CHEST CT USAGE IN COVID-19 PNEUMONIA: MULTICENTER STUDY ON RADIATION DOSES AND DIAGNOSTIC QUALITY IN BRAZIL

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We assessed variations in chest CT usage, radiation dose and image quality in COVID-19 pneumonia. Our study included all chest CT exams performed in 533 patients from 6 healthcare sites from Brazil. We recorded patients’ age, gender and body weight and the information number of CT exams per patient, scan parameters and radiation doses (volume CT dose index—CTDIvol and dose length product—DLP). Six radiologists assessed all chest CT exams for the type of pulmonary findings and classified CT appearance of COVID-19 pneumonia as typical, indeterminate, atypical or negative. In addition, each CT was assessed for diagnostic quality (optimal or suboptimal) and presence of artefacts. Artefacts were frequent (367/841), often related to respiratory motion (344/367 chest CT exams with artefacts) and resulted in suboptimal evaluation in mid-to-lower lungs (176/344) or the entire lung (31/344). There were substantial differences in CT usage, patient weight, CTDIvol and DLP across the participating sites.

INTRODUCTION

As the First World War ended, the Spanish flu pandemic spread worldwide in 1918–19 and claimed a variable death toll of 20–100 million lives1, 2. Radiology was in its infancy as the Spanish Flu infected close to an estimated 50% of the world population3. When the following two pandemics, 1957–58 Asian Flu and 1968–69 Hong Kong Flu, claimed millions of lives across the globe3, 4, radiology was an established presence in the practice of medicine, although CT was not invented until a few years later in 19715, 6. When the 2009 swine flu pandemic raced across 122 countries over a span of six weeks, CT had long established itself as an important tool in diagnosis, monitoring and patient management7. The ongoing Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) or Coronavirus Disease of 2019 (COVID-19) pandemic has infected over 257-million people and claimed over 5.1-million lives5. As opposed to prior pandemics, due to high disease prevalence and paucity of antigen and antibody testing, several studies report using chest CT in initial diagnostic evaluation and assessing disease severity, complications and treatment response6, 10. Several studies have demonstrated the imaging aspects of this disease, with an emphasis on high-resolution CT of the chest11. For a disease with <2% mortality, CT in COVID-19 must be used judiciously due to its associated radiation dose and risks12, particularly in a developing country such as Brazil.
which currently stands at number 3 in terms of the number of infections\(^{(6)}\). Compared with developed countries, availability and testing rates of antigen or antibody COVID-19 assays in Brazil remain disproportionately low\(^{(13)}\). Such low testing rates raise concern over the large-scale deployment of chest CT in Brazil for initial diagnostic evaluation as well as for routine follow-up of infected patients\(^{(14)}\). Assessment of true value of CT in initial diagnosis of COVID-19 is extremely challenging due to lack of adequate confirmatory testing and universal electronic medical record system in Brazil. Therefore, we hypothesized that there are substantial variations in frequency of CT use as well as in applied exposure factors and radiation doses associated with chest CT in patients with known or suspected COVID-19 pneumonia. Thus, the purpose of our study was to assess variations in chest CT usage, radiation dose and image quality in COVID-19 pneumonia in Brazil and to provide specific recommendations on the optimization of scan protocols.

**MATERIALS AND METHODS**

**Approvals and disclosures**

Our study received approvals from institutional review boards of all participating CT centers in Brazil with a waiver from written informed consent for retrospective, blinded evaluation of patient data. The study was approved by the ethics and research committee of University Federal of Pernambuco (CAAE: 34422920.5.0000.5208). Study coauthors have no pertinent financial disclosure related to this study. A study coauthor has received research grants from Siemens Healthineers and Riverain Tech for unrelated projects.

**Patients and participating sites**

Our retrospective, observational study on radiation dose and image quality included 542 patients who had chest CT between 21 March and 19 September 2020. Six healthcare sites (Site A–F) from different provinces of Brazil participated in our study and included: Hospital Delphina Rinaldo Abdel Aziz (Manaus), Hospital das Clinicas da Universidade Federal de Pernambuco (Recife), Hospital Miguel Soeiro (Sorocaba), Universitário Júlio Muller (Cuiabá), Hospital Samel (Manaus) and Hospital Unimed Vitoria (Vitoria). Patients under 18 years of age \((n = 2)\) were excluded from the study. An additional 7 patients were excluded as their image quality and CT findings could not be assessed at the time of preparation of the manuscript. Thus, the study included 841 CT exams from 533 adult patients \((>18\text{ years of age})\). All CT exams represented standard of care procedures, clinically indicated for assessment of either known or suspected COVID-19 pneumonia. The contribution of each site is summarized in Table 1.

