Original Article

Abdominal CT radiation dose optimization at Siriraj Hospital (Phase III)

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Received 28 August 2020; revised 5 April 2021; accepted 6 April 2021
doi:10.46475/aseanjr.v22i1.82

Abstract

Objective: To compare the image quality and the radiation dose between fixed tube current (FTC) low dose abdominal CT currently performed at our hospital and new automatic tube current modulation (ATCM) low dose abdominal CT.

Materials and Methods: We prospectively performed ATCM low dose abdominal CT in 88 participants who had prior FTC low dose CT for comparison. Four experienced abdominal radiologists independently and blindly assessed the quality of FTC and ATCM low dose CT images by using a 5-point-scale satisfaction score (1 = unacceptable, 2 = poor, 3 = average, 4 = good, and 5 = excellent image quality). Each reader selected the preferred image set between FTC and ATCM low dose techniques for each participant. The image noise of the liver and the aorta in both techniques was measured. The volume CT dose index (CTDIvol) of both techniques was compared.

Results: The mean satisfaction scores (SD) for FTC and ATCM low dose CT were 4.38 (0.66) and 4.38 (0.64), respectively with the ranges of 3 to 5 in both techniques, which were all acceptable for CT interpretation. The preferred image set between FTC and ATCM low dose techniques of each participant randomly selected by each reader were varied, depending on the readers' opinions. The mean image noise of the aorta on FTC and ATCM low dose CT accounted for 34.75 and 36.46, respectively, while the mean image noise of the liver was 28.86 and 29.81, respectively. The mean CTDIvol (SD) of FTC and ATCM low dose CT were 8.42 (0.32) and 8.12 (0.43) mGy, respectively.

Conclusion: FTC and ATCM low dose abdominal CT provided comparable acceptable image quality and showed no clinical significance in radiation dose optimization.

Keywords: Abdominal computed tomography, Abdominal CT, Radiation dose optimization, Fixed tube current, FTC, Automatic tube current modulation, ATCM.

Introduction

Nowadays, the new computed tomography (CT) technologies have offered the better image qualities by providing thinner and faster CT images. Despite obtaining better image resolution and ability to achieve a dynamic study, CT comes along with more radiation dose, which is a worldwide concern as one of the potential risks of carcinogenesis [1]. There have been many proposed guidelines for radiation dose optimization, such as minimizing the number of CT acquisitions and area coverage, reducing the tube current, and decreasing peak kilovoltage [2,3] as appropriate. Two accepted techniques of tube current optimization include fixed tube current (FTC) and automatic tube current modulation (ATCM) techniques. FTC is easy to be performed, using a fixed, tube current reduction. ATCM is more complicated, using automatic adjustment of the tube current by a CT scanner according to the size and density of the scanned body part. Both techniques have provided radiation dose reduction with similar image quality [4-6].

However, radiation dose reduction unavoidably increases the image noise, reduces the image quality and decreases diagnostic confidence. For the aforementioned reasons, we have conducted the studies on tube current reduction by either FTC (phase I study) or ATCM (phase II study) techniques to find out the appropriate technique and the amount of tube current reduction and assess the post-processing reconstruction methods which help optimizing the image quality.

Our phase I study [7] was prospectively performed in 119 participants, comparing low dose abdominal CT using the FTC technique (30% reduction of standard tube current) and conventional standard dose CT. We applied the new iterative reconstruction (IR) de-noising method to optimize the image quality of the low dose CT scan. IR provided less image noise than the conventional filtered back projection (FBP) method and could help reduce the radiation dose [8-14]. The IR method used in the study was the Adaptive Statistical Iterative Reconstruction (ASiR), which was specific to our GE CT scanners. We applied various parameters of ASiR (0%, 10%, 20%, and 30%) by post-processing on a CT workstation to improve the low dose CT image quality. The result of the phase I study showed significant radiation dose reduction by the FTC technique with acceptable image quality by the opinions of the four experienced abdominal radiologists.

Our phase II study [15] was prospectively performed in 111 participants, comparing low dose abdominal CT using the ATCM technique and conventional standard dose CT. The ATCM low dose CT images were post-processed on a CT workstation with 4 parameters of ASiR (0%, 10%, 20%, and 30%). The result of the phase II study also showed significant radiation dose reduction by the ATCM technique with acceptable image quality by the opinions of the four experienced abdominal radiologists.

The increment of ASiR technique was helpful in reducing image noise in phase I and phase II studies. However, the images with high percentage of ASiR provided smooth image appearances with a less sharp border. This was the reported major drawback of the IR technique [11,13]. Half of the radiologists in our phase I and phase II studies preferred CT images with lower percentage of ASiR than higher percentage of ASiR. They were possibly familiar with relatively noisy CT images with a sharp border in lower percentage ASiR.

