ORIGINAL ARTICLE

CAREdose 4D Application in Brain CT Scan: The Effect on Dose and Image Quality

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Abstract

Purpose: This study aimed to investigate the effect of CAREdose4D on the dose and image quality in Brain Computed Tomography (CT).

Materials and Methods: Noise, Signal-to-Noise Ratio (SNR), and Contrast-to-Noise Ratio (CNR) for Gray Matter (GM), White Matter (WM), Cerebrospinal Fluid (CSF), and skull bones were investigated in brain CT scans of 60 patients. In addition, a phantom study was conducted to examine the effect of CAREdose 4D on the same subject in the brain, chest, abdomen, and pelvic CT protocols. Volume CT dose index (CTDIvol) and Dose Length Product (DLP) were recorded for each scan. Data were analyzed by T-test and Mann-Whitney statistical test with a significance level of less than 0.05.

Results: The following results were obtained in active and passive modes of CAREdose 4D in brain CT of patients, respectively: CTDIvol, 15.76±3.94 and 16.96±2.14 mGy ($p<0.05$); DLP, 253.81±84.69 and 252.73±43.26 mGy.cm ($p>0.05$). There was no significant difference between SNRs and noise of various tissues of the brain ($p>0.05$) but CNR difference for gray matter, white matter, and cerebrospinal fluid (CSF) was significant ($p<0.05$). In the phantom study, SNR decreased in the active status of CAREdose 4D for the head in sequential and spiral modes, Chest, abdomen and pelvis by 7%, 84%, 45%, 20%, and 22%, respectively.

Conclusion: CAREdose 4D reduces the dose without having an adverse effect on noise and SNR in brain CT scans. It is recommended newbies and untrained technicians to use CAREdose 4D.

Keywords: Brain Computed Tomography; Dose Reduction; Volume Computed Tomography Dose Index; Image Quality.

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1. Introduction

Computed Tomography (CT) scan provides cross-sectional images from the patient body and fulfills the diagnostic needs to some extent [1]. Despite the advantages, radiation dose in CT scan is relatively high which in turn has raised concerns about carcinogenic effects [2, 3]. This issue multiplies the importance of principles of radiation protection in CT scans, including the justification of CT prescription, optimization of the imaging protocol, and adherence to the dose limit [4, 5]. Different dose reduction strategies in CT scans have been proposed. The critical point that should be taken into account when reducing the dose is keeping the image quality to an acceptable level. This issue has become one of the most important challenges for physicists and radiologists in recent years [6, 7].

Brain CT scan is one of the most commonly performed CT procedures today [8, 9]. Several studies have investigated the absorbed dose of different organs in CT scans of the brain [10-12]. Jaffe *et al.* reported the absorbed dose to the cranium, brain, lens, mandible, and thyroid in brain CT as follows, respectively: 2.57–3.47, 2.34–3.78, 2.51–5.03, 0.17–0.48, 0.03–0.28 cGy [13]. This emphasizes employing dose reduction strategies in brain CT scans.

One parameter used to measure the output from a CT scanner is the CT Dose Index (CTDI) [14, 15]. Due to the divergency of the beam and the radiation energy in the range of kilo-voltage, the dose distribution in CT scan is nonuniform both in plane and cross-plane directions. The weighted CTDI (CTDIw) considers the in plane none uniformity by weighting the central CTDI and peripheral CTDI by factors of 1/3 and 2/3, respectively. In axial scan mode there is no table movement when data are acquired but in spiral mode table moves continuously which makes gaps between adjacent slices. CTDIvol takes into account the dose distribution and pitch factor in spiral scan mode and usually is displayed on the CT monitors. This parameter can be used to compare the dose between patients and with Diagnostic Reference Levels (DRLs) [16, 17]. Noise is unwanted information that has an adverse effect on real signals, and changes their shape and causes disturbances [18, 19]. Using the dose reduction methods in CT usually increases the noise which in turn decreases the image quality. Studies show that different image processing methods can reduce the dose between 27 and 65% without reducing image quality [20-23].

