PHYSICS
Iran J Radiol. 2018 July; 15(3):e59554. doi: 10.5812/iranjradiol.59554.
Published online 2018 June 17. **Research Article**

Assessment of Radiation Dose and Image Quality of Multidetector Computed Tomography

Haytham Al Ewaidat,[1,*] Xiaoming Zheng,[2] Yousef Khader,[3] Mostafa Abdelrahman,[1] Mostafa Khaled Mustafa Alhasan,[1] Mohammad Ahmmad Rawashdeh,[1] Dana Samir Al Mousa,[1] and Khaled Zayed Ali Alawneh[4]

[1]Department of Allied Medical Sciences-Radiologic Technology, Faculty of Applied Medical Sciences, Jordan University of Science and Technology, Irbid, Jordan
[2]Medical Radiation Science, School of Dentistry and Health Science, Charles Sturt University, Wagga Wagga, Australia
[3]Medical Education and Biostatistics, Faculty Medicine Medical Sciences, Jordan University of Science and Technology, Irbid, Jordan
[4]Department of Neuroradiology, Faculty of Medicine, Jordan University of Science and Technology, Irbid, Jordan

[*]*Corresponding author*: Dr. Haytham Al Ewaidat, Department of Allied Medical Sciences-Radiologic Tecnology, Faculty of Applied Medical Sciences, Jordan University of Science and Technology, Irbid, Jordan. Tel: +962-2720100026939; Fax: +962-27201087, E-mail: haewaidat@just.edu.jo

Received 2017 August 29; **Revised** 2018 April 19; **Accepted** 2018 April 25.

Abstract

Background: CT techniques and procedures have been expanded in the past decades, leading to an increase in the use of CT. At the same time, the radiation dose to the patient and the concern surrounding this issue has also increased.
Objectives: The goal of this study was to assess clinical image quality and x-ray dose from various computed tomography (CT) scanners in order to identify the CT scanners that produce the least radiation dose to patients with exact acceptable image quality for diagnosis.
Patients and Methods: Non-randomized clinical image data were collected from six hospitals on 16, 32 and 64 slice CT scanners. A total of 900 patients who underwent chest, abdomen, and brain scans were used for image quality evaluation and dose assessment. The image qualities were evaluated by five observers on 1 - 5 visual grading scale. The CT dose volume index (CTDIv) and dose length product (DLP) was documented from the image display.
Results: The averaged CTDIv was 64.96, 70.2, and 75 mGy for the brain, 11.65, 15.53 and 17.11 mGy for the chest, and 13.41, 18.44, and 19.42 mGy for the abdomen from 16, 32 and 64 slice scanners respectively. The averaged image quality scores were 3.68, 3.82, and 4.81 for the abdomen, 3.01, 4.27, and 4.42 for the chest, and 4.92, 4.94, and 4.99 for the brain from 16, 32 and 64 slice scanners respectively.
Conclusion: Sixteen slice CT scanner delivered the minimum radiation dose to patients in contrast with the 32 and 64 slice CT scanners, and the image quality was adequate for diagnosis. Both 32 and 64 slice CT scanners produced more than acceptable image quality as well as more than needed dose to patients. The patient dose from the 32 and 64 slice scanners may be reduced by dropping their image quality to close to the 16 slice CT scanner.

Keywords: Radiation Dose, MSCT, VGA, CTDIv, DLP

1. Background

Recent technological development has brought multiple slices CT (MSCT) scanners into clinical practice from 2, 4, 8, 16, 32 to 64 slices and now the 256 slice scanners are being introduced into clinics (1, 2).

Therefore, there is an ongoing push for the hospitals to acquire newer CT scanners with higher numbers of slices because higher slice CT scanners provide larger organ coverage, faster scan time, better image quality and are open to more clinical applications that require faster acquisition such as cardiac imaging (3). Multiple slice scanners generally produce better image qualities but deliver higher radiation doses to patients than the single slice scanners (4).

While CT techniques and procedures have expanded in the past decades leading to an increase in the use of CT, at the same time, the radiation dose to the patient and concern surrounding this has also increased. CT scanning is able to give high quality and value diagnostic information; however, it is also described and recognized as a high dose procedure (2).

During a CT examination, the radiation dose transmitted to the patient can be high, so it is vital to keep the radiation exposure as low as possible, paying extra attention to the image to maintain a clear image quality that is suitable for diagnosis (5).

Image quality means how precisely obtained CT attenuation data is recreated into an optical image representing definite anatomical characters. The essential reason of radiation dose executive and the “as low as reasonably achievable” (ALARA) idea stems from the link between image quality and radiation dose. The anatomical aspect necessary for an exact clinical diagnosis should instruct whether to choose CT at all, and if so, to decide the parameters and dose used in CT scans. However, decreasing the radiation dose also reduces an image’s aspect and its prospective diagnostic significance.

Manufacturers have been working to improve all aspects of CT scanners including the use of high efficient photon detectors and highly sophisticated computer software to improve image quality (6).

CT scanners are considered to quickly obtain thorough data from large volumes rather than to encourage operator restraint. The high capabilities of technology frequently are not as important as the risk linked to it, and comparatively slight consideration has been paid to apply the ALARA code compared with the efforts concentrated on developing a technology that maximizes image quality (6-8).

In order to minimize radiation doses to patients, the clinical image quality should also be minimized to just acceptable for patient diagnosis because the dose to the patient is generally proportional to the image quality. There are attempts in defining such minimal image quality criteria, (9) but these criteria are not quantitative parameters that could be used in the mathematical optimization of dose and image quality (10, 11).

One of the radiation protection tools in limiting radiation doses to patients is to establish a diagnostic reference level (DRL) for each of the clinical protocols or anatomic regions (12-14).

