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Impact of Tube Voltage on Radiation Dose (CTDI) and Image Quality at Chest CT Examination

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ABSTRACT

During Computed Tomography (CT) scan examinations, it is important to ensure a good diagnosis by providing the maximum information to detect pathologies and this can be done with a reduced dose. In this respect, several methods of dose reduction have been studied and evaluated. This work investigates the effect of tube voltage while varying the tube current on image quality and radiation dose at Chest CT examination. This study was conducted on HITACHI CT 16 slice Scanner using two phantoms for evaluating the dose and image quality; a PMMA phantom and a CATPHAN 500. Two tube voltages of 120 KVp and 100 KVp have been used for some variation of the tube currents (mAs) and recording the values of the measured quantities (CTDIv, spatial resolution, contrast to noise ratio CNR and noise). The scanning with 100 KVp at Chest CT examination led to a reduction in CTDIv until 45 %, an increase of noise from 17 % to 45 %, and the Spatial Resolution fell slightly (6 and 7 pl/cm) compared to the 120 KVp. The CNR shows a slight regression from 11 to 22 % for the 120 KVp and 100 KVp. This study has shown that despite the increase in the image noise at low tube voltage 100 KVp, it is possible to reduce the radiation dose by up to 45 % without degradation of image quality at Chest CT examination. Further works will evaluate the effect of acquisition parameters in other CT examinations.

INTRODUCTION

Computed tomography (CT) scanning is a diagnostic imaging procedure that uses x-rays to build cross-sectional images of the body. Several studies have been carried out on increasing of the CT scans undergoing on adult patients [1,2]. Nowadays, Morocco has recorded a significant technological evolution in the number of multi-slice CT scanners with more than 360 scanners and several radiology departments [3]. On one hand, these CT scanners have a high diagnostic capacity by reducing unidentified lesions. On the other hand, they provide high doses compared to other conventional radiology devices [4-6]. A single CT scan generates about 100 times or more radiation than a conventional x-ray, or about one year of radiation exposure from natural and artificial sources in the environment [7].

These exposures can lead to the development of radiation-induced cancers over time [8]. According to the ALARA principle, dose optimization is necessary to ensure optimal examination quality with a low dose [9-12]. Although the decrease in tube current (mAs) can reduce the dose, it can also confuse the diagnosis [13]. In this regard, several studies have been conducted to justify that it is possible to decrease mAs while reducing the dose without affecting image quality [14,15].

It is important to ensure high-quality examinations with the lowest possible dose. These conditions depend on the choice of acquisition parameters. A reliable CT diagnosis requires high-quality images with an optimal patient dose [15-18]. Despite the fact that Morocco has a very significant number of CT scanners, the quality assurance system following the recommendations of the IAEA

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and the CPIR has not been implemented [19]; Thus, the lack of prior research in this area prompted us to conduct this research, which aims to study the reduction of patient dose by assessing the influence of CT acquisition parameters that affect image quality.

Although decreasing mAs is the most effective way to reduce the CT radiation dose [20-22], this modification may also reduce image quality and affect diagnosis. Some studies have shown that scanning with a low tube voltage can reduce the dose without affecting image quality [23-25].

Therefore, this study aims to evaluate the effect of decreasing tube voltage (KVp) while varying tube current (mAs), on image noise, contrast to noise ratio (CNR), spatial resolution (SR) and dose (CTDIv) at the Chest CT examination.

MATERIALS AND METHODS

The measurements have been performed on a HITACHI Supria scanner 16-slice, which has been installed in a Moroccan hospital since 2017 with a workload of about 30 patients per day. According to a questionnaire carried out at this hospital during 1 month, the tube voltage of 120 KVp has been set at 85 % of all thoracic examinations done.

In this study, two tube voltages of 120 KVp and 100 KVp have been used while varying the tube currents (mAs). These acquisition parameters are used for scanning through two phantoms evaluating the dose and image quality while recording the measured quantities' values (CTDIv, spatial resolution, contrast to noise ratio (CNR) and noise). These two phantoms were scanned three times for each acquisition parameter with tube currents from 75 to 300 mAs to record a single average value.

The first phantom that evaluates the image quality is the type Catphan 500 (Phantom Laboratory, Salem NY, USA) (Fig 1(a)) [26]. It contains four modules. We have measured the CNR (module CTP515), the noise (module CTP486), and the spatial resolution (module CTP528) [27].

The image noise was the first measured quantity (Fig 1(c)). It is calculated using Eq. (1) [28].

