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QUALITATIVE ANALYSIS OF THE ULTRA-LOW-DOSE COMPUTED TOMOGRAPHY WITH TIN FILTRATION IN PATIENTS WITH PNEUMONIA: TOWARDS X-RAY RADIATION DOSE

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Abstract: Background: Currently CT scanners are able to perform ultra-low dose chest CT, with scanning time less than one second, eliminating the need for apnea, decreasing respiratory motion artifacts in patients with pneumonia and severe dyspnea. The aim of this work is to evaluate ultra-low-dose chest CT in patients with pneumonia, regarding the effective dose of ionizing radiation and image quality, comparing cross sectional CT images with a reconstructed chest X-ray, in order to find pulmonary parenchymal abnormalities due to pneumonia. Methods: An ultra-low-dose protocol was designed on a 384-slice Dual Source CT scanner. The inclusion criteria were patients selected from a database, with clinical suspicion or follow up of pneumonia, including those with a positive diagnosis of COVID-19, who underwent ultra-low-dose chest CT protocol, using a tin filter and ultra-fast pitch, named Turbo Flash. The tomographic cross sectional images and the reconstructed X-ray of the patients were evaluated by two experienced radiologists, in a blind study, where the image quality analysis was performed subjectively with Likert Scale. The effective radiation dose of our CT protocol was calculated multiplying DLP by the standard chest K-factor of 0.014. The positive cases on CT were classified according to the percentage of lung involvement as: Mild (up to 25%), Moderate (25-50%) and Severe (greater than 50%). Kappa test was used to compare the results of both radiologists and the statistical significance was $p < 0.001$. The study was approved by the Local Ethics Committee, with the register number of 41005020.6.0000.5474. Results: Sixty-seven patients (mean age: 53.8 ± 15.5 years old; 42 were female) were included. The mean DLP of Chest CT was 16.42 ± 5.71 mGy*cm, corresponding to a mean effective dose of 0.23 ± 0.08 mSv. The Likert evaluation showed substantial agreement between the radiologists ($k = 0.735$, $p=<0.001$), where ultra-low-dose Chest CT image quality had scores 5 (Excellent) and 4 (Good). Using the classification of pulmonary findings, the false negative rates of reconstructed X-ray were Severe: 1.0, Moderate: 0.25 and Mild: 0.79. Conclusions: Ultra-low-dose CT is a potential alternative to digital radiography for lung imaging in cases suspected of pneumonia or disease follow-up, at a comparable radiation dose.

Keywords: Computed Tomography, Chest CT, Pneumonia, Ultra-low-dose, Dual Source CT.

INTRODUCTION

Currently, the 2019 Coronavirus disease (Covid-19), caused by the Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2), has become a topic of worldwide importance given its rapid spreading capacity, leading to the pandemic of most concern in several countries worldwide (1). Some symptoms have been shown to be more evident in several cases, including dry cough, fever and fatigue, where 80% of the cases were mild, 15% severe and 5% very severe, and may progress to death (2).

The reverse transcription polymerase chain reaction test (RT-PCR) is the standard method of diagnosing SARS-Cov2 infection. However, computed tomography (CT) of the chest is often used in patients with known or suspected COVID-19, due to regional preferences, lack of availability of PCR assays and by false-negative PCR, as well as to monitor the progression of disease, complications and response to treatment (3). Given the varied scope of the population, such as children, the elderly, pregnant women, among others, added to the importance of CT in the diagnosis and monitoring of the disease, attention to the theme of ionizing radiation becomes essential. In this context, the ALARA principle (as low as reasonably achievable) must be considered.

(4). Furthermore, previous studies show that some patients with COVID-19 have low white blood cell count and reduced proportion of lymphocytes, associated with radiation from multiple CT exams, which can cause cell damage and increase the apoptosis of peripheral blood lymphocytes. (5).

Chest X-Ray is undoubtedly the most used and important diagnostic imaging test for evaluation of acute respiratory symptoms. In the majority of cases it suffices to reach a confident diagnosis or to exclude complications, especially in the common community acquired bacterial pneumonia. On the other hand it's well known the weakness of chest X-ray to identify diseases which ground glass opacities are the main or only pattern such as Pneumocystosis and some viral pneumonias including Covid-19 lung disease (6).

