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EVALUATION OF EFFECTIVENSS OF COMPUTED TOMOGRAPHY (CT) DOSE REDUCTION STRATEGIES

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ABSTRACT

With the development of science and technology, the advent of computed tomography (CT) in 1970s was a milestone of medical imaging. Its use in the medical field has increased dramatically. In spite of great advances of CT in medical field, however, some attention is required to avoid imposing high risks associated with the ionizing radiation on patients during CT procedures, such as radiation induced cancer because greater radiation dose is used in CT in comparison to most of the radiological examinations. In addition of that early reports of MDCT indicated higher doses delivered to patients when comparing to traditional CT. However, comparable or reduced patient doses will be achieved if dose reduction strategies such as optimizing settings used in traditional CT are applied. The objective of this review is to evaluate the different CT radiation dose reduction strategies leading to identification of the most effective strategy suitable for clinical utilization. In this study 83 articles were collected in the literature search and four common dose reduction strategies including manipulations of kVp, mAs and pitch and shielding were identified. The results indicates that Shielding technique has the highest overall mean of 53% while the pitch manipulation has the lowest value (39%). However, all ANOVA p-values are greater than 0.05 and hence no statistically significant difference was noted among the mean performances of dose reduction techniques.

Keywords: Computed tomography, dose reduction strategy, kVp, mAs, pitch, shielding.

INTRODUCTION

Globally advancement in scanner technology have established computed tomography (CT) as an reliable tool for the quick assessment of human coronary circulation, cardiac anatomy and the great vessels (Hedgire *et al*., 2017). The advent of computed tomography in 1970s was a milestone of medical imaging. Its use in the medical field has increased dramatically. It is reported that more than 62 million CT scans are undertaken in United States each year (Baskerville, 2008; Boone *et al*., 2003). The main advantages of CT are the abilities to provide sectional images but with better resolution and shorter examination time when comparing to other sectional imaging modalities (Brenner and Hall, 2007).

In spite of great advances of CT in medical field, however, some attention is required to avoid imposing high risks associated with the ionizing radiation on patients during CT procedures, such as radiation induced cancer because greater radiation dose is used in CT in comparison to most of the radiological examinations. In CT scans of the chest, for instance, a patient would be exposed by about 100 times the exposure amount of radiation in general radiography examination of the same body part and hence increasing the risk of cancer development (Baskerville, 2008). Sometime computed tomographic (CT) examinations are the largest cause of medical radiation (Metter *et al*., 2008; Hricak *et al*., 2011).

In addition, with the advances of Multi-Detector CT (MDCT) technology image temporal resolution is higher than traditional CT (Hoffmann, 2006). Despite these outcomes of MDCT, its radiation risk becomes even higher. Early reports of MDCT indicated higher doses delivered to patients when comparing to traditional CT. However, comparable or reduced patient doses will be achieved if dose reduction strategies such as optimizing settings used in traditional CT are applied (Valentin, 2007).

The settings that can be optimised include tube current (mA), kilovoltage peak (kVp), collimation, pitch and table speed. If shielding is applied on patient's body part, a higher dose reduction will be obtained. Image quality will be maintained if these parameters are manipulated by medical imaging technologists properly (Yu *et al*., 2009). Yet, the degrees of dose reduction effects contributed by various techniques would be different. For example, tube

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current is linearly related to radiation dose. If the tube current is halved, the radiation dose will halve too. However, a four–fold decrease in radiation dose will happen when kVp is reduced from 140 to 80 kVp. In addition to that by using bismuth material to protect radiosensitive organs such as eye lens, breast and thyroid gland, this will reduce 29 to 57% of radiation dose (Paterson and Frush, 2007).

Although there are different dose reduction approaches available, the extents of the reduction may be different (Kalra *et al*., 2004). The computed tomography dose index (CTDI) is one of the main radiation dose descriptors in CT scans (Table 1). It is defined as the dose absorbed expressed in gray (Gy), i.e., joule per kilogram (J/kg) by a standard cylindrical acrylic phantom for one 360° rotation of the X-ray tube. The CTDI varies across the image plane and is higher at the periphery than in the centre. Therefore a weighted CT dose index ($CTDI_w$) was introduced. The relative areas of the centre and the periphery are approximated by one third and two thirds (McCollough, 2003). The CTDI value was originally defined for circular scan protocols. For helical scanning, however, the pitch influences the absorbed dose and should be taken into account. The volume CT dose index ($CTDI_{vol}$) was introduced as the weighted CTDI divided by the pitch but this value is independent of the scan length. Therefore, dose-length product (DLP) is often used. It multiplies the $CTDI_{vol}$ with the scan length. Although the DLP is a better indication of the biological effect of radiation for a particular examination than the $CTDI_{vol}$, still the radiation sensitivities of different organs are not considered. This gap can be filled by the use of effective dose (Crawley *et al*., 2001).