According to the results of phase I and phase II studies, we have applied FTC technique to reduce the radiation dose in our routine CT practice. We selected the FTC technique because it is simple and easy to be performed compared to the more complicated ATCM technique. We decided to fixedly reduce the tube current by 20%, from 400 to 300 mA on a 64-slice CT scanners and from 340 to 250 mA on a 256-slice CT scanner (standard mA multiplied with mA adjustment factor for 20 % dose reduction of 0.76 and 0.74 for 64-slice and 256-slice CT scanners, respectively). We do not apply the ASiR method in our routine practice due to different radiologists' preference as described above. In this current phase III study, we aimed to directly compare the image quality and the radiation dose between the two techniques of tube current optimization; the FTC technique which has currently been used as our routine practice and the ATCM technique.

Materials and methods

Study Designs and Participants

This study was a prospective, single-centered study performed at a 2,200-bed university hospital in central Thailand. This study was approved by our institutional review board with informed consents required from all included participants.

All participants were over 18 years old who were scheduled for contrast enhanced abdominal CT examinations at our department. They had available prior FTC low dose abdominal CT which has been currently used in our department for the comparison purpose with their current CT using the ATCM low dose technique. Totally, eighty-eight participants met the criteria and were recruited as our study population. The demographic data of each participant including gender and age were recorded by one of our investigators (AS).

CT Techniques

FTC Low Dose Abdominal CT

The prior FTC low dose abdominal CT of our participants was routinely performed by three General Electric (GE) CT scanners including two 64-slice scanners (Discovery CT750 High Definition, GE Healthcare, Milwaukee, WI, USA) and one 256-slice scanner (Revolution CT, GE healthcare, Milwaukee, WI, USA). The CT of each participant was protocoled for a proper number of CT acquisitions and area coverage. All participants were advised to hold their breath during the scan. The scan coverage included at least the upper abdominal area. The slice collimation was 1.25 mm (reconstructed at 7.0 mm) for all scanners. There were varieties on the administration of oral and rectal contrasts according to each participant's appropriate protocol. All participants underwent precontrast and postcontrast studies, before and after a bolus intravenous injection of nonionic iodinated contrast agent (2 mL per kg body weight), followed by 20 mL of water via a power injector at a rate of 3 mL/second. Each participant had at least a portovenous acquisition phase with an 80-second delay for postcontrast study. An additional arterial phase at 35 to 40-second delay or delayed phase at a 5 to 10-

minute delay was obtained in some participants as necessary. The peak kilovoltage was fixed at 120 kVp for all scanners. The tube current of our FTC technique was 300 mA and 250 mA for 64-slice and 256-slice CT scanners, respectively. The rotation time was 0.5 second for all scanners. The pitch was 1.375:1 and 0.992:1 for 64-slice and 256-slice CT scanners, respectively. All images were reconstructed with the standard FBP without the addition of ASiR, and sent to the Picture Archiving and Communication System (PACS) for subsequent reviews.

ATCM Low Dose Abdominal CT

The current ATCM low dose abdominal CT was performed by two GE CT scanners including one 64-slice scanner (Discovery CT750 High Definition, GE Healthcare, Milwaukee, WI, USA) and one 256-slice scanner (Revolution CT, GE healthcare, Milwaukee, WI, USA). The CT scanners for the FTC and ATCM techniques of each participant were not necessarily the same scanners. The CT of each participant was protocoled for a proper number of CT acquisitions and area coverage which at least covered the upper abdominal area. The scan techniques were the same as described in the prior FTC low dose abdominal CT protocol except for the tube current on the portovenous phase was automatically adjusted by the CT scanners according to the size and density of each participant's abdomen. The tube current varied between 150-300 mA with a fixed noise index of 22 on a 64-slice CT scanner; and 120-250 mA with a fixed noise index of 22 on a 256-slice CT scanner. The other phases used the FTC technique as a routine (300 and 250 mA for 64-slice and 256-slice CT scanners, respectively). We chose to study only the portovenous phase because most abdominal organs had homogeneous enhancement in this phase. It was easy for radiologists to evaluate the CT image quality.

All images were reconstructed with the standard FBP without the addition of ASiR, and sent to PACS for subsequent reviews.

For a parameter of radiation dose comparison, we selected the volume CT dose index (CTDIvol) instead of the dose length product (DLP). The DLP would depend on the length of scan which varied among the participants due to the difference in area coverage and the number of CT acquisitions.