One proposed solution by Siemens for dose reduction in CT scans is applying a combined application to reduce exposure (CAREdose 4D). This technology works based on Z-axis tube current modulation or angular dose modulation. The former which has been in our study automatically changes the current of the tube by estimating the thickness of the patient using a topogram image but the latter modulates tube current on the basis of the measured density of regional structures and the absorption values of the object of interest [24]. The effect of CAREdose 4D on image quality has not been well investigated. When applying this system, the image noise may exceed the standard limit. In addition, in some cases, the reference mA defined by technologists for CAREdose 4D is relatively high and the patient dose may be more than what is expected. This study was conducted to determine the effect of using the CAREdose 4D systems on CTDIvol and image quality indexes in different CT scan protocols.

2. Materials and Methods

2.1. Evaluating the Dose and Image Quality on Patients' Images

In this study, the effect of CAREdose 4D on volume CT dose index (CTDIvol) and dose length product (DLP) as well as image quality parameters including noise, Signal-to-Noise Ratio (SNR), and Contrast-to-Noise Ratio (CNR) for gray matter, white matter, Cerebrospinal Fluid (CSF), and skull bone have been investigated in Brain CT scans of 60 patients (30 cases with CAREdose 4D and 30 without applying CAREdose 4D). The study was conducted in accordance with the ethical principles of Hamadan University of Medical Sciences (IR.UMSHA.REC.1399.541). All patients' scans were performed in sequential mode in a head-first supine position. Scan parameters were as such: 110 kVp, average mA 120, rotation time 0.6 s, reconstruction kernel H31S, slice thickness 4.8 mm, collimation 16×1.2mm. The standard deviation of CT number in ROI was considered as noise for each tissue. SNR and

CNR for each tissue in the image were obtained by Equations 1 and 2 as follows [25].

$$SNR = \frac{CTN_{tissue}}{SD_{tissue}} \quad (1)$$

$$CNR = \frac{|CTN_{tissue} - CTN_{water}|}{SD_{water}} \quad (2)$$

CT number and image noise of gray matter, white matter, Cerebrospinal Fluid (CSF) and skull bone were determined by drawing a Region Of Interest (ROI) on axial scans (Figure 1).

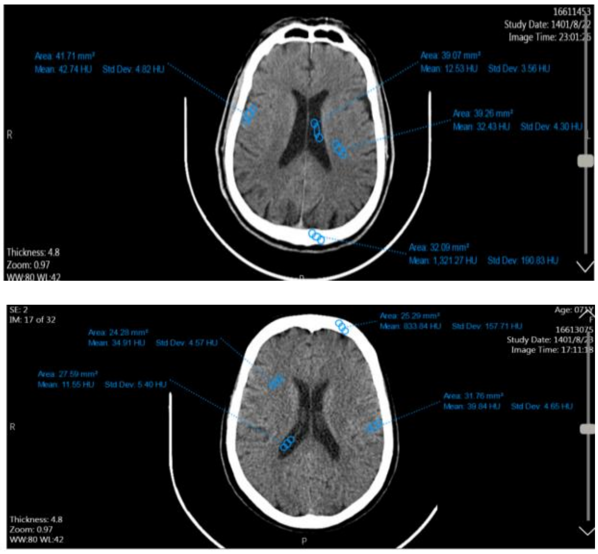

Figure 1. The measurement of the CT number and noise for gray matter, white matter, cerebrospinal fluid (CSF), and skull bone in brain CT scan without CAREdose 4D (top) and with CAREdose 4D(bottom)

For each patient, the CTDIvol and DLP were obtained from the CT monitor. The scanner had a quality control certificate attached to its gantry. The mean Anterior-Posterior (AP) and lateral diameters of the patients' heads were measured using the measuring tools on the device software. The AP diameter was considered as the distance between frontal and occipital bones and lateral diameter as the distance between the eminences of parietal bones.

2.2. Phantom Study

In addition, a phantom study was conducted to examine the effect of CAREdose 4D on the same subject in the brain, chest, abdomen, and pelvis CT protocols. Two phantoms filled with distilled water were used to equate the patient's trunk and head. For the head, the cylindrical distilled water phantom of about 15 cm diameter was placed on the head holder and the scan was performed in sequential and spiral modes. A torso-equivalent phantom of about 32 cm diameter was used to scan the chest, abdomen, and pelvis. For each protocol, the measurement was repeated three times. CT number and noise of water for each protocol were obtained by drawing five ROIs on the center, top, bottom, right, and left of axial images. The average of CT numbers in these five ROIs is considered water CT number. The standard deviation is considered noise. SNR and CNR of the image were calculated according to Equations 3 and 4 as follows [24]:

$$SNR = \frac{CTN_{water\ phantom}}{SD_{water\ phantom}} \quad (3)$$

$$CNR = \frac{CTN_{water\ phantom} - CTN_{air}}{SD_{air}} \quad (4)$$

CTN is the CT number and SD is the standard deviation. Figures 2 and 3 show how the CT number and noise are measured in the axial images of head and body phantoms, respectively.