These diagnostic reference levels are stand on surveys of the doses to patients from a number of hospitals where the 75 percentile of the highest dose delivered to the patients for each of the scan protocols is generally accepted as the dose reference level (15, 16). Any doses higher than the reference level should be questioned and justified. These DRLs provide the up limits for the dose to patients and they can prevent individual CT clinics from making over exposure to patients, but it does not address the radiation protection principle of as low as possible radiation dose to patients because DRL is not the lowest possible radiation to patients. In order to minimize the radiation doses to patients, the clinical image quality should also be minimized to exactly acceptable for patient diagnosis because the dose to the patient is generally proportional to the image quality. There are attempts in defining such minimal image quality criteria, (12) but these criteria are not quantitative parameters that could be used in the mathematical optimization of dose and image quality (10, 11, 17).

A quantitative image quality index or image quality variable is needed in order to minimize the radiation dose to the patients by minimizing the image quality to the exact diagnosable level. It is a challenge to define an exact diagnosable image quality index because it depends not only on physical image quality parameters such as noise, contrast, and resolution, but also on the perception of observers. Several image quality indexes, figure of merit (FOM) or by mathematical calculation using Monte Carlo methods parameters have been suggested, (10, 11) but there is still no generally accepted FOM as yet in measuring the image quality quantitatively (11).

For example, the noise index is taken as the image quality parameter for the popularly implemented automatic exposure control (AEC) in almost every manufacturer’s CT scanner. Although the application of AEC has been successful in reducing the dose to patients, the use of constant noise for adults is not acceptable for children and the same noise level for children may lead to an excessive dose for adults (18, 19). However, this FOM still does not offer the explicit choice for optimization of scan parameters as demonstrated in recent studies (18, 20, 21).

It is clear that any image quality index or FOM must include an observer factor; the image quality ranking index using a visual grading scale by observers appears to be the finest for the image quality index (22, 23). In addition, the visual grading analysis (VGA) method will be used, because it most closely represents what happens in clinical practice, given that humans, not machines, are the ones who read and write the reports dealing with images (24).

2. Objectives

The aim of this study was: 1. to examine clinical multiple slice CT (MSCT) image qualities and radiation doses from different MSCT scanner designs in current practice in order to identify the MSCT scanners that deliver the least dose to the patients and produce acceptable image quality for diagnosis; 2. to employ observers to evaluate current clinical CT images in order to determine the reference level of the exact diagnosable image quality so that the radiation dose to patients may be further minimized.

3. Patients and Methods

This research project was approved by Jordan University of Science and Technology ethics on human research committee. Clinical CT images were collected from six hospitals of Jordan between May 2014 and October 2015. The selection of these six hospitals was without any prejudices. It was our intention to randomly sample imaging centres domestically, but nevertheless this study represents a number of hospitals and locations therefore, it is a non-randomized study. The manufacturers involved were also the major well-known brands in CT imaging practice. The focus of this study was mainly on the adult brain, abdomen and chest as these are the frequently scanned anatomical regions.

3.1. Data Collection

All types and models of CT scanners contain a gantry, an x-ray source and detectors. The x-ray permits through the body part depending on the part's tissue composition, which works due to greater attenuation for bones and lesser for soft tissues. After the x-ray passes through the part of the body that needs to be examined, the beam will be generated in the detector which is used to instruct the image (7).

Non-contrast CT images were collected from six hospitals in Jordan between August 2014 and October 2015. The image data involved a total of 900 adult patients, who underwent abdomen, chest and brain scans using three different MSCT scanners in six hospitals (16, 32 and 64-slice scanners from the manufacturers of Philips, GE and Siemens) as listed in Table 1. The 16, 32 and 64-slice CT scanners are among the most popular CT scanners in current clinical practice. The manufacturers involved were also the major well-known brands in CT imaging practice. The focus of this study was mainly on the adult patient's brain, chest and abdomen, as these are the frequently scanned anatomical regions with beam collimation 16cm for the head and 32cm for the abdomen and chest. These examinations were chosen for the reason that they are normally carried out in most x-ray departments.

Radiological technologists in charge of the scanners were asked to document both technique related parameters (e.g. kVp, mAs), dose length product (DLP) and CT dose volume indexes (CTDIv). The kVp and mAs are the main scan parameters that can be adjusted by the technologists or operators and have significant impact on the image quality and radiation dose to the patients but we asked all operators to follow the same standard CT protocols that are recommended by the manufacturers. The CTDIv and DLP were displayed on the images from multi-slice CT machines as listed in Table 1.

The CTDIv is the averaged dose parameter that has taken into account the pitch number, detector collimation, x-ray tube to iso-centre distance and further procedural parameters (25, 26). During the copying procedure, the option to de-identify the images was selected to maintain patient confidentiality. This option removed the patient name and ID number from the image file header. No other means of identifying the patient was collected.

3.2. Image Quality

The images were assessed by five observers (three radiologists and two technicians) from Jordan. The three radiologists had 5 years of experience and the two technologists had 10 years of experience. Patient information, scan parameters and CT models of manufacturers were all removed from the images, and each of the images were assigned only an image number before being sent out for evaluation. An image quality ranking score was sent to the observers, and they were asked to rank the image quality using a 5-point scale based on the confidence for diagnosis and image noise and artifact. The image quality ranks were: 1, not acceptable since the image quality is so poor that an interpretation is not possible and the study would need to be repeated; 2, poor: the image is of poor quality, however it may view major abnormalities; 3, acceptable: the image quality is sufficient for adequate interpretation but with clearly present artifact; 4, good: it demonstrates better than average image quality with artifacts that are not affecting diagnostic value; and 5, very good: it demonstrates optimum image quality that is free of artifact and minimum noise (23, 27). The observers were also asked to critique the image as well as its rankings by explaining why the image was assigned such a ranking score. The cutoff score in order to accept the image quality was 3.

