ORIGINAL ARTICLE

Evaluation of Patients' Received Doses in Chest CT Scan Protocols: A Retrospective Study

Sadegh Shurche[1], Tinoosh Almasi[2], Maryam Tima[3], Nima Rostampour[2*]

[1] *Department of Medical Physics, Faculty of Medicine, Tarbiat Modares University, Tehran, Iran*

[2] *Department of Medical Physics, School of Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran*

[3] *Medical Imaging Department, Chamran Hospital, Kermanshah University of Medical Sciences, Kermanshah, Iran*

*Corresponding Author: Nima Rostampour
Email: nima.rostampour@kums.ac.ir

Received: 13 February 2023 / Accepted: 16 May 2023

Abstract

Purpose: This study aims to investigate and compare the doses received by Corona Virus Disease (Covid-19) patients on Computed Tomography (CT) scans by changing the scan parameters to diagnose the disease and evaluate its course and effects.

Materials and Methods: The total number of patients was 8290, with 4070 requesting a CT scan of the lungs. In 3512 cases, the purpose of the examination was to verify Covid-19. The remaining 558 scans were for other diseases. Two CT protocols were used for lung imaging: A low-dose protocol (kV=120 kVp and mAs=80ms) to screen for Covid-19 and a Smart protocol (kV=120 kVp and mAs = Smart) for other diseases. Each image was assigned a score from 1 to 5. The score reflects the quality of the image and Covid-19-related features such as Ground Glass Opacities (GGO), crazy paving, consolidation, Nodular Infiltrates (NI), Broncho Vascular Thickening (BVT), and Pleural Effusion (PE).

Results: In the low-dose protocol, the effective dose received by patients varied between 1.98 and 2.66 ± 0.1 milli Sievert (mSv) according to the different Dose-Length Product (DLP) values. The effective dose varies between 2.7 and 8.44 mSv for the Smart protocol. The maximum Size-Specific Dose Estimate (SSDE) was 11.97 ± 0.2 and 21.58 ± 0.9 milli Gray (mGy) for each protocol, respectively. The maximum carcinogenicity was 1.09×10^{-4} and 3.05 × 10−4, respectively. Radiologists gave an overall acceptance rate of 4.9 ± 0.1 and 4.8 ± 0.2 out of a possible 5-point for images with low-dose and smart protocols, respectively.

Conclusion: Decreasing the value of milli Ampere-seconds (mAs) decreases the effective dose, the size-specific dose estimate, and the carcinogenicity of radiation in patients requesting scans of the lungs CT. Images lose quality but are still good enough to determine the progression and impact of Covid-19.

Keywords: Computed Tomography; Corona Virus Disease -19; Low-Dose Protocol; Smart Scan.

DOI:

1. Introduction

Coronavirus Disease (COVID-19) is a viral respiratory disease that was first reported in December 2019, when a group of patients with unknown pneumonia appeared in the city of Wuhan, Hubei Province, China [1, 2]. A Reverse Transcription Polymerase Chain Reaction (RT-PCR) diagnostic test is used to diagnose COVID-19. However, problems such as the limited availability of preferred diagnostic tests, the high number of false-negative results from RT-PCR in the early stages of the disease, and the inability of the test to assess disease severity and progression have led to the increasing use of cross-sectional imaging studies for this purpose, such as CT [3]. Despite reports of chest radiography and nonionizing radiation sonography imaging, CT examination remains the preferred method of imaging in COVID-19 pneumonia [4].

Since the examination CT, which is the main cause of radiation exposure to the population, is a medical diagnostic imaging procedure, it is extremely beneficial to promote low-dose imaging protocols CT. A recent study showed that two broken DNA strands and chromosomal translocations increased in patients undergoing smart-dose examinations CT, while no effects on human DNA were found in patients undergoing low-dose examinations CT [5]. CT is still not a low-dose imaging modality although there have been numerous advances in hardware and software to reduce CT dose, including high-sensitivity detectors, new Automatic Exposure Control (AEC) systems, adaptive X-ray tube voltage, and new image reconstruction algorithms [6]. Therefore, the extent of radiation exposure with this method remains a concern [7].