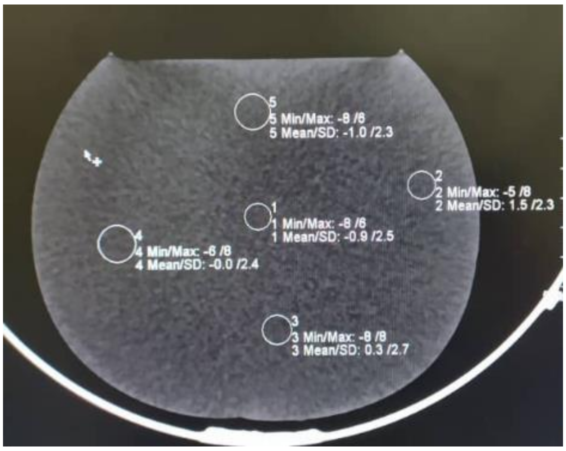

Figure 2. Measuring the CT number and noise in the axial image of the head phantom

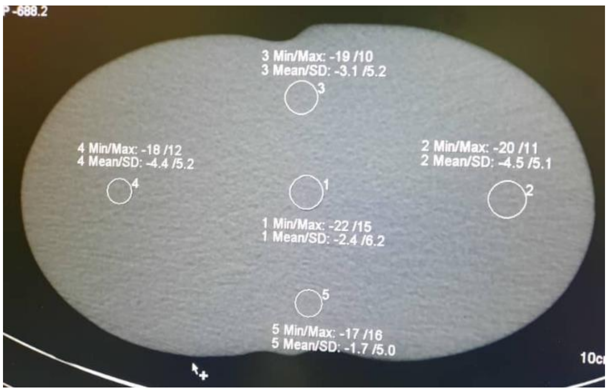

Figure 3. Measuring the CT number and noise in the axial images of the body phantom

3. Results

3.1. Patient Demographic

The number of patients included in this study in terms of sex and status of CAREdose 4D was as follows: 17 women and 13 men with CAREdose 4D and 16 women and 14 men without CAREdose 4D. The mean age of participants with and without applying CAREdose 4D was 42.69 ± 22.93 and 40.56 ± 26.16 years, respectively (p>0.05). The mean anterior-posterior (AP) diameter of the patients' heads with and without applying CAREdose 4D were 17.96 ± 1.02 and 16.96 ± 1.17 cm, respectively (p>0.05). The difference between lateral diameters of the patients' heads with (13.7 ± 0.82 cm) and without (12.98 ± 1.29cm) applying CAREdose 4D was not significant (p>0.05).

3.2. Results of the Dose and Image Quality Parameters Based on Patients' Images

Results of CTDIvol and DLP with and without applying CAREdose 4D in brain CT scan are shown in Table 1. A significant decrease in CTDIvol is seen when applying the CAREdose 4D (p<0.05).

CT number, noise, SNR, and CNR for grey matter, white matter, CSF, and skull bone in brain CT scan with and without CAREdose 4D are shown in Table 2. The difference in noise was not significant for all tissues (p>0.05). Also, there was not a significant difference between SNRs of all tissues as well (p>0.05). A reduction in CNR of the grey matter, white matter, and CSF is seen when applying CAREdose 4D (p<0.05).

Table 1. CTDIvol and DLP of brain CT scan when applying CAREdose 4D and without it

CAREdose 4D	CTDIvol(mGy)	P value	DLP(mGy.cm)	P value
With	15.76±3.94	0.016	253.81±84.69	0.299
Without	16.96±2.14		252.73±43.26	

3.3. Results of the Phantom Study

Table 3 shows the imaging parameters in scans of water phantoms for the head, chest, abdomen, and pelvis protocols.

CTDIvol and DLP for each protocol are shown in Table 4. In all cases, applying CAREdose 4D reduces these parameters. CTDIvol decreased as follows: head 40 % in sequential mode, 44 % in spiral mode, chest 40%, abdomen 51%, and pelvis 62%. DLP has decreased by 41% for the head in sequential mode, 34% for the head in spiral mode, 38% for the chest; 48% for the abdomen, and 58% for the pelvis.