As the observer could not attend the research site, a practical alternative was to have the observer view and compare the images on their own PCs. Images were forwarded to the observer at their places of employment. 900 images needed to be viewed and ranked by each observer. The images, in digital imaging and communication in medicine (DICOM) format, were downloaded in a DVD and sent to the observers. Observers were chosen to rank the images instead of using a software program, because in clinical practice the radiologist reads and writes the report for the images. The inter-observer agreement was tested by employing the Kappa test.

3.3. Data Analysis

Statistical analysis of the collected data was performed by using commercially available software (IBM SPSS statistics 23.0). Averages and standard deviations for the factors affecting the patients' radiation exposure dose (manufacturer, number of detectors, and CT exam type) and im-

Table 1. CT Scan Parameters (kVp, mAs), DLP and CTDIv for Machines Used in This Study[a]

Exam	Hospital	Scanner	Number of slices	Kvp	mAs	CTDIv	DLP
Abdomen	1	Philips	32	120	Auto	18.4496	717.21
	2	Siemens	16	120	Auto	8.991	322.62
	3	Philips	64	120	Auto	19.549	899.316
	4	Philips	64	120	Auto	20.472	1099.42
	5	Philips	16	120	Auto	17.835	853.58
	6	GE	64	110	Auto	18.248	463.36
Chest	1	Philips	32	120	Auto	15.53	591.84
	2	Siemens	16	120	Auto	6.145	267.34
	3	Philips	64	120	Auto	18.062	666.78
	4	Philips	64	120	Auto	16.611	533.06
	5	Philips	16	120	Auto	17.17	722.34
	6	GE	64	120	Auto	16.66	893.1
Brain	1	Philips	32	120	Auto	70.20	1196.94
	2	Siemens	16	120	Auto	66.82	1253.43
	3	Philips	64	120	Auto	72.02	1217.6
	4	Philips	64	120	Auto	71.11	1153.1
	5	Philips	16	120	Auto	63.11	982.54
	6	GE	64	120	Auto	81.87	1569.07

Abbreviations: CTDIv, CT dose volume index; DLP, dose-length product.
[a] DLP and CTDIv are measured in (mGy-cm) and (mGy) respectively.

age quality ratings were analysed. Correlations were calculated to define the effects of the number of detectors on the radiation exposure dose in accordance with CT exam type (abdomen, chest, and brain) and image quality rating. Weighted kappa tests were used to measure the level of agreement between image quality observers.

4. Results

Table 1 lists the scan parameters of kVp and mAs used for each of the CT scanners on brain and abdomen and their resulting volumetric dose index CTDIv (mGy) and DLP (mGy-cm). The kVp are constant for the patients on each of the scanners, while the mAs were auto AEC for the CT scanners.

The six hospitals of this study were the typical imaging centres of which the optimization of image quality and radiation dose have not been evaluated.

Radiation doses to patients were higher from the 64 slice for the abdomen, chest and brain (19.42, 17.11 mGy and 75.0 mGy) and 32 slice (18.44, 15.32 and 70.2 mGy) scanners than those from the 16 slice scanner (13.41, 11.65 and 64.96 mGy), without considering the penumbral effect of multiple slice scanners as listed in Table 2.

Our results show that, on average, the radiation dose to patient increases as the CT slice number increases in current clinical practice. These data were averaged from various hospitals and manufacturers of CT scanners, which are in contrast to our limited sampling number of hospitals and manufacturers.

Table 3 presents the image quality rankings on these clinical images from the five observers. The MSCT machine averaged for each exam (abdomen, chest and brain) image quality scores were 3.68, 3.82 and 4.81, 3.01, 4.27, and 4.42, and 4.92, 4.94 and 4.99 for 16, 32 and 64 slice scanners, respectively as listed in Table 3.

It shows that image quality of the 16 slice CT machine is just adequate (larger than 3) and the 32 slice scanner is more than adequate (larger than 3) for diagnosis of the abdominal area. The image quality of the 64 slice CT scanner is far more (larger than 4) than the acceptable diagnostic image quality. In addition, for the chest, the 16 slice CT machine is just adequate (larger than 3) and the 32 slice scanner is more than adequate (larger than 4) for patient diagnosis.

From Table 4, we can see that the image quality rankings from all five observers are in a strong correlation with each other for CT scan 16 slices (abdomen, chest and brain), also strong positive correlation for the abdomen in 32 and 64 slices. Furthermore, the chest has strong and moderate agreement in 32 and 64 slices. In addition, the brain in 64 slices has constant value of CTDIv, so all observers gave the same ranking. For example, by looking at Table 4, we can see there is a strong positive correlation between R 1 and R

Table 2. List of the Averaged Clinical Scan Parameters (CTDIv and DLP) for the CT Examinations Studied from Three Different Scanner Models

Exam	Number of slices	CTDIv	DLP
Abdomen	16	13.41	588.1
	32	18.44	717.21
	64	19.42	820.70
Chest	16	11.65	494.84
	32	15.53	591.84
	64	17.11	697.65
Brain	16	64.96	1117.99
	32	70.2	1196.94
	64	75.00	1313.26

Abbreviations: CTDIv, CT dose volume index; DLP, dose-length product.

Table 3. Image Quality Scores from Five Observers[a]

CT exam	Number of slices	Observers ratings (Avg)					
		R1	R2	R3	T1	T2	Avg
Abdomen	16	3.6	3.57	3.67	3.66	3.92	3.68
	32	3.88	3.62	3.90	3.60	4.12	3.82
	64	4.79	4.82	4.81	4.80	4.82	4.81
Chest	16	3.15	2.99	3.04	2.94	2.93	3.01
	32	3.92	4.64	4.58	4.52	3.68	4.27
	64	4.64	4.64	4.64	4.10	4.10	4.42
Brain	16	4.92	4.92	4.92	4.93	4.93	4.92
	32	5.00	5.00	4.96	4.92	4.82	4.94
	64	4.98	5.00	5.00	5.00	4.99	4.99

Abbreviations: Avg, Average; R, Radiologist; T, Radiologic Technologist.
[a] The diagnostic image quality score range is 1- 5 with 1, not acceptable; 2, poor; 3, acceptable; 4, good; and 5, very good.