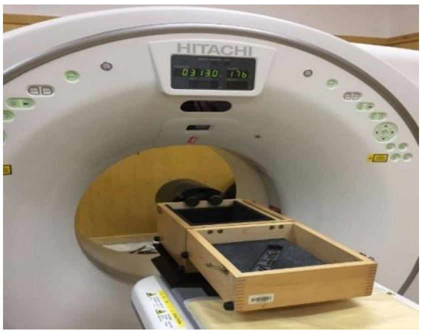
$$B = \frac{\sigma}{NS_{eau} - NS_{air}} \times 100 \quad (\%) \qquad (1)$$

where B (noise), σ (standard deviation), NS_{eau} (number of water scanners), NS_{air} (number of air scanners).

The CNR was the second measured quantity using the image of the CTP515 module as shown in Eq. (2).

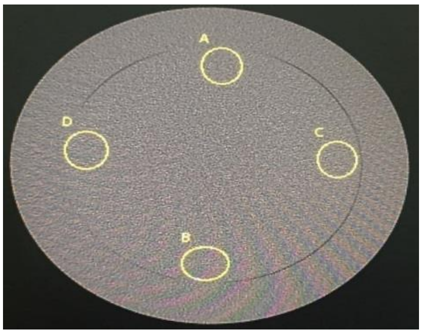
$$CNR = \frac{(nbr\ CT_{int} - nbr\ CT_{ext})}{SD} \qquad (2)$$

where CT_{int} is the CT number inside the circle, CT_{ext} is the CT number outside the circle, and SD is the standard deviation. CNR is calculated for the 15 mm circle, with a 1 % contrast diameter of the CTP515 module's image [28].

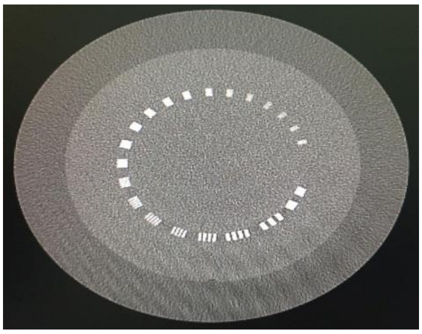


(a)

(b)



(c)



(d)

Fig. 1. (a) Catphan 500 for image quality assessment, (b) PMMA phantom for CTDI measurement of body with a calibrated pencil ionization chamber, (c) ROI's for image noise, (d) Spatial resolution.

The Spatial Resolution (SR) was the last measured quantity (Fig. 1(d)) by counting the number of line pairs per centimeter [29].

The second phantom used to evaluate the dose is of PMMA (Polymethyl-Methacrylate) (Fig .1(b)), with 1.19 g/cm^3 density and contains five holes (center, 3, 6, 9, and 12 hour) [30]. A calibrated pencil ionization chamber (model 10X6-3CT) was also used [31], with an active length of 100 mm, a measurement accuracy of ± 4 %, a dose measurement range of 200nGy-1kGy, an electrometer type of RADCAL CORPORATION (California, USA), and an Accu-Gold+ interface software for displaying the output parameters.

The CTDI$_w$ was calculated according to Eq. (3).

$$CTDI_w = \frac{1}{3}\, CTDI_{100,c} + \frac{2}{3}\, CTDI_{100,p} \text{(mGy)} \quad (3)$$

where CTDI$_w$ is the weighted scanographic dose index; CTDI100, cat the center, and CTDI100, p at the periphery. The CTDIv was calculated by dividing the CTDIw by the factor of the pitch (1.06).

RESULTS AND DISCUSSION

This study focused on the measurement of CTDIv, a good CT index used to estimate radiation dose to patients. This index is a good indicator of comparison between the different acquisition parameters studied.

The CTDIv obtained at each variation of the acquisition parameters are presented in Table 1. The CTDIv reduction rates at 100 KVp versus mAs were approximately 28-45 % of those at 120 KVp. The CTDIv reduction rates at 100 KVp compared to the CTDIv value at 120 KVp and 166 mAs were 63 % at 75 mAs, 59 % at 90 mAs, 57 % at 100 mAs, 55 % at mAs, 46 % at 145 mAs, 43 % at 166 mAs, 29 % at 200 mAs, 23 % at 250 mAs, 6 % at 300 mAs.

Table 1. CTDIv values obtained at each set of acquisition conditions.

Tube current mAs	CTDIv (mGy) 120 KVp	CTDIv (mGy) 100 KVp
75	5.82	3.88
90	6.75	4.39
100	7.70	4.64
115	8.96	4.87
145	9.86	5.81
166	10.70	6.12
200	11.50	7.66
250	12.89	8.32
300	14.09	10.16

The measurements at each scan of the three image quality quantities, including noise, contrast to noise ratio and spatial resolution, are presented in Table 2.

Table 2. Noise, CNR and SR at 120 KVp and 100 KVp.

