CT performed on three different phases where the first phase was obtained before a talk regarding the awareness of reducing patient's radiation dose, the second phase obtained one month after the talk and the third phase obtained one year after the talk. The average scan length of the three phases were reduced by 33%, causing the effective dose to be reduced by 20%. The occurrence of over-scanning has reduced from 58% in the first phase to 27% in the third phase. This has proved to be an effective way reducing patient radiation dose via scan range reduction.

4.3 Limitations of Study

There are some limitations identified in this study. Firstly, this systematic review has a small sample size and meta-analysis was not done, leading to emergence of potential bias. Secondly, a number of studies included conducted their research on patients with different body habitus. This is because when the patient's Body Mass Index (BMI) increases, the penetration ability of x-ray reduces, thus greater parameter is required and more patient radiation dose. Thirdly, manual tube current adjustment and automatic tube current modulation was implemented in a number of studies included to ensure that the image quality produced is suitable for use in diagnosis of disease, thus it leads to contribution of the total dose irradiated by the patient. The use of contrast medium and iterative reconstruction algorithms must also be taken into consideration. Another notable limitation that should be taken note is that all of the studies used machines manufactured by different companies, so the parameter settings for each machine will not be the same compared to others. Furthermore, the diagnostic accuracy for each protocol is not evaluated as this study aims to determine the effect of reducing parameters on dose reduction. Lastly, the effective dose for the protocols may not accurately describe the actual dose received by the patient compared to SSDE as the conversion factor (k-factor) for the organ may not be correctly represented.

4.4 Recommendation

Larger sample size can be acquired by widening the duration for study selection. Studies involving radiation dose should strive to obtain patients with similar BMI. Tube current is recommended to be manually set constantly for both normal kVp protocol and reduced kVp protocol to better identify the effectiveness of reducing tube potential in radiation dose reduction, with the same can be applied to contrast medium usage and iterative reconstruction algorithms. For CT modality, a single machine from the same seller should be used throughout the study. Finally, SSDE, which can be calculated via the usage of software, can be used instead of effective dose for better representation of radiation dose received by patient and calculation error can be prevented.

5. Conclusions

The efficiency of tube potential reduction and optimised scan range in lowering radiation doses in CT has been shown by this systematic review. Reducing the tube potential is a critical parameter for radiation dose optimisation because low tube potentials can be used to achieve significant dose reductions without sacrificing image quality. Besides, dose reduction can also be aided by carefully restricting the scan range to regions of clinical interest. This approach reduces needless exposure and is advantageous for multiple scans when cumulative radiation dose is an issue but care should be exercised to prevent anatomy of interest is excluded from the scan range. Angiography protocols demonstrated the greatest dose reduction in both parameters as angiography procedures implements high exposures. More studies are required to determine the applicability of implementing both protocols in future clinical practices.

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