2 who ranked the abdominal images of 16 slice CT, as the correlation r = 0.918, this value indicates that the strength between R1 and R2 are very high.

Table 5 shows the agreement between the observers regarding image quality ranking for each exam and MSCT using weighted kappa tests. We can see that the image quality rankings from all five observers vary but in total, are in good agreement with each other. The observer's agreement for the 16 slices CT for the abdomen ranged from moderate; k = 0.527 to very good; k = 0.928, the agreement for the chest from the 16 slice CT ranged from moderate; k = 0.650 to very good; k = 0.907, and for the brain, the agreement ranged from very good; k = 0.929 to perfect; k = 1.

Although the observers agreement for the abdomen from 32 slice CT ranged from moderate agreement; k = 0.447to good; k = 0.765, the agreement for the chest from the 32 CT slice ranged from poor agreement; k = 0.091 to good; k = 0.784, and for the brain the results were constant because the CTDIv was the same for all patients and the ranking was nearly the same for all observers.

Moreover, the observers' agreement for the abdomen from 64 slice CT ranged from moderate agreement; k = 0.599 to very good; k = 0.874, the agreement for the chest from 64 slice CT ranged from moderate agreement; k = 0.544 to very good; k = 0.959, and for the brain, the results were constant because the CTDIv was the same for all patients and the ranking was nearly the same for all observers. The inter observer agreement was tested using the weighted kappa tests.

Table 6 shows a strong correlation as well as significant association between image quality scores and CTDIv for each MSCT as the correlation coefficient for the 16 slice ranges from 0.875 to 0.887 and the P.v < 0.01. Similarly, the correlation coefficient for the 32 slice CT ranges from 0. 559 to 0.887 (P value < 0.001). For the 64 slice CT, the correlation coefficient ranges from 0.478 to 0.608 and the (P value < 0.001).

Table 7 shows the cutoff value, sensitivity and specificity of radiation dose to discriminate between the image qualities. According to the area under the curve (AUC) of the receiver operating characteristic (ROC) analysis, the radiation dose had a high predicted power to predict image quality for all body parts and all number of slices (AUC > 0.5) for all CT exams and MSCT scanners.

Table 4. Correlation Between the Observers for Each Exam and MSCT[a]

Exam	Number of slices	IQ observers	Correlation				
			R 1	R 2	R 3	T 1	T 2
Abdomen	16	R 1	1	0.918	0.854	0.872	0.838
		R 2		1	0.886	0.870	0.821
		R 3			1	0.896	0.857
		T 1				1	0.895
		T 2					1
Chest		R 1	1	0.869	0.838	0.803	0.845
		R 2		1	0.960	0.889	0.939
		R 3			1	0.869	0.910
		T 1				1	0.891
		T 2					1
Brain		R 1	1	1	1	1	1
		R 2		1	1	1	1
		R 3			1	1	1
		T 1				1	1
		T 2					1
Abdomen	32	R 1	1	0.808	0.844	0.816	0.879
		R 2		1	0.841	0.714	0.704
		R 3			1	0.811	0.743
		T 1				1	0.779
		T 2					1
Chest		R 1	1	0.788	0.783	0.85	0.535
		R 2		1	0.876	0.826	0.584
		R 3			1	0.86	0.69
		T 1				1	0.561
		T 2					1
Brain		R 1	1	0.788	0.836	0.85	0.535
		R 2		1	0.737	0.826	0.584
		R 3			1	0.859	0.574
		T 1				1	0.561
		T 2					1
Abdomen	64	R 1	1	0.740	0.678	0.593	0.672
		R 2		1	0.840	0.749	0.788
		R 3			1	0.865	0.815
		T 1				1	0.863
		T 2					1
Chest		R 1	1	0.958	0.929	0.624	0.550
		R 2		1	0.943	0.614	0.540
		R 3			1	0.644	0.569
		T 1				1	0.951
		T 2					1
Brain		R 1	-	-	-	-	-
		R 2			-	-	-
		R 3				-	-
		T 1					-
		T 2					-

Abbreviations: MSCT, multiple slice CT R, Radiologist; T, Radiologic Technologist.
[a] - = No statistics are computed because the variables are constant; IQ, image quality.

Table 5. Agreement Between the Observers for Each Exam and MSCT[a]

Exam	Number of slices	IQ observers	Agreement									
			R1		R2		R3		T1		T2	
			M.A	P.v	M.A	P.v	M.A	P.v	M.A	P.v	M.A	P.v
Abdomen	16	R1			0.928	< 0.001	0.700	< 0.001	0.750	< 0.001	0.553	< 0.001
		R2					0.754	< 0.001	0.736	< 0.001	0.527	< 0.001
		R3							0.792	< 0.001	0.561	< 0.001
		T1									0.616	< 0.001
		T2										
Chest		R1			0.733	< 0.001	0.725	< 0.001	0.650	< 0.001	0.728	< 0.001
		R2					0.907	< 0.001	0.802	< 0.001	0.876	< 0.001
		R3							0.780	< 0.001	0.797	< 0.001
		T1									0.777	< 0.001
		T2										
Brain		R1			1.000	< 0.001	1.000	< 0.001	0.929	< 0.001	0.929	< 0.001
		R2					1.000	< 0.001	0.929	< 0.001	0.929	< 0.001
		R3							0.929	< 0.001	0.929	< 0.001
		T1									1.000	< 0.001
		T2										
Abdomen	32	R1			0.629	< 0.001	0.765	< 0.001	0.620	< 0.001	0.744	< 0.001
		R2					0.680	< 0.001	0.631	< 0.001	0.454	< 0.001
		R3							0.624	< 0.001	0.616	< 0.001
		T1									0.447	< 0.001
		T2										
Chest		R1			0.307	< 0.001	0.365	< 0.001	0.406	< 0.001	0.321	< 0.001
		R2					0.766	< 0.001	0.675	< 0.001	0.125	< 0.001
		R3							0.784	< 0.001	0.150	< 0.001
		T1									0.091	0.002
		T2										
Brain		R1	1	< 0.001	-	-	-	-	-	-	-	-
		R2					-	-	-	-	-	-
		R3							-	-	-	-
		T1									-	-
		T2									1	< 0.001
Abdomen	64	R1			0.751	< 0.001	0.693	< 0.001	0.599	< 0.001	0.671	< 0.001
		R2					0.849	< 0.001	0.746	< 0.001	0.782	< 0.001
		R3							0.854	< 0.001	0.807	< 0.001
		T1									0.874	< 0.001
		T2										
Chest		R1			0.959	< 0.001	0.931	< 0.001	0.624	< 0.001	0.554	< 0.001
		R2					0.945	< 0.001	0.613	< 0.001	0.544	< 0.001
		R3							0.641	< 0.001	0.570	< 0.001
		T1									0.898	< 0.001
		T2										
Brain		R1			-	-	-	-	-	-	-	-
		R2					-	-	-	-	-	-
		R3							-	-	-	-
		T1									-	-
		T2										