For patients with suspected or known COVID-19 pneumonia, there is less clarity and guidance on specific CT techniques and protocols for imaging. For suspected or known COVID-19 pneumonia, most publications report single-phase, noncontrast chest imaging CT without contrast injection, or postcontrast series [8-10]. A significant proportion of patients with COVID -19 pneumonia either are short of breath or have a cough when the scan parameters for the thoracic protocol CT are selected. The choice of individual test parameters depends on the type and make of the CT scanner. In general, most low-dose thoracic examinations CT can be performed with less than or more than 100 kV and low tube current. The use of a programmed tube current matching method should be preferred, as it allows for a programmed change in tube current based on sustained body habitus while storing variables that allow for more rapid testing. Programmed tube current balancing strategies require the client to specify an image quality parameter to ensure that lower dose examinations are performed in the chest CT compared to routine chest examinations CT [3].

There are a few considerations for evaluating low-dose CT convention in patients with known or suspected COVID-19 pneumonia. Kang *et al.* have described a satisfactory evaluation of aspiratory opacities associated with COVID-19 pneumonia at 100 kV with tin channel and iterative recovery procedure with a volume CT dose index ($CTDI_{vol}$) of 0.4 mGy versus a standard dose of 3.4 mGy [8]. Another study combined 100 kV with tin channel and 0.6 s insertion time using a high tilt and fast gantry rotation time to secure chest CT studies in COVID-19 pneumonia with 0.6 mGy $CTDI_{vol}$ comparable to chest CT with 6.4 mGy [8].

Several articles have investigated dose reduction due to changes in scan parameters [11-14]. However, the value of $CTDI_{vol}$ and the dose-length product are often not reported in these articles, and the value of SSDE is not calculated. Another issue is the small number of patients studied in these studies. In addition, these studies did not consider the wide range of age groups, and often only, a specific age group was studied.

Reducing the mAs parameter may reduce the dose to the patient, but it should be noted that excessive reduction of imaging parameters, including mAs, will result in loss of anatomical information about certain areas of the patient's body and make the diagnosis of the disease more difficult [15, 16].

Although new methods have been presented, such as the use of Convolutional Neural Network (CNN) algorithms to reduce the doses received by the patient, they are not applicable and reliable in the clinic because the patient's anatomical information is lost [17]. It is not easy to convert conventional full-dose imaging protocols CT to low-dose protocols using neural network algorithms because of the concerns about increased rates of false positives due to high noise and lost anatomical structures [18].

This study aimed to investigate and compare the doses received by COVID-19 patients undergoing a scan of the lungs CT by changing the scan parameters for the diagnosis and evaluation of disease severity, progression, and complications. Our goal is also to compare two protocols with variable parameters to reduce the dose patients receive as much as possible while the disease can be diagnosed.

2. Materials and Methods

2.1. Patient Selection

In this study, we retrospectively collected a dataset containing 8290 chest CT scans together with their clinical reports between March 21, 2021, and March 21, 2022.

The age and sex of the patients were recorded. They were divided into nine groups according to age (in years): 0-15, 16-25, 26-35, 36-45, 46-55, 56-65, 66-75, 76-85, and 86-94.

2.2. CT Protocol

The GE 16-slice scanning device CT was used in this study. Table 1 shows the protocols used for thoracic imaging.

Table 1. Parameters of protocols used for lung imaging

Imaging protocol Imaging parameters	Low-dose protocol	Smart protocol
kV	120	120
mAs	80	80-300
Tilt	0	0
sFOV	Large	Large
Interval (mm)	5	5
Thick Speed	5	5
Scan Type	Helical Full 1 s	Helical Full 1 s
Total Exposure Time	8.4	8.4

2.3. Effective Radiation Dose and Cancer Risk Estimation

The effective dose was calculated for the chest scan test CT as the product of the Dose-Length Product (DLP) taken from the patient information and the corresponding conversion coefficients (the value of 0.014 proposed by the European Committee on Radiation Protection [19]).

The American Association of Physicists in Medicine (AAPM) has published 204 Size-Specific Dose Estimation (SSDE) concepts calculated as the product of a size-dependent conversion coefficient and $CTDI_{vol}$. This provides a simple estimate of the mean patient dose from CT at the center of the scan area that accounts for patient size and can be easily calculated by measuring scanner output, i.e., $CTDI_{vol}$. The value of SSDE can be calculated using the following equation (Equation 1) [20].

$$\text{size specific dose estimate} = SSDE = f_{size}^{32X} \times CTDI_{vol}^{32} \quad (1)$$

The AP and lateral diameters required to calculate the SSDE are measured on the CT scan image as shown in Figure 1.