The details of CT scanners, study dates, and CTDIvol in the portovenous phase of each participant's prior FTC low dose abdominal CT and current ATCM low dose abdominal CT were recorded by one of our investigators (AS). The time interval between the two studies was calculated.

Image Assessment

In the qualitative image assessment, four board-certified, abdominal radiologists (PA, KM, WT, and SP with 24, 24, 18, and 18 years of experience in abdominal CT evaluation) blindly reviewed portovenous abdominal CT image sets of the FTC and the ATCM techniques of each participant. They separately graded the image quality of both low dose techniques by using a 5-point-scale satisfaction score on a visual scale as follows:

1: Unacceptable image quality, unable to interpret
2: Poor image quality, interfering with interpretation
3: Average image quality, possible interpretation
4: Good image quality
5: Excellent image quality

The satisfaction scores of 3 to 5 were acceptable for CT interpretation. Subsequently, the radiologists independently selected one preferred image set between the FTC and the ATCM techniques for each participant.

In the quantitative image assessment, the image noise (HU) of the aorta and the liver was measured on FTC and ATCM low dose CT image sets by one of our investigators (AS) on a CT workstation (Advantage workstation AW 4.6, GE healthcare, Milwaukee, WI, USA). The image noise was measured by drawing a circular region of interests (ROIs) at four locations (one aortic and three hepatic regions) on a 1.25-mm slice portovenous image at the same locations and levels of these two image sets. For image noise of the aorta, the ROI was drawn at the most central part to avoid calcified plaque at the aortic wall. For image noise of the liver, three hepatic ROIs were routinely applied on the left lobe, the anterior right lobe, and the posterior right lobe (Figure 1). The hepatic ROIs were placed at the homogenous enhancing hepatic areas avoiding vessels, bile ducts, hepatic lesions, calcifications and surgical materials. The mean image noise of each liver was calculated from these three hepatic ROIs of image noise. The area of aortic and hepatic ROIs was in a range of 93-106 mm^2, mean 100.5 $mm^2 \pm 2.92 mm^2$.

Statistical Analysis

The demographic data of participants, CT scanners, time interval between CT studies, the image quality (satisfaction scores, readers' preferred low dose techniques, and image noise) and CTDIvol of FTC and ATCM low dose CT were presented as percentage (%), mean (standard deviation, SD), and range. A paired t-test was used to compare the mean CTDIvol and the mean image noise of the aorta and the liver between the FTC and the ATCM low dose CT.

All statistical data analyses were performed by using PASW 18.0 (SPSS Inc., Chicago, IL, USA). A 2-sided p-value of less than or equal to 0.05 was considered as a statistical significance.

Figure 1. *The image noise measurement of the aorta (1 ROI) and the liver (3 ROIs at the left lobe, the anterior right lobe and the posterior right lobe). The ROIs were positioned at the same locations and levels on FTC and ATCM image sets.*

Results

Participants

Eighty-eight participants in this study included 46 (52.3%) men and 42 (47.7%) women. The mean age (SD) of the participants at the time of the ATCM low dose CT scan was 62.5 (12.1) years with the range of 21-86 years.

CT Techniques

The FTC low dose abdominal CT of 50 (56.8%) and 38 (43.2%) participants were performed by 64-slice and 256-slice scanners, respectively. The ATCM low dose abdominal CT of 56 (63.6%) and 32 (36.4%) participants were performed by 64-slice and 256-slice scanners, respectively. The time interval between the two studies ranged from 38 to 208 days (median 133 days).

The mean CTDIvol (SD) of the FTC and the ATCM low dose CT were 8.42 (0.32) and 8.12 (0.43) mGy, respectively (p-value <0.001).

Image Assessment

In terms of the qualitative image assessment, the satisfaction score of the FTC and the ATCM low dose abdominal CT graded by four readers ranged from 3 to 5, which were all acceptable for CT interpretation. The mean satisfaction scores of FTC and ATCM low dose abdominal CT graded by each reader were summarized in Table 1. The preferred image set between the FTC and the ATCM low dose techniques of each participant randomly selected by each reader were varied, depending on the readers' opinions (Table 2).

In the quantitative image assessment, the image noise of the aorta and the liver on the FTC and the ATCM low dose abdominal CT were summarized in Table 3.