Abbreviations: IQ, image quality; M.A, measurement of agreement kappa; MSCT, multiple slice CT; P.v, P value; R, Radiologist; T, Radiologic Technologist.
[a]- = No statistics are computed because the variables are constants.

Comparison of our statistics with other CT dose studies is given in Table 8. The X-ray dose is less than established in the Norway survey from 2009, but higher than the rest for the brain, while the abdomen and chest are the highest from all the surveys and recommendations as listed in Table 8.

5. Discussion

If the current patient dose is unusually high, there must be a local assessment of procedures and the tools in order to decide whether the procedure has been sufficiently optimized. If not, measures aimed at reducing doses should be taken; a number of scan parameters and

Table 6. Correlation Between CTDIv and Image Quality Scores for Each MSCT

Category	Number of slices	Image quality observers ratings									
		R 1		R 2		R 3		T 1		T 2	
		C.C	P.v	C.C	P.v	C.C	P.v	C.C	P.v	C.C	P.v
CTDIv	16	0.882	< 0.01	0.883	< 0.01	0.883	< 0.01	0.887	< 0.01	0.875	< 0.01
	32	0.877	< 0.01	0.559	< 0.01	0.613	< 0.01	0.622	< 0.01	0.789	< 0.01
	64	0.608	< 0.01	0.596	< 0.01	0.586	< 0.01	0.478	< 0.01	0.489	< 0.01

Abbreviations: C.C, Correlation Coefficient; CTDIv, CT dose volume index; R, Radiologist; T, Radiologic Technologist; MSCT, multiple slice CT; P.v, P value.

Table 7. Productive Power of Dose to Predict Image Quality[a]

Exam	Number of slices	Cut-off	Sensitivity	Specificity	Area under the curve
Abdomen	16	14.15	98.3%	88.3%	0.986
	32	17.43	100%	96.9%	1.000
	64	19.09	85.4%	49.1%	0.703
Chest	16	15.94	98.8%	98.8%	0.998
	32	13.19	100%	81.8%	0.941
	64	15.86	36.6%	24.7%	0.598
Brain	16	-	-	-	-
	32	-	-	-	-
	64	-	-	-	-

[a] - = No statistics are computed because the variables are constants.

Table 8. Comparisons International DRLs [CTDIvol (mGy) and DLP (mGy)] with the DRLs Obtained in This Study[a]

Exam	EU 2004		UK 2003		Norway 2009		Switzerland 2010		Germany 2010		Ireland 2010		Jordan 2016	
	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP
Head	60	990	100	930	75	1000	65	1000	65	950	66	940	70.05	1209.4
Abdomen	16	726	14	560	15	710	15	650	20	900	12	600	17.09	708.33
Chest	12	430	13	580	15	400	10	400	12	400	9	390	14.76	594.77

Abbreviations: CTDIv, CT dose volume index; DLP, dose-length product; DRL, diagnostic reference level.
[a] The data in this table is based on reference (28).

technical measures have to be considered for reduction in the dose of radiation associated with CT scans.

In general, image quality means how precisely obtained CT attenuation data is recreated into an optical image representing definite anatomical characters. The essential reason of radiation dose executive and the ALARA idea stems from the link between image qualities and radiation dose. The anatomical aspect necessary for an exact clinical diagnosis should instruct whether to choose CT at all, and if so, to decide the parameters and x-ray dose used in CT scans. Nevertheless, decreasing the radiation dose also decreases an image's aspect and its prospective diagnostic significance.

The high capabilities of the technology are frequently not as important as the risk linked to it, and comparatively slight consideration has been paid to apply the ALARA code compared with the efforts concentrated on developing technology that increase image quality.

Nevertheless, companies have developed dose-reduction mechanisms such as the automatic exposure control (AEC) system. Many efforts to reduce radiation dose, as well as imperfections in measuring, and positioning can degrade image quality. A better image quality necessitates a higher radiation dose since it encompasses minor sampling gaps. This shows the multifaceted relationship between image quality and dose reduction (29).

The results were limited to six CT scan machines from six institutes using 16, 32 and 64-slice CT. These results showed that the radiation dose increased by increasing the number of detectors in the CT scan machine.

In addition, the image quality improved from 16 to 64-slice CT, meaning that the more the detectors, the better the image quality. This provides evidence that better image quality necessitates a higher radiation dose. By looking closely at Table 2 and Table 3, we can see that the high quality diagnostic information is linked to the higher dose.

Various studies have discussed and agreed that the radiation dose from MSCT is higher than conventional CT (30, 31). Nishizawa et al. (32) discussed the radiation dose from conventional CT and MSCT. They pointed out that the radiation dose from MSCT was slightly higher than conventional CT.