Noise increased and SNR decreased by applying Caredose4d in all protocols. According to the findings of Table 5, Noise has increased for the head by 23 % in Sequential mode, 34 % in spiral mode, the chest 48%, the abdomen 41%, and the pelvis 60%. SNR decreased by 7% for the head in sequential mode and 84% in spiral mode, the chest 45%, the abdomen 20%, and the pelvis 22%.

4. Discussion

In recent years, a concern has been raised about the carcinogenesis effect of CT scans. Brain CT scan is one of the most commonly performed CT procedures [8, 9]. In CT scans, tissues in the scan field are exposed to primary and scatter radiations. Tissues beside the scan

Table 2. The measured CT number, noise, SNR, and CNR for the grey matter, white matter, CSF, and bone in brain CT scan when applying CAREdose 4D and without it

tissue	CAREdose4d	CT number	noise	p-value	SNR	p-value	CNR	p-value
Grey matter	with	35.3±6.38	4.78±0.94	0.45	7.69±2.33	0.15	7.44±4.07	<0.001
	without	38.15±2.13	4.59±1.35		9.33±3.89		11.13±4.85	
White matter	with	31.58±2.52	5.03±0.90	0.20	6.44±1.14	0.08	6.82±3.47	0.001
	without	32.37±2.01	4.58±1.08		7.55±2.26		9.57±4.11	
CSF	with	11.92±2.10	5.44±0.72	0.11	2.22±0.48	0.24	2.73±1.27	0.03
	without	10.01±3.16	5.07±1.09		2.06±0.83		3.32±1.44	
Bone	with	990.12±284.34	175.43±82.24	0.94	8.45±9.16	0.94	205.87±132.61	0.06
	without	996.02±3.16	179.55±101.91		10.7±16.48		275.16±159.6	

Table 3. Imaging parameters in scans of water phantoms for the head, chest, abdomen, and pelvis protocols

organ	Scan mode	CAREdose 4D	Topogram			Scan						
			Tube Position	kVp	mAs	kVp	mAs	Collimation(mm)	Slice thickness(mm)	Pitch factor	kernel	window
Head	Sequential	with	Lateral	110	25	110	176	16×1.2	4.8	-	H31s medium	Base orbita
		without	Lateral	110	25	110	290	16×1.2	4.8	-	H31s medium	Base orbita
	Spiral	with	Lateral	130	25	130	128	16×0.6	5	0.55	H31s medium	Base orbita
		without	Lateral	130	25	130	220	16×0.6	5	0.55	H31s medium	Base orbita
Chest	Spiral	with	Top	130	25	130	40	16×0.6	5	1.5	B70s sharp	Lung
		without	Top	130	25	130	70	16×0.6	5	1.5	B70s sharp	Lung
Abdomen	Spiral	with	Top	130	25	130	56	16×1.2	5	0.6	B41s medium	Abdomen
		without	Top	130	25	130	120	16×1.2	5	0.6	B41s medium	Abdomen
Pelvis	Spiral	with	Top	130	120	130	48	16×0.6	5	1.2	B41s medium	Pelvis
		without	Top	130	120	130	135	16×0.6	5	1.2	B41s medium	Pelvis

Table 4. CTDIvol and DLP in the head, chest, abdomen, and pelvis CT scan in active and passive modes of CareDose4D

Organ		care dose 4D	CTDIvol	Reduction in CTDIvol	DLP mGy*Cm	Reduction in DLP
Head	Sequential	with	25.48±0.34	40%	146.77±11	41%
	Sequential	without	42.63±00		245.55±11	
	Spiral	with	29.31±0.74	44%	120.34±11.42	34%
	Spiral	without	51.98±00		181.76±7.50	
Chest	Spiral	with	4.71±0.41	40%	74.63±0.49	38%
		without	7.90±00		118.54±0.54	
Abdomen	Spiral	with	5.90±0.16	51%	106.34±1.04	48%
		without	12.27±00		203.26±1.27	
Pelvis	Spiral	with	5.73±0.21	62%	111.47±1.09	58%
		without	15.27±00		262.04±5.29	

field are somewhat exposed to X-ray due to scattering effect, leakage, over scanning and over beaming, and limited collimator efficiency [14]. Hence, Dose reduction is of great importance in CT but it is also necessary to keep the quality of the image. Degradation of image quality is inevitable to some extent when lowering the dose. Applying CAREdose 4D as an option has been suggested by Siemens to reduce the dose while keeping the image quality to an acceptable level. The results of this study showed that CAREdose 4D reduced