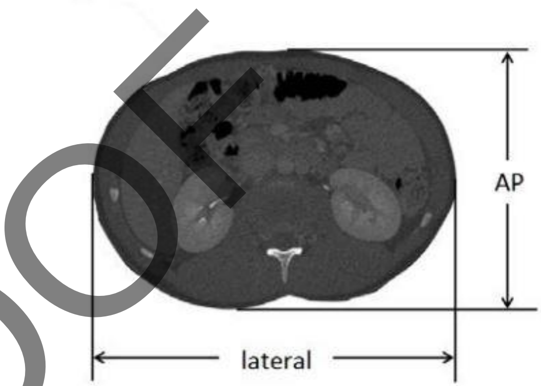

Figure 1. Method of measuring AP and lateral diameters on the CT scan image

Subsequently, the carcinogenesis probability can be calculated as the product of the mean effective dose resulting from the smart-dose and low-dose scan studies CT and the risk coefficient (0.055 Sv^{-1}) (The value is 0.041 Sv^{-1} for adults and 0.055 for the total population [21]). It can be compared in the two protocols (the normal and the low dose).

The total number of visits to the hospital CT scan department was 8290 patients. Figure 2 shows the numbers of low-dose and smart-dose lung CT scans.

Figure 3 shows the number of lung CT scan requests with respect to the patients' age distribution. The majority of patients lie within the age range of 36-45 years, and the minority are between 86 and 94 years old.

The score reflects the quality of the image and Covid-19 related features such as Ground Glass Opacities (GGO), crazy paving, consolidation, Nodular Infiltrates (NI), Broncho Vascular Thickening (BVT), and Pleural Effusion (PE). This process was done by a radiologist.

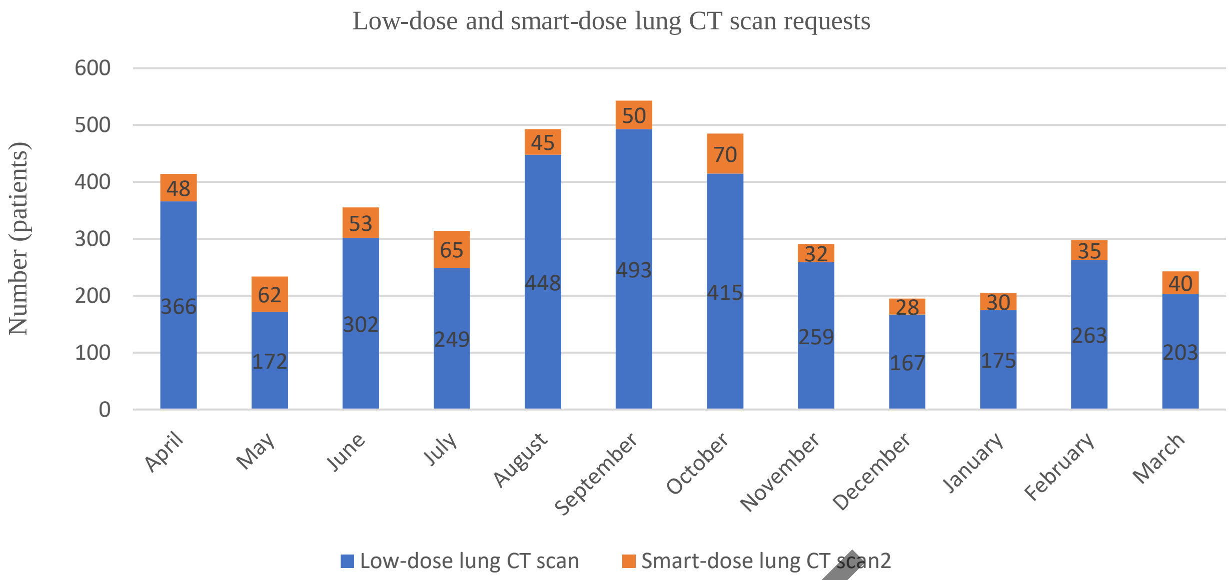

Figure 2. Comparison of the numbers of low-dose and smart-dose lung CT scan requests (The total number of lung CT scan requests was 4070)