With the technological advancement, CT scanners are able to perform an ultra-low dose chest CT, with an acquisition speed of less than 1 second, eliminating the need for apnea, which significantly decreases respiratory motion artifacts caused by the symptoms of a patient with pneumonia, including by COVID-19, as severe dyspnea. Furthermore, advances such as Tin Filter, dose modulation and iterative reconstruction found in different types of CT scanners also contribute to the reduction of the dose of ionizing radiation and maintenance of image quality (7). The aim of this original work is to evaluate the Chest CT with the ultra-low-dose protocol in patients with pneumonia, regarding the effective dose of ionizing radiation and diagnostic capacity of tomographic image, comparing CT images with a reconstructed chest X-ray, in search of pulmonary parenchymal changes related to Pneumonia.

MATERIALS AND METHODS

This is a retrospective observational study, approved by the local Ethics Committee (41005020.6.0000.5474).

STUDY POPULATION

This research was carried out at an outpatient diagnostic facility. Patients with suspicion or follow-up of pneumonia, including those with a positive diagnosis of COVID-19, who underwent ultra-low-dose chest CT with a tin filter and ultra-fast pitch, from May to August 2020 were included. Patients who underwent chest CT with different imaging acquisition protocols or who received intravenous iodinated contrast were excluded. Clinical and laboratory data were collected from the electronic medical record and quantitative information related to the radiation dose was collected from the PACS. The following variables were analyzed in the study: age, sex, DLP and effective dose.

CT PROTOCOL

All patients were scanned on a 384-slice Dual Source scanner SOMATOM Force (Siemens Healthineers, Forchheim, Germany). The scanner is equipped with two tubes delivering high power at voltages between 70 kV and 150 kV in steps of 10 kV with automatic modulation of kV and mA, tin filters for spectral shaping and with high-efficiency detectors. The low-dose chest protocol included high-pitch ultrafast acquisitions (Turbo Flash) with tin filter, tailored to the patient's body diameter. The image acquisition protocol included iterative reconstruction (ADMIRE, Siemens Healthineers, Forchheim, Germany) and the scan time was, approximately, 0.3 seconds.

Images were acquired in helical mode, with a pitch of 3, gantry rotation time of 0.25 seconds, and collimation of 192 × 2 × 0.6 mm. Scanning parameters were kV of Sn110 and mAs (ref.) of 106. Scanning was acquired without contrast agent injection and obtained in caudo-cranial direction. CT images were reconstructed with 1 mm thickness at 0.7 mm increment, with a medium to soft convolution kernel (Bf32) using ADMIRE-5 and a sharp kernel for lung window (Br49) and for High Resolution (Br64) using ADMIRE-3. Radiation dose metrics were obtained with patient protocol of the scanner. The reconstructed chest X-ray was performed from the chest CT, reconstructing a coronal MPR image with the calculated thickness corresponding to the measure of anteroposterior length of each individual's chest (Figure 1). The analysis of the radiation dose was based on the values of Dose Length Product - DLP and effective dose in the millisievert unit (mSv) from the conversion according to the European Commission, where the Chest conversion factor is 0.014 mSv/mGy*cm.

QUALITATIVE ANALYSIS

CT images and the reconstructed X-ray of all patients were blindly evaluated by two experienced radiologists. The first analysis was performed to identify lung opacities in a binary fashion (positive or negative). The cases of positive findings on CT images were classified as: Mild, Moderate and Severe according to the percentage of lung involvement, where Mild = up to 25%, Moderate = 25-50% and Severe = greater than 50%. The second qualitative analysis was performed using the Likert scale, in order to assess the image quality of the Turbo Flash ultra low-dose CT protocol. The Likert scale is a type of psychometric response scale, being more used in opinion polls. When responding to a questionnaire based on this scale, the respondents specify their level of agreement with a statement (7). The analyzed volumes were: a reconstruction of the mediastinum 1.0 mm thick and 0.7 mm increment in the Bf32 filter (ADMIRE 5) with mediastinum window; a lung reconstruction with 1.0 mm thick and 0.7 mm increment using the Br49 filter (ADMIRE 3) and lung window. And, in the case of the present study, the question was: What is the diagnostic quality of CT to evaluate lung parenchyma and soft tissue, based on image noise? The scale ranges from 1 to 5, where:

1.Very poor; 2. Poor; 3. Regular; 4. Good; and 5. Excellent.

