OPTIMIZATION OF LUNG CT PROTOCOL FOR THE DIAGNOSTIC EVALUATION OF COVID-19 LUNG DISEASE

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This study intends to evaluate the different lung CT scan protocols used for the diagnostic evaluation of COVID-19-induced lung disease in Iranian imaging centers in terms of radiation dose and image quality. After data collecting, subjective image quality, radiation dose and objective image quality such as noise, SNR and CNR were assessed. Statistically significant differences in effective dose and image quality were evident among different lung CT protocols. Lowest and highest effective dose was1.31 ± 0.53 mSv related to a protocol with activated AEC (reference mAs = 20) and 6.15 ± 0.57 mSv related to a protocol with Fixed mAs (mAs = 100), respectively. A protocol with enabled tube current modulation with 70 mAs as a reference mAs, and protocol with 20 mAs and enabled AEC had the best and lowest image quality, respectively. To optimize the scan parameters, AEC must be used, and a range of tube currents (between 20 and 50 mAs) can produce acceptable images in terms of diagnostic quality and radiation dose for the diagnosis of COVID-19-induced lung disease.

INTRODUCTION

Since the new coronavirus disease (COVID-19) outbreak in December 2019, various methods have been introduced to diagnose this viral infection. Although real-time polymerase chain reaction (RT-PCR) is now the standard method of diagnosing the COVID-19, chest computed tomography (CT) scans can be very helpful in the early diagnosis of viral lung infection. The sensitivity of the chest CT scan to detect lung involvement compared to the RT-PCR method is very high and exceeds 95%. In some references, the total rate of a positive RT-PCR for throat swab samples was reported to be between 30 and 60% at the initial presentation. In many patients who have symptoms of COVID-19, despite a negative result of RT-PCR, the result of the lung CT is positive in those patients\textsuperscript{1, 2}. Therefore, chest CT scans can benefit patients in the early stages of COVID-19 disease, particularly when they are symptomatic, and may be used to triage patients before admitting them to the intensive care unit.

Typical radiologic features of COVID-19 pneumonia such as ground-glass opacities, multifocal patchy consolidation and interstitial changes with a peripheral distribution can be detected in lung CT scan\textsuperscript{2, 3}.

Because a CT scan is a relatively easy, fast, and reliable method to diagnose COVID-19 lung involvement, it has caused chest CT to be considered as a routine method for the diagnostic evaluation of COVID-19 lung disease, as well as to monitor the progress and response to treatment of this disease\textsuperscript{4, 5}. An important issue in the use of CT scans for the diagnostic evaluation of lung disease is the radiation dose and its associated stochastic effects\textsuperscript{6}. CT scans apply a higher individual and collective radiation dose than other diagnostic methods, which increases the risk of stochastic effects of radiation such as cancer and genetic effects in the future, so the use of low-dose CT protocols is recommended\textsuperscript{7–10}.

Different protocols for performing the lung CT are used in different centers according to the patient’s specific parameters such as BMI, radiologist’s knowledge about the radiation dose and image quality parameters, and the radiologist’s opinions to diagnose of this disease. Therefore, this study intends to evaluate different lung CT scan protocols for the diagnostic evaluation of COVID-19-induced lung disease in Iranian imaging centers in terms of radiation dose and image quality. The authors hope that this study will be able to provide an optimal method for performing lung CT in the diagnostic evaluation of...
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Table 1. The CT scan devices and scanning parameters of lung CT in different chest CT protocol.

| CT scanner model & scan parameters | Protocol | kVp | ref. mAs | AEC | Collimation | Rotation time (Sec) | pitch |
|-----------------------------------|----------|-----|----------|-----|-------------|---------------------|-------|
| Siemens 16 slice Somatom (Scope)  | A        | 110 | 20       | Enable | 16 x 1.2 | 0.6                 | 1.5   |
|                                   | B        | 110 | 100      | Disable | 16 x 1.2 | 0.6                 | 1.5   |
|                                   | C        | 110 | 70       | Enable | 16 x 1.2 | 0.6                 | 1.5   |
| Siemens 16 slice Somatom (Emotion)| D        | 110 | 50       | Enable | 16 x 1.2 | 0.6                 | 1.35  |
|                                   | E        | 110 | 50       | Disable | 16 x 1.2 | 0.6                 | 1.35  |
| Philips 16 slice Ingenuity Flex    | F        | 120 | 50       | Enable | 16 x 1.5 | 0.5                 | 1.188 |
|                                   | G        | 120 | 50       | Disable | 16 x 1.5 | 0.5                 | 1.188 |

In the Siemens device, the automatic exposure control is known as CARE DOSE 4D and in the Philips device, it is known as Dose Right.