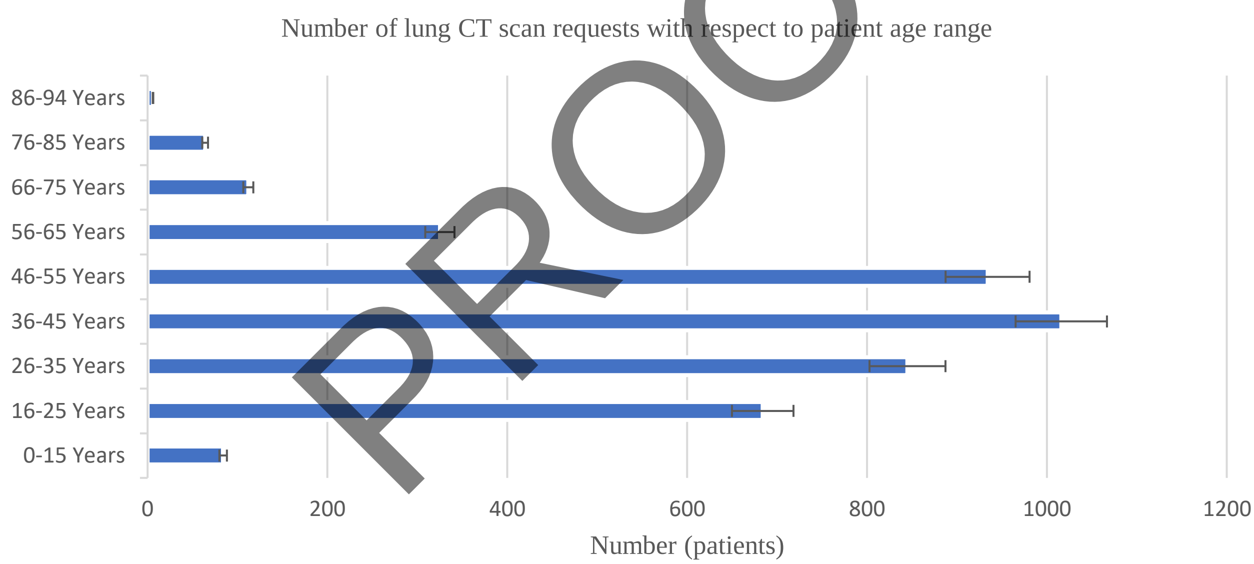

Figure 3. Number of lung CT scan requests with respect to patients' age distribution (The total number of lung CT scan requests was 4070

3. Results

Effective dose values based on the low-dose protocol ranged from 1.98 to 2.66 ± 0.1 mSv for patients with different DLP values. Values based on the smart protocol ranged from 2.8 to 7.44 ± 0.1 mSv.

The maximum carcinogenesis probability was 1.09×10^{-4} for the low-dose protocol and 3.05×10^{-4} for the smart protocol.

Table 2 shows the values of SSDE for the low-dose protocol. The largest value refers to a patient with an effective diameter of 24 cm, and the smallest refers to one with 60 cm.

Table 2. SSDE values in mGy for different effective diameters and the low-dose protocol

Lat+AP (Dim (cm))-Effective Dim	Conversion Factor	CTDI$_{vol}$ (mGy)	Size specific dose estimate (mGy)
24	2.41	4.97	11.97±0.2
26	2.32	4.97	11.53±0.1
28	2.24	4.97	11.13±0.1
30	2.16	4.97	10.73±0.2
32	2.08	4.97	10.33±0.3
34	2.01	4.97	9.98±0.1
36	1.94	4.97	9.64±0.3
38	1.87	4.97	9.29±0.1
40	1.80	4.97	8.94±0.2
42	1.74	4.97	8.64±0.2
44	1.67	4.97	8.29±0.1
46	1.62	4.97	8.05±0.2
48	1.56	4.97	7.75±0.3
50	1.50	4.97	7.45±0.1
52	1.45	4.97	7.20±0.3
54	1.40	4.97	6.95±0.4
56	1.35	4.97	6.70±0.1
58	1.30	4.97	6.46±0.3
60	1.25	4.97	6.21±0.1

Table 3. SSDE values in mGy for different effective diameters and the smart protocol