STATISTICAL ANALYSIS

Clinical and demographic data were collected through the Carestream Vue RIS/PACS v.12.1.6.1005 (Carestream Health, Inc, Rochester, NY) and syngo.via (VB30 software version, Siemens Healthineers, Forchheeim, Germany), respectively. The results were thresholded at $p < 0.001$, therefore, the adopted level of statistical significance (alpha) was less than 1 in a thousand chance, hence, there is strong evidence against the null hypothesis.

Sensitivity, sensibility, positive predictive value and negative predictive value of the simulated X-Ray were obtained using ultra low-dose CT as gold standard. These data were calculated from the whole sample as well as stratifying, according extent of lung abnormalities at CT. The Kappa test was used to assess inter-observer agreement.

RESULTS

Demographic and clinical characteristics of patients are shown in Table 1. Sixty-seven patients were included in the final analysis. Mean age of patients was 53.8 15.5 years old; 42 (62.7%) were female. Patients with symptoms of cough, fever and dyspnea, with clinical suspicion or control of pneumonia were included, and the evaluation of laboratory tests showed that 38 of 67 patients (56.7%) were positive for Sars-Cov2 PCR (Polymerase chain reaction), moreover, 24 (35.8%) had no PCR's data.

Chest CT images revealed lung

abnormalities in 50 patients (17 patients had no lung abnormalities). The Kappa test showed substantial inter-reader agreement (k=0.693, p=<0.001) regarding the lung findings associated with Pneumonia such as ground glass opacity (GGO) or consolidations on simulated Chest X-ray. Our reconstructed chest X-ray had a specificity of 1; a sensibility of 0.29 (reader 1: 0.32; reader 2: 0.26); a positive predictive value of 1 and a negative predictive value of 0.32 (reader 1: 0.33; reader 2: 0.31). Stratifying according to the extent of lung abnormalities at CT, the false negative rates of reconstructed X-ray were Severe disease at CT: 1.0, Moderate disease at CT: 0.25 and Mild disease at CT: 0.79 (reader 1: 0.73; reader 2: 0.89).

The mean of Dose Length Product (DLP) of Chest CTs was 16.42 ± 5.71 mGy*cm [median: 14.28; min. 10, max. 35.71] corresponding to a mean effective dose (ED) of 0.23 ± 0.08 mSv [median: 0.20; min. 0.14, max. 0.50], as shown in Table 2. Regarding quality of CT images there were a substantial agreement between the readers (k = 0.735, p=<0.001), where ultra-low-dose Chest CT image quality had scores 5 (Excellent: reader 1: 43 CTs, reader 2: 45 CTs) and 4 (Good; observer 1: 24 CTs, observer 2: 22 CTs). There were no 3 (Regular), 2 (Poor) or 1 (Very poor) scores on Likert evaluation.

DISCUSSION

CT imaging plays an important role in the evaluation of COVID-19 pneumonia at an early stage when RT-PCR tests may be negative or unavailable – a common scenario especially in developing countries. Typical findings on a chest CT are GGO, consolidation, "crazy-paving", airways abnormalities and the reversed halo sign. These findings vary according to the stages of the infection. Chest X-ray abnormalities mirror those of CT, demonstrating bilateral peripheral consolidation, although less dense opacities such as ground glass may be very difficult to detect. Recent studies on COVID-19 reported a sensitivity of 69% for chest X-rays (8) and 98% for CTs (9). CT is also applied to assess potential complications, such as viral and bacterial co-infections, pulmonary embolism or other conditions. Considering that these patients may have dyspnea, that some are young and that some may need repeated examinations as follow-ups, a quick and low-dose CT scan protocol is preferred. In this case, a so-called "Turbo Flash mode" is applied, providing ultra-fast scanning and an ultra-low radiation dose. The scanning is performed and completed in, approximately, 0.3 s. This is enabled by a high pitch spiral scanning with a maximum table movement speed of 737 mm/s. The mean effective dose of 0.23 mSv was achieved in our study, which is within the dose range of a standard chest X-ray (10), without compromising CT image quality. This significant dose reduction is mainly enabled by an advanced tin filter technology, which optimizes the X-ray spectra, minimizes beam-hardening artifacts and optimizes image quality by improving the air/tissue contrast. Standard dose reduction techniques, such as CARE Dose4D™ (automatic controlled tube current modulation) and ADMIRE (advanced modeled iterative reconstruction) also contribute to dose optimization (Figure 2).