COVID-19 lung disease, considering the optimization and justification principles.

MATERIAL AND METHODS

Data collection

Data were collected from patients who underwent non-contrast enhanced chest CT scan at several imaging centers for the diagnostic evaluation and follow-up of COVID-19 treatment. Data were collected from the five centers with the highest number of suspected COVID-19 or patients with corona disease who were referred for lung disease evaluation. Data were collected from 490 patients (58% male and 42% female) who underwent lung CT due to COVID-19. Data for 70 patients were collected for each protocol. The median patient age was 47 years (interquartile range, 35–65 years). The difference in effective diameter obtained according to the AP and Lat dimensions of patients was not significant for different protocols ($P$-value = 0.264)(11). Exclusion criteria included pediatrics, images with motion artifact, patients who had a placement of a metallic device in the thorax, or patients who had a lung CT with intravenous contrast injection.

Data including age, sex, as well as anterior–posterior (AP) and lateral body thickness of patients were collected using graphical tools available on CT scan at the level of 6–7 thoracic vertebrae.

The specification of CT devices and scanning parameters of lung CT in current study for different chest CT protocols are presented in Table 1. All lung CT scans were performed in a spiral mode.

Objective image quality

Image noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) as image quality criteria in lung window (window level — 600, window width 1600) and 5-mm slice thickness (usually sent to referring physician for diagnosis or printed on film) were examined in different protocols.

Image noise was defined as the standard deviation (SD) of the attenuation measured (Hounsfield unit) in four circular regions of interest (ROI) in the right anterior and posterior as well as left anterior and posterior lung parenchyma with diameter of 2–3 cm² at the level of 6–7 thoracic vertebrae in the axial image, the mean value of these measurements was considered as noise. Background noise was measured in two ROIs in the same level and size on the right and left thoracic wall soft tissue; and the mean value of these two standard deviations was considered as background noise (Figure 1).

The SNR was defined and calculated by the ratio of the mean pixel values within ROI _CT number (HU)_ to its SD as the following equation:

$$ SNR = \frac{|HU_{ROI}|}{\sigma_{ROI}} $$

(1)
CNR was defined as the difference between the mean of the Hounsfield unit of the pulmonary parenchyma and the soft tissue of the thoracic wall (as a reference) to the noise, the equation is presented as the following.\(^{(12, 13)}\).

$$\text{CNR} = \frac{|H_{\text{ROI}} - H_{\text{Thoracic wall soft tissue}}|}{\sqrt{\frac{\sigma_{\text{ROI}}^2 + \sigma_{\text{Thoracic wall soft tissue}}^2}{2}}}$$ \quad (2)

In the equations\(^{(1, 2)}\), \(\sigma\) corresponds to the standard deviation of image noise in the ROI.

**Subjective image quality**

Images in lung window and 5-mm slice thickness were assessed by two radiologists with 20 and 13 years of experience in the CT scan field. The radiologists were independent and blinded to the scan parameters. Image quality assessment was performed by them for COVID-19-induced lung disease in the PACS system and same monitor resolution. Image quality was ranked in 4 categories: 1 denotes high-quality images without blurring and artifact, 2 denotes images with low blurring without effect on diagnosis, 3 denotes image with blurring that diagnosis is uncertain and 4 denotes image quality is not suitable for diagnosis of COVID-19. Finally, the scores (in percent) given by the two radiologists to all exams related to a protocol were used to compare different protocols.

**Radiation dose estimation**

Volume CT dose index (CTDI\textsubscript{vol}) and the dose length product (DLP) were recorded from the Dose Information and patient protocol page, which is displayed for each CT exam on the Phillips and Siemens devices, respectively.