Lat+AP (Dim (cm))-Effective Dim	Conversion Factor	CTDI$_{vol}$ (mGy)	Size specific dose estimate (mGy)
24	2.41	5	12.05±0.1
26	2.32	5.4	12.52±0.2
28	2.24	5.85	13.10±0.6
30	2.16	6.25	13.50±0.2
32	2.08	6.64	13.81±0.1
34	2.01	6.94	13.94±0.2
36	1.94	7.26	14.08±0.5
38	1.87	7.63	14.26±0.3
40	1.80	7.98	14.36±0.1
42	1.74	8.14	14.16±0.2
44	1.67	8.35	13.94±0.3
46	1.62	8.68	14.04±0.1
48	1.56	8.96	13.97±0.2
50	1.50	9.32	13.98±0.5
52	1.45	9.56	13.86±0.3
54	1.40	9.95	13.93±0.1
56	1.35	11.67	15.75±0.3
58	1.30	13.85	18.00±0.1
60	1.25	15.99	19.98±0.1
62	1.21	17.84	21.58±0.9

Table 3 shows the values of SSDE in mGy for different effective diameters and the smart protocol. The largest value refers to an effective diameter of 62 cm and the smallest to one of 24 cm.

Table 4 contains the ranges of the different parameters in the low-dose and smart protocols.

Table 4. Different parameters in the low-dose and smart protocols

KVp	mAs	CTDI$_{vol}$ (mGy)	DLP (mGy-cm)	Phantom (cm)
120	80	4.97	142-190	Body 32
120	80 - 300	5 - 17.84	200 - 532	Body 32

Table 5 summarizes the overall image quality ratings assigned by human viewers for the various lesions.

Table 5. Scores of image quality assigned by human viewers to different lesions

Lesion	Low-Dose Protocol	Smart Protocol
GGO	4.8 ± 0.1	5 ± 0.3
CS	4.9 ± 0.2	4.9 ± 0.3
CP	5 ± 0.1	5 ± 0.2
NI	4.9 ± 0.5	5 ± 0.2
BVT	5 ± 0.6	5 ± 0.1
PE	4.8 ± 0.2	4.9 ± 0.3

GGO: Ground Glass Opacities; CS: Consolidation; CP: Crazy Paving; NI: Nodular Infiltrates; BVT: Bronchovascular Thickening; PE: pleural effusion.

Scores (Excellent, 5; Good, 4; Adequate, 3; Poor, 2; Non-interpretable, 1).

Table 6 shows the visual ratings of the various images for different aspects of the CT findings, including lesion status, margin, shape, and density.

To review the imaging parameters and dose to patients, various studies with our study are listed in Table 7.

Table 6. Assessment of image quality through visual scoring of different images documenting different aspects of the CT findings. Scores (Excellent, 5; Good, 4; Adequate, 3; Poor, 2; Non-interpretable, 1)

CT Findings	Low-Dose Protocol	Smart Protocol
Lesion status	4.9 ± 0.1	5 ± 0.3
Margin	4.8 ± 0.1	4.9 ± 0.1
Shape	5 ± 0.3	5 ± 0.1
Density	4.9 ± 0.1	5 ± 0.1

4. Discussion

Despite the fierce controversy and debate over the potential stochastic effects of small amounts of ionizing radiation and the linear no-threshold theory, there are still concerns about radiation exposure [28]. CT imaging is widely used in clinical diagnosis, prognosis, assessment of response to treatment, and tracking of a variety of diseases. Therefore, it helps increase the dose of radiation to patients in modern health care [29]. In the current COVID-19 crisis, chest imaging CT is the most rapid diagnostic approach. However, it is still a high-dose imaging method. Therefore, developing a low-dose protocol that ensures optimal image quality is clinically effective for public health management.

Table 7. Data from a series of studies performed on patients infected with COVID-19 focus on chest examination parameters CT

Author name	No. of cases	Studied population	Tube voltage (kV)	Tube currenttime (mAs)	$CTDI_{vol}$ (mGy)	DLP (mGy cm)	SSDE (mGy)	Effective dose (mSv)	Reduce patient dose
Kang *et al.* [8]	-	-	100	112/96*	0.39 L	14.5	-	0.20	1/8 to 1/9
Tabatabaei *et al.* [15]	63	50 years or older	120	30	3.505 ± 0.83	112.23 ± 26.55	-	1.80	73%
Caruso *et al.* [10]	158	57 years ± 17	120	100–250	-	-	-	-	-
Wen *et al.* [22]	103	-	120	145–300	9.34 ± 4.13	-	-	-	-
Yang *et al.* [23]	102	15–79 years old	120	350	-	-	-	-	-
Pan *et al.* [24]	21	25-63 years	120	-	8.4 ± 2.0	-	-	-	-
Liu *et al.* [25]	15	-	120	-	4.1 ± 0.9	-	-	-	-
Song *et al.* [26]	51	16–76 years	120	180–400	-	-	-	-	-
Wang *et al.* [27]	114	-	120	320	-	-	-	-	-
Current study	4070	0-94 years	120	80-300 (standard-dose) 80 (low-dose)	5 - 17.84 (standard-dose) 4.97 (low-dose)	200 – 532 (standard-dose) 142-190 (low-dose)	12.05±0.1 - 21.58±0.9 (standard-dose) 6.21±0.1 - 11.97±0.2 (low-dose)	2.8 - 7.44 ± 0.1 (standard-dose) 1.98 - 2.66 ± 0.1(low-dose)	by up to 35 percent