At the time of writing this paper, there were limited published studies that discussed the radiation dose of 16, 32 and 64 slice multidetector computed tomography (MDCT) for the brain, abdomen and chest. Jaffe et al. (30) and Alzimami (33) have discussed the radiation dose of 16 and 64 slices and they reported that the radiation dose of the 64 slice machine is lower than 16 slice machine. However, recent studies from Pera et al. (34), Karim et al. (35) and Tsapaki et al. (36) conducted a study to compare the radiation dose between 2, 4, 16, 32 and 64 slice MSCT for the brain, chest and abdomen and they found that 64 slice MSCT causes more radiation dose compared to 16, and 32 slice MSCT.

All of the CT scans were using 120 kVp. The 120 kVp appears to be a standard value for most of the CT protocols in current clinical imaging and some lower peak voltages such as 110 kVp, 100 kVp and 80 kVp were reported in an attempt to reduce radiation dosage to patients (34, 37-40).

The results showed that 16 has the lowest radiation dose and the lowest ranked image quality, followed by 32, and 64-slice CT scanners generally give the highest radiation dose also the best image quality, as listed in Table 2 and Table 3.

The image quality of the 64 slice CT scanner is far more (larger than 4) than the acceptable diagnostic image quality. Furthermore, the image quality ranking for the brain for all MSCT scanners is nearly 5 and that is the strongest evidence in supporting the concern that the image quality produced in current imaging practice may be more than enough for diagnosis and the radiation dose to patients may be more than necessary (10, 11, 16, 17).

Many studies have discussed the dose of different MSCT scanners, and agreed that the doses of 16-slice machines are similar or lower than the doses of 64-slice CT machines. A study by Fujii et al. (41) investigated the radiation dose involved in 64-slice CT examinations using a phantom study. Their study showed that 64-slice CT provides the same organ and effective doses for adults and children, similar to those with 4-slice, 8-slice and 16-slice CT scanners.

Our study shows that the image quality scores significantly increase as the CTDIv increases especially in the 16-slice CT scanner but as we step up to 32 and 64- slice scanners, the association between image quality scores and CTDIv becomes less significant than that of the 16- slice CT scanner and this is justified by the already higher CTDIv values of both 32 and 16- slice scanners. This result is parallel with the study done by Brian C. Allen on the effect of altering automatic exposure control settings and quality reference mAs on radiation dose, image quality, and diagnostic efficacy in MDCT enterography of active inflammatory Cohn's disease and reported that for 16-MDCT, CTDIvol decreased from 12.82 to 10.14 mGy and for 64-MDCT, from 15.72 to 11.42 mGy between original to intermediate dose levels. Images were rated suboptimal or nondiagnostic more often in the intermediate dose level (42).

This is the first time Jordanian detailed data have been collected for CT scan CTDIv and DLP and this study demonstrates that current CT dose levels are higher recommended value (Table 8).

The values of our CTDIv and DLP data are still beyond the achievable levels set in the surveys shown in Table 8, indicating that the hospitals included in this study can improve patient dose by optimizing their CT protocols.

There is a major shift towards multiple-slice scanners, in particular the 64 slice CT scanner and a significant decrease in single slice CT scanners in clinical practice. Our results and those from New Jersey project indicate that higher slice number CT scanners deliver higher radiation doses to patients in current clinical practice. It appears in contradiction to the claims that recently manufactured multiple slice CT scanners provide comparable radiation dose to patients as the single slice CT scanners but much better image quality (4). We believe that this is because the image quality and radiation dose were not optimized in most imaging centres and did not take the advantage of much less dose for comparable image quality from recently manufactured CT scanners.

Our results suggest that the higher dose of MSCT (16, 32 and 64-slices) scanners is mainly due to the higher mAs employed in these MSCT scanners. The normalized CTDIv (per 100mAs) indicate the scanner's dose output per 100mAs. It should be pointed out that the higher dose output per mAs does not mean that it is a better CT scanner, as the dose output varies from scanner to scanner even from the same manufacturer. One of the trends in CT manufacturing is that the dose output has improved over the years as the new generation CT scanners are introduced to the market (43).

These results highlight the importance of dose and image quality optimization in clinical practice. It could well be the case that most current imaging centres are ignoring the radiation doses to patients by providing the radiologists with the best image quality the CT scanners can produce, as the six hospitals of this study were randomly selected and represent the typical imaging centres. There is a major shift in current practice towards multiple-slice scanners, in particular the 64-slice CT scanner, and a significant decrease in single slice CT scanners in imaging centres (26, 43-45). The optimization of image quality and dose to patients for MSCT is urgently needed as MSCT scanners are more capable in producing high quality images as well as high radiation dose to patients.

One limitation of the study was that the study was based on data from only six hospitals and the inclusion of more data would have strengthened the study. Also, this work relied on the accuracy of reported DLP and CTDIv from each scanner. In addition, there was no control for patient height included within this study, which may impact the DLP values reported if variations of scan length are used.

In conclusion, the 16 slice CT scanner produced least image quality and radiation dose to patients in comparison with the 32 and 64 slice scanners. The CT scanners with higher numbers of slices deliver better image quality but also higher radiation doses to the patients. The 64 slice CT scanner produced the best image quality and highest radiation to patients in this study. The image quality produced by the16 slice CT scanner was acceptable for diagnosis and the 32 and 64 multiple slice CT scanners produced more than adequate image quality, therefore, delivered more radiation dose to patients than necessary in current clinical practice. As more and more multiple slice CT scanners are being introduced into clinical imaging centres, the image quality and radiation dose to patients should be optimized.

Acknowledgments

We would like to thank our respectful research assistants for their distinguished role in data collection.

Footnotes

Funding / Support: This work was supported by Jordan University of Science and Technology, Irbid-Jordan, under grant number 20140176.