Since the degrees of dose reduction effects contributed by various techniques would be different, it is important to investigate this issue by studying the radiation doses expressed in different parameters obtained from these interventions. It will reveal to medical imaging technologists and radiologists the best options available for CT radiation dose reduction, while to medical practitioners it will highlight the possibilities of reducing the amount of radiation exposed to patient. This would in turn reduce the examination risks associated with radiation and promote CT as a safe and effective tool in medical diagnosis. Moreover, this provides information for CT manufacturers to understand the effectiveness of each strategy and implement relevant functionalities in their scanners to facilitate strategy application. The aim of this review is to evaluate the different CT dose reduction strategies leading to identification of the most effective strategy suitable for human clinical utilization. Moreover, dose reduction figures to compare the figures of dose reduction strategies as a way to evaluate their effectiveness.

METRAILS AND METHODS

A comprehensive literature search was conducted using the several indexing databases of different indexing services including Science Direct, PubMed, Medline and ProQuest databases by using the keywords, ‘Computed Tomography’ and ‘dose reduction strategy’ to identify articles focusing on CT radiation doses obtained from various reduction strategies. Only articles provided the most relevant information in regards to the subject matter and published were selected for the review. Dose reduction figures and associated imaging parameters such as mA, kVp, pitch, table speed and collimation were extracted from the selected articles. The extracted dose reduction figures were then transformed to dose reduction percentages. Mean and standard deviation (SD) of dose reduction percentages were calculated for each technique. Analysis of Variance (ANOVA) was conducted through the use of GraphPad Instat 3 to compare the mean values across different techniques and identify the most effective dose reduction strategy.

RESULTS AND DISCUSSION

US National Council on Radiation Protection and Measurements (2009) indicated that in the United States of America Computed tomography (CT) alone contributes nearly one half of the total radiation exposure from medical use and one quarter of the average radiation exposure per capita.

In this review there were 83 articles collected in the published literature search and four common dose reduction strategies including manipulations of kVp, mAs and pitch and shielding were identified. Their performance of dose reduction was summarized in Table 2. Shielding technique has the highest overall mean of 53% while the pitch manipulation has the lowest value (39%). However, all ANOVA p-values are greater than 0.05 and hence no statistically significant difference was noted among the mean performances of dose reduction techniques. A range of CT dose reduction strategies including manipulations of mA, kVp, collimation, pitch, table speed, gantry rotation time and detector configuration and shielding was noted in the literature (Yu *et al*., 2009). However, only four common techniques including manipulations of kVp, mAs and pitch and shielding for the regions of head, cervical spine (C. spine), chest, abdomen and pelvis were included in the evaluation because the performances of some strategies were only reported in few studies and hence it is insufficient for statistical analysis (Paterson and Frush, 2007). The commonly most sample method to reduce radiation dose is to reduce the tube current (mAs). There is a direct linear relationship between dose and mAs with a proportional decrease in dose with a decrease in tube current (Kevin and Yee, 2013).

Table 1. Computed tomography Dose Index metrics - CTDI. (Source: Huda, 2011).

CTDI Parameter (units)	Measurement method
$CTDI_{100}$ (mGy)	Air kerma measurement made in a 100-mm long ionization chamber
$CTDI_{air}$ (mGy)	CTDI measured free in air at the CT scanner isocenter
$CTDI_p$ (mGy)	CTDI measured at the periphery of any CT dosimetry phantom
$CTDI_c$ (mGy)	CTDI measured at the center of any CT dosimetry phantom
$CTDI_w$ (mGy)	Weighted CTDI that defined as: 1/3 ($CTDI_c$) + 2/3 ($CTDI_p$)
$CTDI_{vol}$ † (mGy)	Equal to $CTDI_w$ divided by pitch
Dose – length product† (mGy-cm)	Product of $CTDI_{vol}$ and the scan length L (cm)

† Metrics displayed on all current clinical CT scanners. c: Center; CTDI: CT dose index; L: Length; p: Periphery; vol: Volume; w: Weighted.

Table 2. Performance of dose reduction techniques for different regions.