| Site | Patients number | Gender (M:F) | Age (Mean ± SD) |
|------|----------------|--------------|-----------------|
| A    | 46             | 31:15        | 58 ± 15         |
| B    | 47             | 17:30        | 50 ± 16         |
| C    | 247            | 153:94       | 52 ± 18         |
| D    | 48             | 20:28        | 49 ± 17         |
| E    | 49             | 27:22        | 47 ± 12         |
| F    | 96             | 55:41        | 51 ± 16         |

**Scanner and exposure factors**

CT scan vendor, number of detector rows for individual scanners and the year of installation of the scanners were collected from each participating site. In addition, each site provided information on number of CT exams for each patient, number of scan phases for each CT, exposure factors (tube potential, tube current, automatic exposure control (AEC), pitch, gantry rotation time, detector configuration, image reconstruction technique and reconstructed section thickness) and separate radiation dose indices per series (volume CT dose index—CTDI\(_{vol}\) and dose length product—DLP). CT technologists from each participating site recorded the exposure factors and dose information for each CT from the archived dose information pages. Separately, scan protocols, image quality and radiation doses were reviewed to make recommendations on radiation dose and image quality optimization. All sites used routine, non-contrast chest CT protocol without any specific changes pertaining to its use in COVID-19 or high-resolution protocol.

**CT findings and subjective image quality**

A total of six general radiologists (with 10–24 years of post-residency experience) from all participating sites (one radiologist per site) independently evaluated all CT exams from their respective sites\(^{(15)}\). Radiologists graded the overall diagnostic quality of CT images on a 4-point scale \((1 = \text{optimal for evaluation of lung lobes}; 2 = \text{suboptimal in lung apices}; 3 = \text{suboptimal in other parts of lungs but not in the entire lungs}; 4 = \text{suboptimal in entire lungs})\). For suboptimal exams, radiologists specified or selected the most likely cause (respiratory motion artefacts, cardiac pulsation motion artefacts, streak artefacts from...
Overall diagnostic quality of CT images (4-point scale)
1 = optimal for evaluation of lung lobes
2 = suboptimal in lung apices
3 = suboptimal in other parts of lungs but not in the entire lungs
4 = suboptimal in entire lungs

Causes of suboptimal CT
- Respiratory motion artefacts
- Cardiac pulsation motion artefacts; streak artefacts from shoulders
- Inflowing contrast or metallic implant
- Excessive image noise

CT findings of COVID-19 pneumonia
- Groundglass opacities
- Crazy pavement (groundglass with interlobular septal thickening)
- Consolidation
- Nodules
- Mixed (combination of opacities)
- Others (such as masses and cavities)

How typical are CT findings for COVID-19 pneumonia?
Typical (peripheral, bilateral or multifocal rounded groundglass opacities with or without consolidation or interlobular septal lines and reverse halo appearance or other findings of organizing pneumonia)
Indeterminate (diffuse, multifocal, perihilar or unilateral groundglass with or without consolidation, presence of few small groundglass without typical distribution or rounded shape)
Atypical (isolated lobar or segmental consolidation, centrilobular nodularity, cavitary lung lesions and smooth septal thickening with pleural effusion)
Negative for pneumonia (without CT appearance of pneumonia)

Shoulders, inflowing contrast or metallic implant, and excessive image noise. Prior to the evaluation of CT examinations, the six participating radiologists took part in 10-hour long joint web meetings for building consensus on evaluation of imaging findings, classification of COVID-19 pneumonia on CT and image quality.

Each radiologist recorded CT findings of COVID-19 pneumonia and diagnostic quality of CT for evaluation of lung parenchyma in a standardized template in Microsoft EXCEL. Since the diagnostic acceptability of CT can vary based on the type of pulmonary opacities, we assessed both the type of opacities and image quality. For example, dense or large opacities such as consolidation and mass-like opacities are often assessable even with limited image quality and substantial artefacts. In contradiction, subtle groundglass opacities, smaller nodules or interlobular septal thickening are difficult to assess on artefact-impaired CT images. Pulmonary opacities were classified into groundglass opacities, crazy pavement (groundglass with interlobular septal thickening), consolidation, nodules, mixed (combination of opacities) and others (such as masses and cavities).

Based on the type of pulmonary opacities, each radiologist classified the CT appearance of COVID-19 pneumonia as typical (peripheral, bilateral or multifocal rounded groundglass opacities with or without consolidation or interlobular septal lines and reverse halo appearance or other findings of organizing pneumonia), indeterminate (diffuse, multifocal, perihilar or unilateral groundglass with or without consolidation, presence of few small groundglass without typical distribution or rounded shape), atypical (isolated lobar or segmental consolidation, centrilobular nodularity, cavitary lung lesions and smooth septal thickening with pleural effusion) and negative for pneumonia (without CT appearance of pneumonia). The Radiological Society of North America Expert Consensus Statement proposed this classification for chest CT findings in patients with COVID-19 pneumonia. The criteria used to evaluate chest CT images are summarized in Table 2.