Ethical Approval: This research project was approved by Jordan University of Science and Technology ethics on human research committee. The study was approved by JUST institutional review boards (IRB).

References

1. Efstathopoulos EP, Kelekis NL, Pantos I, Brountzos E, Argentos S, Grebac J, et al. Reduction of the estimated radiation dose and associated patient risk with prospective ECG-gated 256-slice CT coronary angiography. *Phys Med Biol*. 2009;**54**(17):5209–22. doi: 10.1088/0031-9155/54/17/009. [PubMed: 19671974].
2. Mori S, Endo M, Nishizawa K, Murase K, Fujiwara H, Tanada S. Comparison of patient doses in 256-slice CT and 16-slice CT scanners. *British J Radiol*. 2006;**79**(937):56–61.
3. Arthurs O, Yates S, Set P, Gibbons D, Dixon A. Evaluation of image quality and radiation dose in adolescent thoracic imaging: 64-slice is preferable to 16-slice multislice CT. *Br J Radiol*. 2014;**87**(1036):20130621. doi: 10.1259/bjr.20130621. [PubMed: 24288400]. [PubMed Central: PMC4067011].
4. Valentin J. *Managing patient dose in multi-detector computed tomography (MDCT)*. Elsevier; 2007.
5. Jurik AG, Jessen KA, Hansen J. Image quality and dose in computed tomography. *Eur Radiol*. 1997;**7**(1):77–81. doi: 10.1007/s003300050114. [PubMed: 9000403].
6. Iannaccone R, Catalano C, Mangiapane F, Murakami T, Lamazza A, Fiori E, et al. Colorectal polyps: detection with low-dose multidetector row helical CT colonography versus two sequential colonoscopies. *Radiology*. 2005;**237**(3):927–37. doi: 10.1148/radiol.2373041747. [PubMed: 16304113].
7. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JA, et al. Strategies for CT radiation dose optimization. *Radiology*. 2004;**230**(3):619–28. doi: 10.1148/radiol.2303021726. [PubMed: 14739312].
8. Kalra MK, Rizzo S, Maher MM, Halpern EF, Toth TL, Shepard JA, et al. Chest CT performed with z-axis modulation: scanning protocol and radiation dose. *Radiology*. 2005;**237**(1):303–8. doi: 10.1148/radiol.2371041227. [PubMed: 16183938].
9. Menzel H, Schibilla H, Teunen D. European guidelines on quality criteria for computed tomography. *Luxembourg Europ Commission*. 2000:16262.
10. Vite C, Mangini M, Strocchi S, Novario R, Tanzi F, Carrafiello G. Dosimetric and image quality assessment of different acquisition protocols of a novel 64-slice CT scanner. Medical Imaging. *Int Societ Optic Photonic*. 2006;**6142**.
11. Nagel HD. *CT parameters that influence the radiation dose. Radiation dose from adult and pediatric multidetector computed tomography*. Springer; 2007. p. 51–79.
12. Bongartz G, Golding S, Jurik A, Leonardi M, Van Meerten E, Geleijns J. European guidelines on quality criteria for computed tomography. *EUR(Luxembourg)*. 1999.
13. Gray JE, Archer BR, Butler PF, Hobbs BB, Mettler FJ, Pizzutiello RJ, et al. Reference values for diagnostic radiology: application and impact. *Radiology*. 2005;**235**(2):354–8. doi: 10.1148/radiol.2352020016. [PubMed: 15758190].
14. Seeram E, Brennan PC. Diagnostic reference levels in radiology. *Radiol Technol*. 2006;**77**(5):373–84. quiz 385-7. [PubMed: 16709686].
15. Shrimpton P, Hillier M, Lewis M, Dunn M. National survey of doses from CT in the UK: 2003. *Br J Radiol*. 2014.
16. Brix G, Nagel HD, Stamm G, Veit R, Lechel U, Griebel J, et al. Radiation exposure in multi-slice versus single-slice spiral CT: results of a nationwide survey. *Eur Radiol*. 2003;**13**(8):1979–91. doi: 10.1007/s00330-003-1883-y. [PubMed: 12687286].
17. Kalender WA. *Computed tomography: fundamentals, system technology, image quality, applications*. John Wiley & Sons; 2011.
18. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. *Radiol Clin North Am*. 2009;**47**(1):27–40. doi: 10.1016/j.rcl.2008.10.006. [PubMed: 19195532]. [PubMed Central: PMC2743386].
19. Yu L, Liu X, Leng S, Kofler JM, Ramirez-Giraldo JC, Qu M, et al. Radiation dose reduction in computed tomography: techniques and future perspective. *Imaging Med*. 2009;**1**(1):65–84. doi: 10.2217/iim.09.5. [PubMed: 22308169]. [PubMed Central: PMC3271708].
20. McCollough C, Cody D, Edyvean S, Geise R, Gould B, Keat N. The measurement, reporting, and management of radiation dose in CT. *Report AAPM Task Group*. 2008;**23**:1–28.