Region	Dose Reduction Techniques								
	kVp (n = 25)		**mAs** (n = 25)		**Shielding** (n = 16)		**Pitch** (n = 17)		**P value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Head (n = 22)	34%	7%	48%	16%	48%	5%	47%	4%	0.1421
C Spine (n = 17)	57%	10%	59%	12%	49%	6%	49%	0%	0.4053
Chest (n = 23)	52%	13%	53%	5%	53%	12%	54%	7%	0.9908
Abdomen (n = 16)	43%	9%	57%	23%	-	-	-	-	0.3398
Pelvis (n = 5)	40%	12%	26%	0%	62%	0%	6%	0%	Too few values
Overall	47%	24%	48%	28%	53%	8%	39%	6%	0.4256

It was anticipated that there would be different among the mean values of different strategies. However, all ANOVA p-values were greater than 0.05 representing their performances are similar (Table 2). This result may be due to reasons such as small number of articles collected and article searching approach (Summers *et al*., 2006). As noted in Table 2, the largest number among them is kVp and mAs have the same number while shielding is 16 and the smallest one is pitch 12 resources. Hence, this limited number of articles leads to the area of searching is restricted resulting inability to conduct data analysis properly and eventually impact on the results (Paterson and Frush, 2007).

However, the mean values of different strategies provided some insights of their effectiveness. For example, shielding has the highest overall mean percentage (53%) among other techniques. In the literature review, many studies have proven the importance and significance of this strategy. For instance, shielding considers the simplest and accessible methods to be applied on patient's body part compared to other strategies such as mAs or kVp which are required more knowledge to reduce radiation dose since shielding achieves a higher dose reduction between 40 to 67% of radiation dose (McCollough *et al*., 2009). Moreover, some studies show that shielding has been evaluated for dose reduction in radiosensitive organs such as eye lens and breasts in MDCT where a dose reduction of 42 percent in the eye and 29 percent in the breast has been achievable (Mukundan *et al*., 2007). In addition, a maximum radiation dose reduction of 97% have accomplished with using shielding of double layers (Neeman *et al*., 2006).

On the other hand, pitch has the lowest overall mean percentage (39%) among other methods. In the literature review, many studies have shown that in many systems, MDST scanners, the pitch factor is not selected directly; once the slice collimation and feed per rotation are selected the pitch factor can be calculated, as well as the choice of pitch will depend on the detector array, rotation times and available algorithms for image reconstruction and some scanners will automatically compensate for the increase in pitch by increasing the mA to keep the image noise constant. Furthermore, MSCT scanners the default of pitch is 1 by the manufactures and typically can vary between 0.5 and 2 in the other procedures (Kulama, 2004). A recent study Sulieman *et al*. (2018) conducted in Saudi Arabia reported that mean patient effective doses for CT brain and chest were 1.9 mSv (with a range of 0.6-2.5 mSv) and 7.4 mSv (with a range of 0.5-34.8 mSv) respectively, while the radiogenic risk to patients ranged from between 10^{-5} and 10^{-4} per procedure.

LIMITATIONS

Limitations in this reviews included articles not providing adequate dose information for analysing. These may affect the reliability and validity of the study. ANOVA p-values greater than 0.05 are unexpected findings. However, the obtained dose reduction percentages correlate with figures in the literature suggesting the impact should be minimal. In addition, some useful articles, which have related to the issue are not authorized to access unless providing financial membership, as well as the time factor is limited to cover the entire topic intensely.

RECOMMENDATIONS

Based on the presented results, shielding is the most effective strategy and 53% of radiation dose can be reduced. Previous studies also recommended that using bismuth material to protect radiosensitive organs and this can yield 29 to 57% of radiation dose reduction (Paterson and Frush, 2007). However, for some departments and medical centers, shielding is not accessible. Manipulations of kVp and mAs become the choices as studies reported that mAs and kVp techniques can reduce radiation dose up to 50% (Britten *et al*., 2004). This also matches with the figures presented in this study (kVp: 47% and mAs: 48%). Therefore, this leads the medical imaging technologists and radiologists the best options accessible as well as CT manufacturers to implement relevant functionalities in their scanners to facilitate strategy application to highlight the possibilities of reducing the amount of radiation exposed to patient. However, further research should be conduct to explore the capabilities of other dose reduction strategies not covered in this study such as exploitation of slice thickness, collimation, AEC, gantry rotation time, scanning phases and x-ray beam geometry (Janet *et al*., 2008).

CONCUSION

There are many different MDCT dose reduction strategies available for clinical uses including manipulations of mA, kVp, collimation, pitch, table speed, shielding, gantry rotation time and detector configuration, but commonly using in the clinical practise are kVp, mAs, shielding and pitch in the regions of head, C spine, chest, abdomen and pelvis. The most effective CT dose reduction strategy is shielding which has the highest overall mean percentage (53%) among other methods. We recommend radiologists and technologists always try to use the shielding strategy to reduce the amount of radiation exposed to patient, to promote CT as a safe and effective tool in medical diagnosis.

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