CTDI\textsubscript{vol}, DLP and scan parameters related to each protocol including kVp, effective mAs, reference mAs, collimation, pitch factor as well as active or inactive automatic exposure control (AEC) were also collected and summarized in Table 1.

The effective radiation dose (in millisieverts) was calculated using the National Cancer Institute CT (NCICT 2.1) dosimetry system\(^{(14, 15)}\). In this software, it is possible to calculate the organ and effective dose based on age (pediatric and adult) and body size for male and female. Information such as scanner model, filter type (body or head), kVp, tube current, pitch factor, CTDI vol, DLP and scan length are required as the input data to calculate organ and effective dose. NCICT software uses hybrid voxel computational phantoms to calculate organ and effective dose according to tissue weighting factors recommended by the International Commission on Radiological Protection (ICRP) 103\(^{(16)}\).

**Statistical analysis**

Continuous variables were reported as mean ± SD, and subjective image quality was reported as percentages. The extent of interobserver agreement in terms of subjective assessment of image quality was determined with the aid of Cohen kappa statistics. A kappa value of: \(0 \leq \kappa \leq 0.2\) was regarded as poor, \(0.2 < \kappa \leq 0.4\) was fair, \(0.4 < \kappa \leq 0.6\) was moderate, \(0.6 < \kappa \leq 0.8\) was good, and \(\kappa > 0.8\) was excellent. Analysis of variance (ANOVA) was used to compare continuous variables, and nonparametric tests were used to compare ordinal variables and data that were not normally distributed among different protocols.

All statistical analyses were performed by SPSS version 23, a \(P\)-value < 0.05 was considered significant.

**RESULTS**

After collecting and analyzing the data, the results were summarized and expressed in tables. The mean and standard deviation of the effective mAs as well as the CTDI\textsubscript{vol} for each protocol, the results related to the effective dose, and the image quality indicators including noise, SNR and CNR are presented in Table 2.

As shown in Figure 2 and Table 2, in terms of objective image quality analysis, protocol A showed lower image quality than the other protocols significantly \((P\text{-value} < 0.001)\). The highest and lowest noise levels are related to protocols A and B, respectively. The highest and lowest SNR are related to protocols G and A, and the highest and lowest CNR are related to protocols C and A, respectively.

The results of subjective image quality assessment according to the intended ranks are presented in Table 3. According to the radiologists’ opinion, none of the lung CT images related to any of the protocols were reported as unsuitable for diagnosing.

COVID-19. Subjectively, of the images associated with the various protocols, only less than 10% of the images associated with protocol A were uncertain for the diagnosis of COVID-19 (rank 3). The rest of the images related to different protocols were of high quality or with low blurring that did not affect the diagnosis. In general, the lung CT images related to protocol A had the lowest quality for detecting typical radiologic features of COVID-19.

Statistically significant differences in CTDI\textsubscript{vol}, DLP and effective dose were evident among the seven CT protocols \((P\text{-value} < 0.001)\), protocol A results in the lowest CTDI\textsubscript{vol}, DLP, and effective dose. 

\[\text{CNR} = \frac{|H_{\text{ROI}} - H_{\text{Thoracic wall soft tissue}}|}{\sqrt{\frac{\sigma_{\text{ROI}}^2 + \sigma_{\text{Thoracic wall soft tissue}}^2}{2}}} \quad (2)\]
Table 2. The mean and standard deviation of the effective mAs, CTDI\textsubscript{vol}, effective dose, and the image quality indicators including noise, SNR and CNR for each protocol.