The present study shows that ultra-low-dose Chest CT has enough image quality for pneumonia diagnosis and follow-up, including cases of COVID-19. This CT protocol has advantages over a chest X-ray – similar radiation dose, faster speed and higher sensitivity – to evaluate pneumonia, even at an early stage when chest X-ray is more prone to false negative results.

Our results showed that more than a half of cases positive at CT were missed in our simulated X-Ray by both observers, with high rates of false negatives (68% for observer 1 and 74% for observer 2). From the 50 positive CTs, 41 (82%) were classified as a mild disease by both observers and most of these cases were missed at simulated X-Ray, what is an expected result. Only 1 case was classified as severe disease at CT by our observers and this lonely case was marked as negative at simulated X-Ray by both of them (Figure 3). This false negative X-Ray, classified as Severe disease at CT is noteworthy, since abnormalities involved more than 50% of the lungs. Although huge in extension the parenchymal abnormalities were low in density and that was the reason for the false negative result at X-Ray. This is not something new as it is well known that it is far more easy to identify high density opacities such as calcification and consolidation than low density abnormalities such as emphysema and ground glass when reading X-Rays (Figure 4).

When an imaging test based on ionizing radiation (mainly CT and X-Ray) is needed to evaluate a lung disease three questions must be answered before choosing it, considering that both are readily available. First: "Which one will bring better results?"; Second: " What is the radiation dose?"; Third: "What is the cost?". The answers for the first and third questions are easy. CT will be better and R-Xay cheaper. Tied game we must answer the second question.

Previous studies showed that technological improvements, with iterative reconstruction, for example, have lowered the radiation dose of a chest CT close to that of a PA and lateral chest x-ray, adding that the ultra-low dose chest CT has an image quality that is degraded on purpose, yet remains diagnostic in many clinical indications. Furthermore, ultra-low-dose Chest CT is already validated for the detection and the monitoring of solid parenchymal nodules, for the diagnosis and monitoring of infectious lung diseases and for the screening of pleural lesions secondary to asbestos exposure. Its limitations are the analysis of the mediastinal structures, the severe obesity (BMI>35) and the detection of interstitial lesions (11, 12).

The study has several limitations. First of all is that we didn't have a truly state of art digital chest X-Ray, only the reconstructed image from the CT. It is a single-center study with a small population to evaluate the feasibility of a low-dose CT protocol in an acute setting. The small size of the sample did not allow for more sophisticated statistical analysis. There was no information about the BMI (Body Mass Index), which is considered a limitation to evaluate the relation between BMI, radiation dose and image quality.

In conclusion, ultra-low-dose CT is a potential alternative to digital radiography for imaging the lungs in cases of pneumonia diagnosis or follow-up, providing good quality images and with higher sensitivity that the reconstructed x-ray, at a comparable radiation dose of a digital radiography.

LIST OF ABBREVIATURES

ALARA: As Low as Reasonably Achievable
CT: Computed Tomography
DLP: Dose Length Product
HU: Hounsfield Unit
Kg: kilograms
kV: kilovolt
mAs: milliampere-second
mm: millimeters
mSv: millisievert unit
ref.: reference
ADMIRE: Advanced Modeled Iterative Reconstruction

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TABLES

		%	
n	67	100	
Gender	Female: 42	62.7	
Age	53.8 (±15.5)		
SARS-Cov2 PCR+	38	56.7	Undefined:24 (35.8%)

Demographic Data shows the characteristics of the 67 included patients in this study, where n = total number of patients; mean (± standard deviation).

Table 1: Demographic Data

Collimation detector	2x96x0.6 mm
Rotation Time	0.25 s
Pitch	3
Tube voltage (kV)	Sn110
mAs ref.	106
DLP (mGy.cm)	16.42 ± 5.71 [14.28; 10, 35.71]
ED (mSv)	0.23 ± 0.08 [0.20; 0.14, 0.50]

Data are presented as mean ± standard deviation; Numbers in brackets are ranges [median; min, max]; DLP = Dose Length Product; ED = Effective Dose; Sn = Tin Filter.