Statistical analysis
All data were recorded in Microsoft EXCEL (Microsoft Inc., Redmond, Washington, USA). We estimated mean and standard deviations (SD) for patients’ age and weight. We arbitrarily classified patients into different age groups (<40 years, 40–59 years, 60–79 years or ≥80 years of age) to assess the presence of age-based variations in radiation doses since younger patients are at higher radiation risk than older patients. Median and interquartile range were estimated for CTDIvol and DLP for all CT exams.

For patients with multiple CT exams, we assessed changes in CTDIvol, and DLP over initial and follow-up chest CT exams, as well as the cumulative DLP for all CT exams per patient combined. Multivariable analyses of variance was used for comparing doses across patients in different subgroups of participating sites, scanner vendors, types of pulmonary
Table 3. Summary of number of CT exams performed per patient at various sites. Please note that Sites A and E belonged to the same city (Manaus).

| Sites | Mean # CT (per patient) | #CT = 1 (per patient) | #CT = 2 (per patient) | #CT = 3 (per patient) | #CT ≥ 4 (per patient) |
|-------|-------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Site A | 1.4 ± 0.7               | 46                    | 16 (34.8%)            | 2 (4.3%)              | 1 (2.2%)              |
| Site B | 1.0 ± 0                 | 47                    | —                     | —                     | —                     |
| Site C | 1.8 ± 1                 | 247                   | 138 (55.9%)           | 44 (17.8%)            | 23 (9.3%)             |
| Site D | 1.2 ± 0.5               | 48                    | 8 (16.7%)             | 2 (4.2%)              | —                     |
| Site E | 2.5 ± 1.4               | 49                    | 36 (73.5%)            | 24 (49.0%)            | 13 (26.5%)            |
| Site F | 1.0 ± 0                 | 96                    | —                     | —                     | —                     |
| Total  | 1.6 ± 0.9               | 533                   | 198 (37.1%)           | 72 (13.5%)            | 37 (69.4%)            |

opacities and diagnostic quality of CT. Radiation doses across different grades of CT appearance of COVID-19 pneumonia were compared with Kruskal Wallis test. A P-value less than 0.05 was considered as statistically significant difference.

RESULTS

Sites and CT usage

Table 3 summarizes patient distribution and usage of CT in suspected or known COVID-19 pneumonia across the six participating sites. There was no significant difference in patients’ age (P > 0.2) across the six sites although patients’ weight varied significantly (P < 0.001).

All sites had 16–64 section multidetector-row CT scanners installed between 2012 and 2020 from four different CT vendors (Canon Medical Solutions, GE Healthcare, Philips Healthcare, Siemens Healthineers) (Table 4). Most patients had one chest CT (533/841, 63.4%) followed by two (198/841, 23.5%), three (72/841, 8.6%) and four or more CT exams (37/841, 4.4%).

Subjective image quality

Of the 841 chest CT exams included in the study, most had typical chest CT findings of COVID-19 pneumonia (522/841; 62.1%), followed by indeterminate (208/841; 24.7%) and atypical (42/841; 5.0%) findings. The remaining 69 chest CT were deemed as negative for findings related to COVID-19 infection (69/841; 8.2%). Distribution of image quality and artefacts in patients with a spectrum of COVID-19 findings are summarized in Table 5. Most respiratory motion artefacts were present on chest CT exams with typical findings of COVID-19 pneumonia (195/344 chest CT exams with respiratory motion; 57%) followed by those with indeterminate findings (111/344; 32%).

Predominant pulmonary opacities on chest CT exams included groundglass opacities (n = 443/841 chest CT exams; 53%), mixed groundglass and consolidative opacities (n = 192/841; 23%), crazy-pavement appearance (n = 88/841; 10%), consolidation (n = 50/841; 6%) and pulmonary nodules (n = 14/841; 2%). Most evaluation limiting artefacts were present in chest CT exams with pure groundglass opacities or those mixed with interlobular septal thickening (229/367 chest CT exams with artefacts 62%). There was no significant difference in the distribution of type (groundglass, consolidation or mixed opacities) and the lobar extent of pulmonary opacities on chest CT exams performed at different sites (P = 0.065).

Most artefacts were related to respiratory motion (344/367 chest CT exams; 94%), whereas streak artefacts and too much noise were present on only 4% of chest CT exams (16/367 chest CT exams). There were no substantial artefacts in just over one-half of the chest CT exams (474/841 chest CT exams; 56%). Two-fifth chest CT exams (344/841; 41%) had respiratory motion artefacts with suboptimal evaluation of findings in either mid-to-lower lungs (176/344; 51%), lung apices (11/344; 3%) or the entire lung (31/344; 9%). There was no compromise in the evaluation of lung findings on the remaining 126 chest CT exams (126/344; 37%) with minor respiratory motion.