| CT scanner model & scan parameters | Protocol | effective mAs mean ± SD (mGy) | CTDI\textsubscript{vol} mean ± SD (mGy.cm) | DLP mean ± SD (mGy.cm) | Effective dose (mSv) | Noise | SNR | CNR |
|------------------------------------|----------|-------------------------------|---------------------------------|----------------------|---------------------|-------|------|------|
| Siemens 16 slice Somatom Scope     | A        | 23.04 ± 8.49                 | 1.61 ± 0.63                     | 57.99 ± 21.79        | 1.31 ± 0.53         | 220.63 ± 77.75     | 4.48 ± 1.75 | 4.09 ± 1.59 |
|                                    | B        | 100 ± 0.00                   | 6.82 ± 0.00                     | 244.34 ± 25.05       | 6.15 ± 0.57         | 71.99 ± 8.77       | 11.63 ± 1.69 | 11.18 ± 2.16 |
|                                    | C        | 68.19 ± 21.85                | 4.68 ± 1.49                     | 156.69 ± 52.16       | 2.88 ± 0.93         | 78.43 ± 25.58      | 12.32 ± 3.91 | 11.29 ± 3.59 |
| Siemens 16 slice Somatom Emotion   | D        | 47.86 ± 15.02                | 3.49 ± 1.08                     | 116.41 ± 37.17       | 2.17 ± 0.67         | 88.40 ± 25.98      | 11.09 ± 3.43 | 9.84 ± 3.04  |
|                                    | E        | 50 ± 0.00                    | 3.62 ± 0.00                     | 129.59 ± 11.82       | 2.64 ± 0.27         | 76.29 ± 22.52      | 12.20 ± 3.87 | 10.14 ± 2.42 |
| Philips 16 slice Ingenuity Flex     | F        | 46.61 ± 18.50                | 2.96 ± 1.21                     | 96.99 ± 38.76        | 1.85 ± 0.75         | 86.05 ± 30.83      | 11.58 ± 4.74 | 10.84 ± 4.44 |
|                                    | G        | 50 ± 0.00                    | 3.11 ± 0.00                     | 106.73 ± 14.88       | 2.12 ± 0.29         | 81.63 ± 21.29      | 12.87 ± 3.80 | 11.05 ± 2.27 |

Figure 2: Comparison of objective image quality indicators including noise, SNR, CNR and effective dose in different protocols.

dose, with the mean value of 1.61 ± 0.63 mGy, 57.99 ± 21.79 mGy.cm and 1.31 ± 0.53 mSv, respectively. The maximum values of CTDI\textsubscript{vol}, DLP and effective dose are related to protocol B, which are equal to 6.82 ± 0.00 mGy, 244.34 ± 25.05 mGy.cm and 6.15 ± 0.57 mSv, respectively. So that the effective dose in protocol B is more than four folds that of protocol A.
Table 3. Scoring of various lung CT protocols in term of subjective image quality analysis by two radiologists to diagnosis of COVID-19. The results are expressed in percentage and inter-observer agreement was determined by kappa value.

| CT scanner model & scan parameters | Protocol | First radiologist (%) | Second radiologist (%) | Kappa value |
|-----------------------------------|----------|------------------------|------------------------|-------------|
|                                   |          | Score 1 | Score 2 | Score 3 | Score 4 | Score 1 | Score 2 | Score 3 | Score 4 |               |
| Siemens 16 slice Somatom (Scope)  | A        | 34.33   | 59.15   | 6.52    | -      | 25.00   | 66.67   | 8.33    | -      | 0.758        |
|                                   | B        | 53.85   | 46.15   | -       | -      | 61.54   | 38.46   | -       | -      | 0.659        |
|                                   | C        | 84.62   | 15.38   | -       | -      | 76.92   | 23.08   | -       | -      | 0.752        |
| Siemens 16 slice Somatom (Emotion)| D        | 68.73   | 31.27   | -       | -      | 77.42   | 22.58   | -       | -      | 0.769        |
|                                   | E        | 61.19   | 38.81   | -       | -      | 67.82   | 32.18   | -       | -      | 0.684        |
| Philips 16 slice Ingenuity Flex   | F        | 88.45   | 11.55   | -       | -      | 78.31   | 21.69   | -       | -      | 0.714        |
|                                   | G        | 53.31   | 46.69   | -       | -      | 69.33   | 30.67   | -       | -      | 0.727        |

DISCUSSION

Regarding to the sensitivity of lung CT scan as a fast method to early diagnosis of coronavirus pneumonia\(^1, 4\), the important issue in the use of CT scan is the carcinogenicity of radiation. Using an appropriate protocol with the lowest possible radiation dose to the patient with acceptable image quality are the best target according to radiation protection principles\(^{17}\). According to the large number of people who undergo lung CT scan for the diagnostic evaluation of COVID-19-induced lung disease, if the scan parameters are not optimized and the CT scan is performed with routine lung CT conditions, considering the diagnostic reference level of this examination, a high collective dose will be imposed on the public\(^{18}\). In this study, different protocols used in various centers have been investigated in terms of image quality and radiation dose.