Table 2: CT protocol and radiation dose

IMAGES

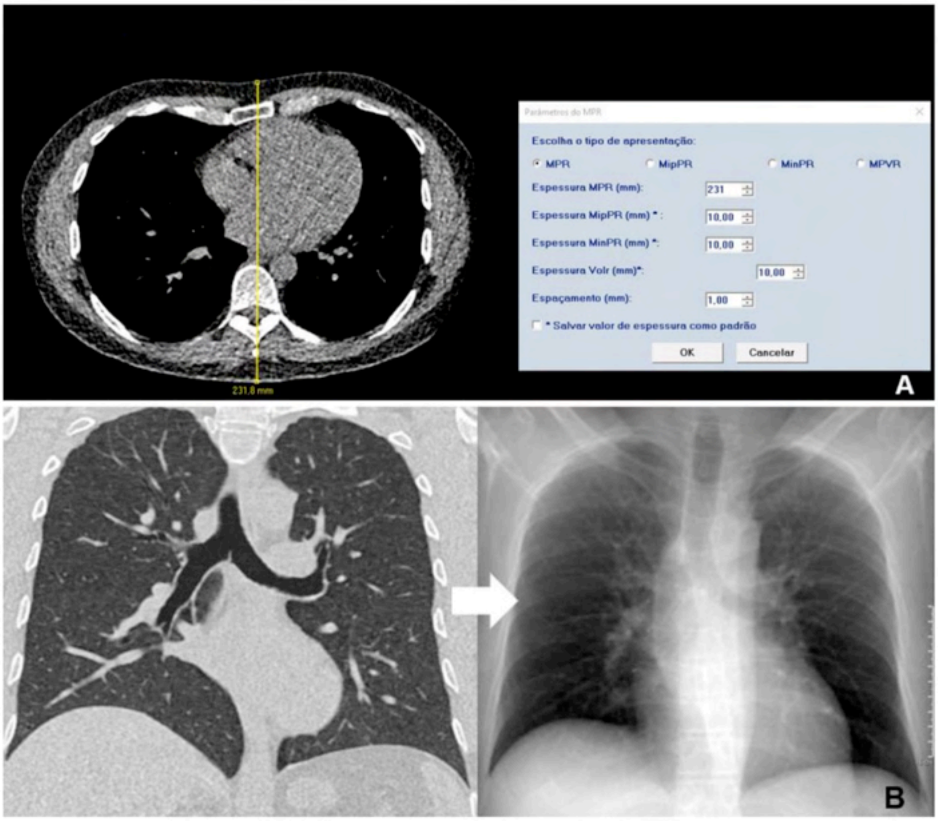

Figure 1: (A) - Details of the reconstruction of the simulated x-ray. MPR reconstruction using the thickness equal to the anterior posterior diameter of the patient's chest. (B) - coronal, ultra-low dose CT lung window and simulated X-Ray.

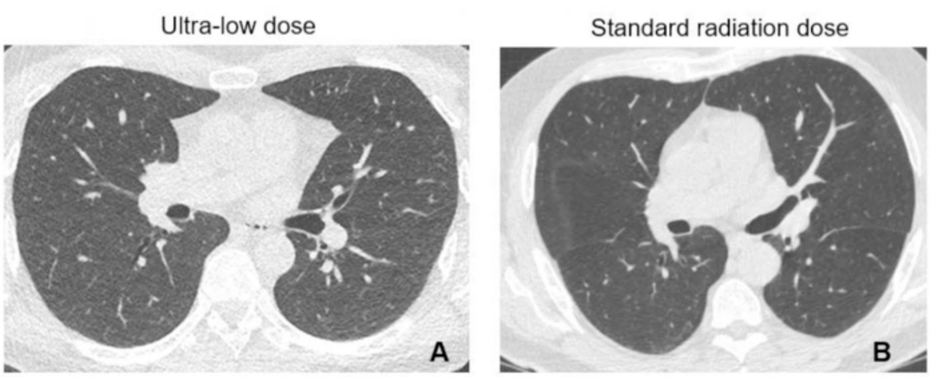

Figure 2: (A) - ultra-low dose chest CT and (B), chest tomography with a routine protocol with standard radiation dose. Even with lower radiation dose, the image quality remains adequate to analyze.