Therefore, in response to the COVID-19 outbreak and the resulting demand for CT imaging for a large population, a low-dose imaging approach was proposed to minimize their radiation exposure. This is achieved by reducing the mAs.

This study aims to compare the dose received by patients of different age groups on two standard protocols and low dose, to calculate the value of SSDE in patients of different age groups, to determine the probability of carcinogenesis, and to investigate the possibility of using images of the low-dose protocol to diagnose COVID-19 disease.

Table 2 shows that the SSDE values for the low-dose protocol decrease with the increase of the effective diameter, which is due to the decrease of the conversion factor. Table 3 shows that with the increase of the effective diameter in the smart protocol, the value of SSDE increases, which is due to the change of the values of $CTDI_{vol}$. As can be seen in Table 4, the decrease in mAs value also decreases the values of $CTDI_{vol}$ and DLP. Our results show that there is no significant difference between the low-dose and standard-dose images CT in the diagnosis of radiographically normal, laboratory-confirmed COVID-19 pneumonia cases, with an excellent agreement rate between readers (Tables 5 & 6).

Several previous studies have confirmed that low-dose breast CT protocols have similar diagnostic accuracy to standard dose despite poorer image quality. In a comprehensive study by Kubo *et al.*, low-dose and standard-dose techniques were shown to have statistically the same ability to detect intrathoracic abnormalities. More specifically, their study showed that low-dose chest examination CT (50 mAs) was as accurate as standard dose examination (150 mAs) in detecting abnormalities of the lung parenchyma (languor, emphysema, micronodules, honeycombs, and reticular compaction) and mediastinal/pleural findings (aortic aneurysm, coronary artery calcification, pleural effusion, lymphadenopathy, and mediastinal tumors) [30]. Other studies have examined low-dose capability in CT pulmonary angiography [31]. However, there is currently no approved low-dose protocol for routine chest examination CT in selected clinical scenarios, such as COVID-19 pneumonia.

As shown in Table 7, the various studies often use a small number of patients, and the age group studied is small. Tabatabaei *et al.* [15] used mAs equal to 30, which causes all parameters of their study, including $CTDI_{vol}$, DLP, and effective dose, to decrease more compared with our study, e.g., the effective dose in their study was 1.8 mSv, using the low-dose protocol in our study was 1.98, and also the value of carcinogenesis probability in their study was 0.74×10^{-4}, whereas in our study this value was 1.09×10^{-4}. Among the problems of excessive reduction of mAs value is the loss of anatomic information about some areas, which was not present in our study, in contrast to the work of Tabatabaei *et al.*

Although the use of deep-learning algorithms greatly reduces the values of $CTDI_{vol}$ and DLP, resulting in a significant reduction in the effective dose to patients, the images are of lower quality than other methods that have higher mAs values [17].

5. Conclusion

The results of our study show that the use of the low-dose protocol reduces effective dose compared with the smart protocol (by up to 35 percent), carcinogenesis probability (by up to 35 percent), $CTDI_{vol}$ (by up to 27 percent), DLP (by up to 35 percent), and SSDE (by up to 55 percent).

The results of the study showed that the use of the low-dose protocol allowed the generation of lower-dose images of acceptable quality. Although the quality of the predicted images was not exactly, the same as that of the full-dose images CT, most COVID-19 features were almost the same.

Acknowledgments

This article is from Research Plan No. 4000837, approved and fully funded by the Research and Technology Officer of Kermanshah University of Medical Sciences, with ethics code IR.KUMS. MEED.REC.1400.096.

We appreciate the collaboration made to us by the esteemed personnel at the Department of CT Scan of Shahid Doctor Chamran Hospital, in Kermanshah Province, to carry out the project.

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