Comparison of protocols A, B and C: In these protocols, except for the tube current (mAs) and the use of automatic exposure control, all other parameters including kVp, collimation, rotation time, pitch, reconstruction algorithm and scanner model are the same, so the factor that affects the image quality and radiation dose is the mAs. In protocols A and C, the AEC mode is applied and the reference mAs is 20 and 70, respectively, while in protocol B, the mAs is fixed and the same for all patients (mAs = 100). When AEC is used, the scanner applies different tube currents depending on the BMI of the patients and a change in body thickness over the scan length results in an effective mAs, which is 23.04 ± 8.49 and 68.19 ± 21.85 in protocols A and B, respectively. The effective mAs depends on the following factors: 1—selected reference mAs, 2—patient’s BMI or effective diameter and 3—the amount of body thickness change over the scan length\(^{19, 20}\). In comparison, in a protocol with fixed mAs such as protocol B, a constant mAs is applied during the scan and no change in tube current occurs with changes in BMI and body thickness. Figure 3 shows the mAs changes with the increase in effective diameter.

![Figure 3: Correlation between effective mAs in relation to the increase in effective diameter (Siemens Emotion 16 slice) (Reference mAs = 50, AEC = enabled).](image)

Objective image quality analysis

Changing the mA value changes the beam intensity directly and thus the number of x-rays proportionally, and it directly affected on image quality and absorbed dose. Acquisitions that deposit higher doses tend to result in lower image quality and better SNR and CNR\(^8, 21\). The relationship between noise and mAs (number of photons) is inverse, so that as the tube current increases, the noise decreases\(^{22}\). As shown in Table 2, the mAs in Protocol B are about five times the mean of the effective mAs in Protocol A, but the noise in Protocol A is about three times that of Protocol B. This is due to the use of AEC in Protocol A, and the tube current applied according to the patient’s BMI in this protocol. Also, the average amount of SNR and CNR in protocol B is significantly higher than protocol A (about 2.5 times).

In comparison between protocols B and C, despite the difference between the tube currents of the two protocols, the difference in the objective image quality criteria, including noise, SNR and CNR, is not significant due to AEC in protocol C. The AEC is
based on real-time anatomy-dependent tube current modulation \( (P\text{-value} = 0.898) \)\(^{(20)} \).

The average effective dose in protocol B is significantly higher than protocol A (more than about 4.5 times) \( (P\text{-value} < 0.001) \). The difference in effective dose in different patients in protocol B, despite the same CTDI and scan parameters, is the result of differences in scan length and DLP. The effective dose in protocol B is also significantly higher than in protocol C (more than twofold) \( (P\text{-value} < 0.001) \). The high radiation dose of protocol B compared to protocols A and C is due to the direct effect of the tube current on the CTDI and consequently on the effective dose\(^{(23)} \).

Subjective image quality analysis

Subjectively, images related to protocol B have a higher quality than protocol A \( (P\text{-value} < 0.001) \), while in protocol A, most images were rated in category 2, and less than 10% of images are reported to be blurred and diagnosis of COVID-19 is uncertain, which should be considered to prevent repeat of CT scans.

Subjective image quality analysis by the radiologists showed that the images related to protocol C have a higher quality than protocol B \( (P\text{-value} < 0.02) \). Overall, there is a good agreement between the two radiologists in terms of image quality for these two protocols \( (\kappa = 0.659 \text{ and } 0.752 \text{ for protocols B and C, respectively}) \). In general, the comparison of protocols B and C clearly shows the effect of selecting the appropriate scan parameters as well as the effect of using AEC on the image quality and reducing the radiation dose. Despite the higher mAs in protocol B, the difference and increase image quality related to protocol C compared to protocol B is due to the use of AEC in protocol C. The tube current is applied effectively and optimally by the system according to changes in body thickness and also BMI changes in different patients. Therefore, the minimum and maximum effective mAs according to the BMI of patients in protocol C are 36 and 122, respectively. In comparison, in protocol B, the same tube current is applied for all patients \( (\text{mAs} = 100) \). On the other hand, in protocols A and C for a patient, due to the change in body thickness during the scan length, the tube current will also change, so that in areas with higher thickness and more attenuation such as shoulders and upper abdomen, higher current is applied and in the middle part of the chest, due to less attenuation, the mAs is lower. For example, in a patient whose effective mAs is 51 in this protocol, the range of mAs due to changes in body thickness is from 20 to 86\(^{(20)} \).