21. Huda W, Ogden KM, Khorasani MR. Converting dose-length product to effective dose at CT. *Radiology*. 2008;**248**(3):995–1003. doi: 10.1148/radiol.2483071964. [PubMed: 18710988]. [PubMed Central: PMC2657852].
22. Tapiovaara MJ. Review of relationships between physical measurements and user evaluation of image quality. *Radiat Prot Dosimetry*. 2008;**129**(1-3):244–8. doi: 10.1093/rpd/ncn009. [PubMed: 18252851].
23. Zarb F, Rainford L, McEntee MF. Image quality assessment tools for optimization of CT images. *Radiograph*. 2010;**16**(2):147–53.
24. Tingberg A, Bath M, Hakansson M, Medin J, Besjakov J, Sandborg M. Evaluation of image quality of lumbar spine images: a comparison between FFE and VGA Oxford Journals. *Radiat Protect Dosimetr*. 2005;**114**(1-3):53–61.
25. McCollough C, Cody D, Edyvean S, Geise R, Gould B, Keat N. *The Measurement, Reporting, and Management of Radiation Dose in CT*. 2008. Available from: http://www.aapm.org/pubs/reports/rpt_96.pdf.
26. Rehani M, Kalra M, McCollough C, Nagel HD, Collins L, Kalender W. *Managing Patient Dose in Multi-detector Computed Tomography (MDCT)*. 2006.
27. Tingberg A, Bath M, Hakansson M, Medin J, Besjakov J, Sandborg M, et al. Evaluation of image quality of lumbar spine images: a comparison between FFE and VGA. *Radiat Prot Dosimetry*. 2005;**114**(1-3):53–61. doi: 10.1093/rpd/nch566. [PubMed: 15933081].
28. Foley SJ, McEntee MF, Rainford LA. Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol*. 2012;**85**(1018):1390–7. doi: 10.1259/bjr/15839549. [PubMed: 22595497]. [PubMed Central: PMC3474022].
29. Furlow B. Radiation Dose in Computed Tomography radiologic. *Technol*. 2010;**81**:437–50.
30. Jaffe TA, Yoshizumi TT, Toncheva G, Anderson-Evans C, Lowry C, Miller CM, et al. Radiation dose for body CT protocols: variability of scanners at one institution. *AJR Am J Roentgenol*. 2009;**193**(4):1141–7. doi: 10.2214/AJR.09.2330. [PubMed: 19770340].
31. Thornton FJ, Paulson EK, Yoshizumi TT, Frush DP, Nelson RC. Single versus multi-detector row CT: comparison of radiation doses and dose profiles. *Academic Radiol*. 2003;**10**(4):379–85.
32. Nishizawa K, Mori S, Ohno M, Yanagawa N, Yoshida T, Akahane K, et al. Patient dose estimation for multi-detector-row CT examinations. *Radiat Prot Dosimetry*. 2008;**128**(1):98–105. doi: 10.1093/rpd/ncm244. [PubMed: 17595212].
33. Alzimami K. Assessment of Radiation doses to Paediatric Patients in Computed Tomography Procedures. *Pol J Radiol*. 2014;**79**:344–8. doi: 10.12659/PJR.890806. [PubMed: 25289112]. [PubMed Central: PMC4186214].
34. Pera CM, Girjoaba OI, Cucu A, Iosif M. Comparison of radiation dose in abdomen-pelvis and trunk imaging between 64 slice and 16 slice CT. *Physica Medica*. 2016;**3**(Supplement 3):295.
35. Karim M, Hashim S, Sabarudin A, Bradley D, Bahruddin N. Evaluating Organ Dose and Radiation Risk of Routine CT Examinations in Johor, Malaysia. *Sains Malaysiana*. 2016;**45**(4):567–73.
36. Tsapaki V, Aldrich JE, Sharma R, Staniszewska MA, Krisanachinda A, Rehani M, et al. Dose reduction in CT while maintaining diagnostic confidence: diagnostic reference levels at routine head, chest, and abdominal CT–IAEA-coordinated research project. *Radiology*. 2006;**240**(3):828–34. doi: 10.1148/radiol.2403050993. [PubMed: 16837668].
37. Heyer CM, Mohr PS, Lemburg SP, Peters SA, Nicolas V. Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: prospective randomized study. *Radiology*. 2007;**245**(2):577–83. doi: 10.1148/radiol.2452061919. [PubMed: 17940308].
38. Waaijer A, Prokop M, Velthuis BK, Bakker CJ, de Kort GA, van Leeuwen MS. Circle of Willis at CT angiography: dose reduction and image quality–reducing tube voltage and increasing tube current settings. *Radiology*. 2007;**242**(3):832–9. doi: 10.1148/radiol.2423051191. [PubMed: 17229873].
39. Nakayama Y, Awai K, Funama Y, Hatemura M, Imuta M, Nakaura T, et al. Abdominal CT with low tube voltage: preliminary observations about radiation dose, contrast enhancement, image quality, and noise. *Radiology*. 2005;**237**(3):945–51. doi: 10.1148/radiol.2373041655. [PubMed: 16237140].
40. Ogbole GI. Radiation dose in paediatric computed tomography: risks and benefits. *Ann Ib Postgrad Med*. 2010;**8**(2):118–26. [PubMed: 25161479]. [PubMed Central: PMC4111023].
41. Fujii K, Aoyama T, Yamauchi-Kawaura C, Koyama S, Yamauchi M, Ko S . Radiation dose evaluation in 64-slice CT examinations with adult and paediatric anthropomorphic phantoms. *Br J Radiol*. 2014.
42. Allen BC, Baker ME, Einstein DM, Remer EM, Herts BR, Achkar JP. Effect of Altering Automatic Exposure Control Settings and Quality Reference mAs on Radiation Dose, Image Quality, and Diagnostic Efficacy in MDCT Enterography of Active Inflammatory Crohn's Disease. *America J Roentgenol*. 2010;**195**(1):89–100.
43. Elojeimy S, Tipnis S, Huda W. Relationship between radiographic techniques (kilovolt and milliampere-second) and CTDI(VOL). *Radiat Prot Dosimetry*. 2010;**141**(1):43–9. doi: 10.1093/rpd/ncq138. [PubMed: 20406742].
44. Golding SJ. Multi-slice computed tomography (MSCT): the dose challenge of the new revolution. *Radiat Prot Dosimetry*. 2005;**114**(1-3):303–7. doi: 10.1093/rpd/nch545. [PubMed: 15933126].
45. Tsapaki V, Rehani M. Dose management in CT facility. *Biomed Imaging Interv J*. 2007;**3**(2). e43. doi: 10.2349/biij.3.2.e43. [PubMed: 21614279]. [PubMed Central: PMC3097661].