Tables 5. Noise and SNR in the head, chest, abdomen, and pelvis CT scans in active and passive modes of CareDose4D

Organ	Scan Mode	Care dose 4D	CT number (HU)	Signal to noise ratio	Reduction in SNR	noise	Increase in noise
Head	Sequential	Active	0.82±0.77	0.29	7%	2.59±0.13	23%
	Sequential	Passive	0.61±2.6	0.31		2.1±0.05	
	Spiral	Active	0.58±0.4	0.028	84%	3.36±0.39	34%
	Spiral	Passive	-0.07±0.53	0. 17		2.5±0.27	
Chest	Spiral	Active	-4.61±1.58	-0.47	45%	9.72±0.08	48%
		Passive	-5.57±0.64	-0.85		6.55±0.47	
Abdomen	Spiral	Active	-4.42±0.87	-0.58	20%	7.59±0.03	41%
		Passive	-3.91±0.82	-0.72		5.37±0.47	
Pelvis	Spiral	Active	-4.83±1.54	-0.51	22%	8.44±0.1	60%
		Passive	-3.52±2.23	-0.66		5.27±0.25	

CTDIvol by 7.07% in brain CT scans without having a significant adverse effect on noise and SNR. The SNRs for all studied tissues do not change significantly but the CNR increased when applying CAREdose 4D. CAREdose 4D adjusts the tube mA according to body thickness when the scan is performed. The AP and lateral diameters of patients' heads are not the same. Without applying CAREdose 4D the mA is constant in all projections which causes the patients to receive excessive dose in those projections with low thickness. Refereeing to acquisitions parameters in non-applying CAREdose 4D scans in this study, the mA is higher than those scans applying it (110 vs. 95). Other parameters such as kVp, collimation, rotation time, slice thickness, and pitch factor are similar. Tube current is the key parameter that influence both noise and dose. CAREdose 4D is usually less than mA selected by technicians. Technicians are not able to adjust the mA based on thickness and usually select mA based on the thickest part of the tissue. Noise strongly depends on the number of photons reaching the detector. Applying CAREdose 4D reduces the mA compared to the default setting of the scanner or selected one by the technician which in turn causes the reduction in the number of photons reaching the detector. The results obtained from the phantom study showed that Applying CAREdose 4D decreased the CTDIvol and DLP but increased the image noise and SNR. In our study applying CAREdose 4D in phantom scanning led to a reduction in CTDIvol and an increase in noise for all protocols. The results of this study are consistent with the results of other similar studies. In a study by Sari *et al.*, the effect of care dose on CTDIvol and noise was investigated using three water phantoms with diameters of 165, 230, and 305 mm. CARE Dose 4D reduced the CTDIvol by 54.34% but increased the noise [26]. Wang *et al.* evaluated the effect of the Care Dose 4D along with Sinogram Affirmed Iterative Reconstruction (SAFIRE) on image noise reduction and radiation dose. Applying the CAREdose 4D decreased the dose by 74.85% [24]. Soderberg *et al.* stated that CAREdose 4D leads to a reduction in the dose of the neck between 34 and 57%, the chest by 51 to 88%, and the abdomen by 56 to 91% [27]. Greess *et al.* showed that CAREdose 4D could reduce the radiation dose from 10 to 60% in children's CT scans [28]. Shah *et al.* reported that CTDI decreased by 31.82% in brain CT scans when applying both CARE kV and CAREdose 4D without considering the effect on image noise [29]. The strength of our study is that the effect of CAREdose 4D on dose and noise for different tissues in brain CT scans has been investigated; something that has not been addressed in other studies. In our study, the brain CT was performed with only one topogram taken in the lateral tube position. Due to the unsymmetrical geometry of the skull, it seems that the CAREdose 4D can be more efficient using two topograms taken in the top and lateral tube positions. Another important point is the correct setting of reference mA when applying caredose4D.

5. Conclusion

Caredose 4D is an efficient practical solution for dose reduction in CT scans provided that the reference current tube is adjusted correctly and the topogram covers the entire scan box. If this is the case, it reduces the dose without having an adverse effect on noise and SNR in brain CT scans. It is recommended that newbies and untrained technicians use CAREdose 4D.

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