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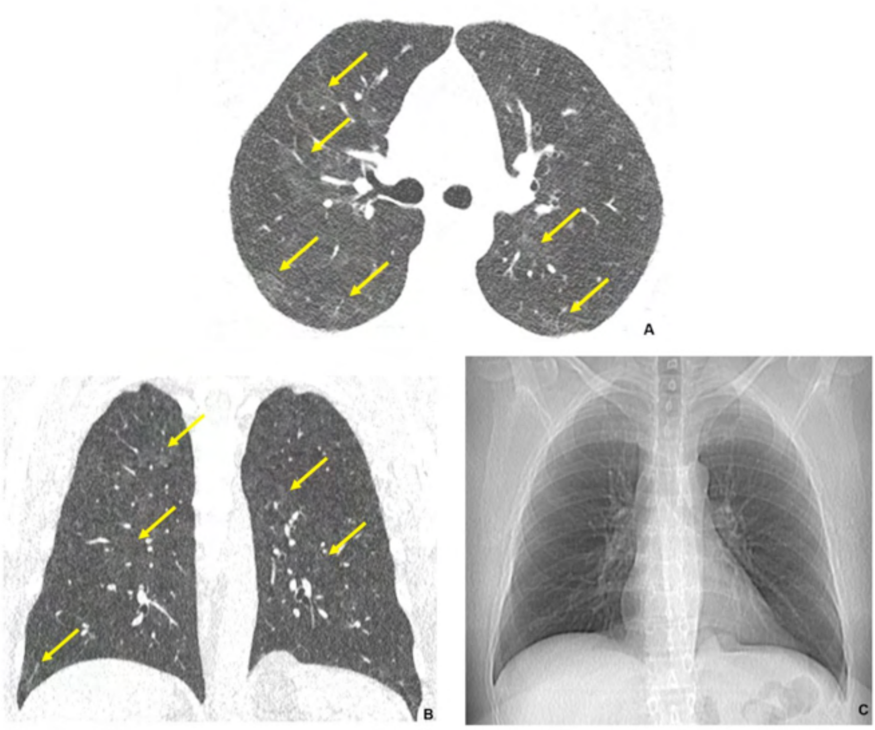

Figure 3: axial (A), and coronal (B), ultra-low dose CT images with lung window showing very low-density ground glass opacities (arrows) missed at simulated X-Ray (C) by both observers.

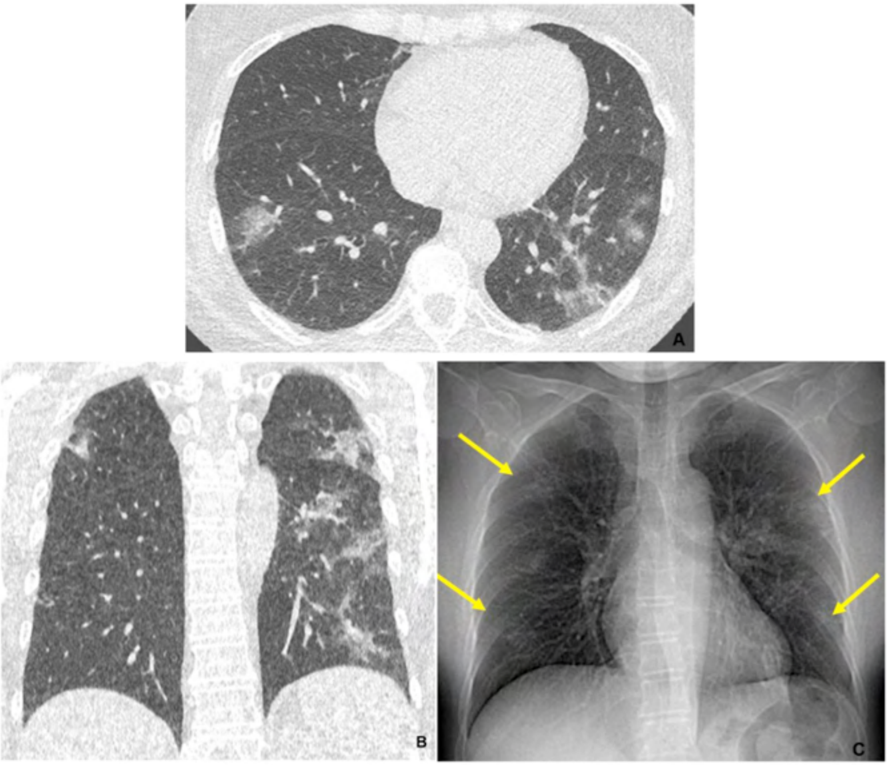

Figure 4: axial (A), and coronal (B), ultra-low dose CT images with lung window showing ground glass opacities. Simulated X-Ray (C) was read as positive by both observers (arrows).