Table 1. *The mean satisfaction scores of the FTC and the ATCM low dose abdominal CT graded by four readers.*

	Mean Satisfaction Score (SD)	
	FTC	ATCM
Reader1	4.24 (0.77)	4.24 (0.70)
Reader2	4.47 (0.57)	4.43 (0.54)
Reader3	4.48 (0.61)	4.56 (0.62)
Reader4	4.34 (0.68)	4.33 (0.64)
All reader	4.38 (0.66)	4.38 (0.64)

Table 2. *The preferred image set between the FTC and the ATCM techniques selected by 4 readers.*

	Number of Preferred Image Set (%)		Total
	FTC	ATCM	
Reader1	38 (43.2)	50 (56.8)	88 (100.0)
Reader2	48 (54.5)	40 (45.5)	88 (100.0)
Reader3	33 (37.5)	55 (62.5)	88 (100.0)
Reader4	37 (42.0)	51 (58.0)	88 (100.0)
All reader	156 (44.32)	196 (55.68)	352 (100.0)

Table 3. *The image noise (HU) of the aorta and the liver on the FTC and the ATCM low dose abdominal CT.*

		FTC	ATCM	Differences of Mean Image Noise between FTC and ATCM (95% CI)	p-Value
Aorta	Mean (SD)	34.75 (7.28)	36.46 (7.72)	-1.71 (-3.30,-0.12)	0.035
	Min, Max	21.78, 55.12	22.88, 53.71		
Liver	Mean (SD)	28.86 (6.38)	29.81 (5.94)	-0.95 (-1.59,-0.31)	0.004
	Min, Max	12.03, 52.84	14.90, 53.71		

Discussion

From our previous phase I [7] and phase II [15] studies, both FTC and ATCM low dose abdominal CT provided significant radiation dose reduction compared to the standard dose CT, and at the same time offered acceptable image quality. The purpose of this current phase III study was to directly compare these two aforementioned low dose CT techniques in either image quality or radiation dose.

The result of this study showed no clinically significant difference in the image quality between the FTC and the ATCM low dose abdominal CT, similar to the findings shown in prior studies [5,6]. Both techniques demonstrated acceptable satisfaction scores for interpretation ranging from 3 to 5. Interestingly, the mean satisfaction score of the FTC and the ATCM were similar (4.38), but the number of the preferred study selected by readers was slightly higher on the ATCM (55.68%) compared to the FTC (44.32%) techniques. These could be explained in cases when the readers gave the same satisfaction score for both techniques but selected one of them to be a preferred study. The mean satisfaction score would possibly not go along with the number of preferred studies as shown in our result.

The radiation dose of the FTC technique in this study was slightly higher than the ATCM technique with statistical significance (CTDIvol of 8.42 vs 8.12 with p-value <0.001). As mentioned earlier that the ATCM technique automatically adjusted the tube current according to the size and density of the scanned body part, the radiation dose in the ATCM technique was more suitable with each participant than the FTC technique [5,6]. Nevertheless, the difference in a radiation dose of these two techniques was not clinically significant. With slightly more radiation dose, the FTC technique did show less image noise of the aorta and the liver compared to the ATCM technique.

From our experiences performing 3 consecutive studies with a low dose abdominal CT, we assured that a low dose abdominal CT with an optimal technique and an appropriate amount of radiation reduction would provide CT images with an acceptable quality. Radiologists should be concerned about radiation hazard and realize the importance of radiation dose optimization. They have to open their mind to adopt low dose CT images with acceptable quality in their routine work. There are many proposed techniques of radiation dose optimization. They just select the technique that is most suitable with their CT machines and radiological practice.

There were several limitations of our study. First, there were variables in our CT scanners. Although they were all GE scanners, two were 64-slice scanners and one was a 256-slice scanner. Of which, some CT parameters (i.e. mA and pitch) were not the same. Inherent differences in scanners could affect the image quality. Plus, the CT scanners for the FTC and the ATCM techniques of each participant were not necessarily the same scanners. Second, the long interval time between the prior FTC low dose CT and current ATCM low dose CT ranged from 38 to 208 days (median 133 days). With such a long interval time, there would be changes in participants' habitus or conditions that would affect the image quality. Third, image noise was measured on a 1.25 mm slice portovenous image of each image set. As a matter of fact, image noise should be measured by choosing 3-5 consecutive CT slices and the noise should be averaged for the statistical accuracy. Lastly, our study focused only on the image quality (satisfaction score, preferred image set, and image noise). We did not study diagnostic performances of these low dose techniques. To accurately evaluate the diagnostic performances between the 2 techniques, these 2 techniques should be performed on the same date and almost the same acquisition phase. These will inevitably increase the radiation dose received by the participants.

In conclusion, the FTC low dose abdominal CT and the ATCM low dose abdominal CT provided a comparable acceptable image quality, and demonstrated no clinical significance in radiation dose optimization.

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