Tube current mAs	Image noise		CNR		SR	
	120 KVp	100 KVp	120 KVp	100 KVp	120 KVp	100 KVp
75	8.20	9.86	0.76	0.60	6	6
90	7.61	9.08	1.13	0.98	6	6
100	7.36	8.62	1.33	1.12	6	6
115	6.60	7.95	1.41	1.23	7	6
145	5.02	7.12	1.56	1.34	7	6
166	4.85	6.80	1.62	1.45	7	7
200	4.46	6.25	1.70	1.60	7	7
250	4.11	5.96	1.85	1.71	7	7
300	3.69	5.12	1.98	1.80	8	7

The spatial resolution (SR) was evaluated using the CTP528 module of the Catphan. The mean values were measured according to the variation of mAs at 120 KVp and 100 KVp. For the 120 KVp, the values varied between 6 and 8 pl/cm, 6 pl/cm at mAs between (75-100), 7 pl/cm at mAs (115-250) and 8 pl/cm at 300 mAs. For the 100 KVp, the SR has been changed slightly between 6 and 7 pl/cm.

The CNR was evaluated at the 15 mm diameter circle at a contrast of 1 % of the CTP515 module image. It is found that the values of the CNR at 120 KVp tube voltage increase with the increase in mAs, from 0.76 to 1.98. In addition, the rate of change between the parameters of 120 KVp and 100 KVp shows a slight regression from 11 to 22 %.

Figure 2 shows that the image noise was inversely correlated to the mAs. The lowest noise was observed at 120 KVp-300 mAs, and the highest noise was observed at 100 KVp-75 mAs. Compared to the noise obtained with 120 KVp at 145 mAs, the noise obtained with 100 KVp at 75-300 mAs was higher (P <0.001) which is consistent with the results of C. Ludes et al [25].

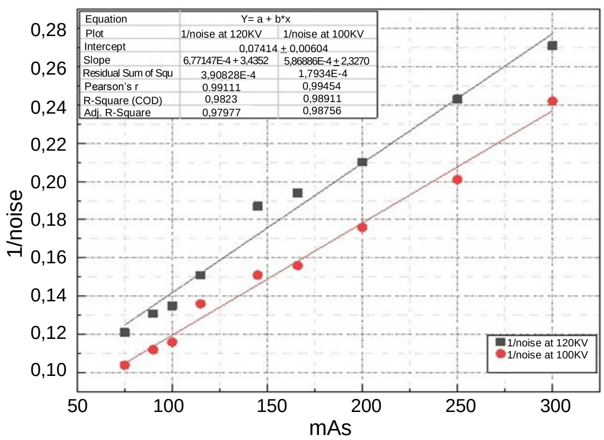


Fig. 2. Correlation between image noise and tube current mAs.

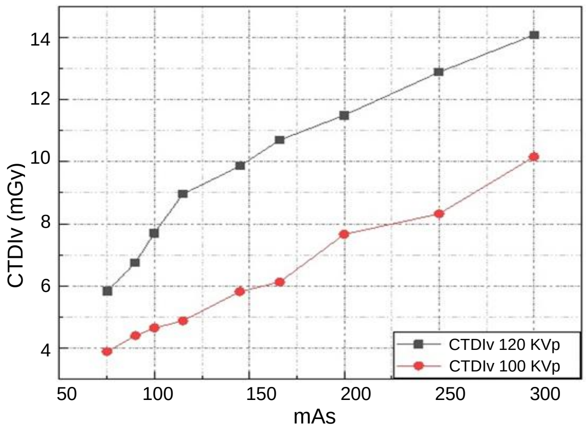


Fig. 3. CTDIv at 120 KVp and 100 KVp.

In this study, we performed several different scans divided into two series, one for different mAs at 120 KVp and the other at 100 KVp while taking into account the image quality degradation.

Scanning with the tube voltage of 100 KVp led to a reduction in CTDIv of 28 to 45 % (Fig. 3) with an increase in noise of 17 to 45 %. This is consistent with the conclusions of Emilio Quaia [32], who concluded that the reduction in KVp allows the dose to be reduced without compromising image quality.

This study showed that scanning with a low tube voltage can reduce the dose without affecting image quality. This is consistent with the findings of Maria Taekker et al [33].

CONCLUSION

Several studies have investigated the reductions in parameters used to acquire CT protocols in several anatomical regions, such as the skull, chest, and abdomen. These studies have shown that reductions in the values of mAs and KVp made it possible to reduce the dose to patients, while preserving an adequate quality of images to establish a reliable diagnosis. The study results to the proposed protocol have shown that despite the increase in image noise at a low tube voltage, it is possible to reduce the radiation dose of patient (CTDIv) by up to 45 % without causing a degradation of CNR and SR.

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AUTHOR CONTRIBUTION

M. El Mansouri, A. Choukri and M. Talbi equally contributed as the main contributors of this paper. O. K. Hakam contributed to analysis of data. All authors read and approved the final version of the paper.

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