Comparing protocols, A and C

The objective and subjective quality of images in protocol C are significantly higher than protocol A. On the other hand, the average radiation dose in protocol C is almost twice that of protocol A \( (P\text{-value} < 0.001) \). Differences in the effective mAs of the two protocols can explain these differences.

But the question is whether the optimal protocol can be chosen definitively based on the above comparisons? Therefore, other protocols were examined.

Protocols D and E

The only difference between the two protocols is the use of AEC. In both protocols, the reference mAs is 50, but in protocol D, the automatic exposure control is active, in contrast, in protocol E, the tube current is constant and the AEC is inactive. Due to changes in patient’s BMI, the mean effective mAs in protocol D is lower than E, but this difference is not significant \( (P\text{-value} = 0.993) \). Statistically, the differences in objective image quality criteria, including noise, SNR and CNR, between the two protocols are not significant \( (P\text{-value} = 0.997) \). However, the mean effective dose in protocol D is lower than in protocol E. The results show that the effect of automatic exposure control on dose reduction \( (P\text{-value} < 0.036) \).

Subjectively, no significant difference was observed between the two protocols D and E \( (P\text{-value} = 0.528) \). These conditions also exist for protocols F and G, which are used in another scanner and differ only in the use of AEC. The results of comparing the image quality and their radiation dose are almost similar to protocols D and E. The results show that there is no significant difference in image quality from subjective and objective point of views \( (P\text{-value} = 0.624) \), but in terms of radiation dose, their difference is statistically significant \( (P\text{-value} < 0.041) \).

Protocols C and E

Since the effective dose in protocol D is lower than protocol E and the image quality of the two protocols is not significantly different, so protocols C and E are compared. The difference between protocols C and E is the use of different pitch factors as well as different reference mAs, which is 70 and 50 for protocols C and E, respectively. AEC is enabled in both Protocols. Due to the indirect relationship between the pitch and the number of photons, decreasing the pitch increases the photons and increases the SNR and the CNR. On the other hand, reducing the pitch increases the patient’s radiation dose\(^{(24, 25)} \). Comparison of objective criteria for image quality between the two protocols shows that although the average of noise in protocol E is higher than protocol C due to the low effective mAs, but it is not statistically significant \( (P\text{-value} = 0.859) \), also the SNR and CNR in both protocols are not significantly different \( (\text{SNR}: P\text{-value} = 0.395, \text{CNR}: P\text{-value} = 0.083) \).

Subjectively, the percentage of images that have excellent quality (rank 1) is higher in protocol C,
but there is no significant difference between the two protocols ($P$-value = 0.260). In general, patients receive a lower radiation dose in protocol E and the difference between the two protocols is significant ($P$-value < 0.001). It seems that the reduction of the pitch could adequately compensate for the effect of low effective mAs and reduction of image quality criteria in protocol E and also had negligible effect on increasing the received radiation dose.

CONCLUSION

In conclusion, in the above protocols, the most important factors affecting the image quality and radiation dose were the use of different mAs as well as AEC. It was found that in order to optimize the scan parameters, an automatic exposure control must be used, and also for the diagnostic evaluation of COVID-19 lung disease, a range of tube currents between 20 and 50 mAs can produce acceptable images in terms of diagnostic quality and radiation dose. It should be noted that lung CT with other protocols and parameters such as high kVp and mAs, low pitch, high-resolution CT (HRCT) of lung may be performed to diagnosis of the coronavirus pneumonia and should try to consider two important principles of justification and optimization in the selection of scan parameters.

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