Variations in radiation dose

There were significant differences in patient weights (P < 0.001) as well as CTDIvol (P = 0.004), and DLP (P < 0.001) for chest CT exams performed at the six participating sites. As summarized in Table 4, sites with patients with lower body weight did not use lower radiation dose (CTDIvol and DLP) as compared with sites with larger body habitus patients. There was a significant difference in body weights (P = 0.026) and CT radiation doses indices (P ≤ 0.002) between male [mean ± SD weight: 90 ± 21 kg; median (interquartile range) CTDIvol: 10 (4) mGy; DLP: 367 (166) mGy.cm; estimated effective dose (EED): 5.1 (2.3) mSv] and female [mean ± SD weight: 77 ± 18 kg; median (interquartile range) CTDIvol:
Table 4. Tabular summary of CT scanners, patient body weight, tube potential (in kilovoltage), gantry rotation time and median CTDIvol (in mGy) at each site. Median DLP per CT and per patient. Figures in parenthesis for CTDIvol and DLP represent interquartile range. Higher total DLP at Site C was related to frequent use of follow-up CT.

| Sites | CT vendor (year) | Weight (kg) (mean ± SD) | kV | Pitch | Rotation time (seconds) | Median CTDIvol (mGy); EED (mSv) | Median DLP per CT (mGy.cm); EED (mSv) | Total DLP per patient (mGy.cm); EED (mSv) |
|-------|------------------|-------------------------|----|-------|-------------------------|---------------------------------|------------------------------------|--------------------------------------|
| Site A | GE 16 (2015)     | 76 ± 11                 | 120 | 1.4:1 | 0.8                     | 13 (4.4)            | 437 (134); 6.1 (1.9) | 490 (325); 6.9 (4.6) |
| Site B | Toshiba 64 (2015)| 69 ± 11                 | 120 | 1.4:1 | 0.8                     | 9 (11)            | 344 (213); 4.8 (2.8) | 306 (158); 4.3 (2.8) |
| Site C | Philips 64 (2011)| 90 ± 13                 | 120 | 1.4:1 | 0.8                     | 9 (6)            | 299 (143); 4.3 (2.0) | 339 (510); 4.7 (7.1) |
| Site D | Philips 16 (2020)| 74 ± 13                 | 120 | 1.4:1 | 0.8                     | 10 (3.9)           | 238 (137); 7.3 (1.9) | 480 (545); 6.7 (7.6) |
| Site E | Siemens 16 (2012)| 85 ± 23                 | 130 | 1.5:1 | 0.8                     | 7 (3.3)            | 341 (45); 4.8 (0.6)  | 341 (45); 4.8 (0.6)  |
| Site F | Siemens 16 (2012)| 85 ± 23                 | 110 | 1.5:1 | 0.6                     | 10 (11)            | 341 (45); 4.8 (0.6)  | 341 (45); 4.8 (0.6)  |

There was no difference in the number of CT exams ($P = 0.244$), CTDIvol ($P = 0.106$) and DLP ($P = 0.141$) in patients <40 years, 40–59 years, 60–79 years or ≥80 years of age. Although all sites used AEC for acquiring chest CT exams, sites did not modify the AEC image quality parameter to adjust dose for patients in different age groups or for those undergoing follow-up chest CT exams. Apart from the use of AEC, sites did not change any other scan parameters based on patient size.

None of the sites used lower radiation dose for follow-up CT exams as compared with the initial CT exams (CTDIvol across multiple exams per patient, $P = 0.19$; DLP across multiple CT exams per patient, $P = 0.82$) (Table 6). The cumulative DLP ($P < 0.001$) was significantly higher in patients with multiple chest CT exams as compared with those with only one chest CT.

There were no significant differences between radiation doses (CTDIvol and DLP) among patients with typical, indeterminate, atypical or negative CT findings for COVID-19 pneumonia ($P > 0.5$).

Figure 1 summarizes median CTDIvol and DLP for patients who had optimal and suboptimal diagnostic quality for evaluation of lung findings. As compared with chest CT exams without artefacts, CT exams with respiratory motion artefacts were obtained at substantially lower pitch (0.7:1 vs. 0.9:1, $P < 0.001$) and slightly higher DLP (360 vs. 333 mGy.cm; EED 5.0 vs. 4.7 mSv, $P = 0.001$) (Figure 2). Notably, on some scanners (GE and Toshiba), there is a small increase in radiation dose with the use of lower pitch. Gantry rotation speed across patients without and with motion artefacts was similar (0.72 vs. 0.74 second).

Recommendations

Following completion of data analyses, we created and shared a series of recommendations with the different participating sites to help optimize radiation dose indices and improve image quality (Table 7).

DISCUSSION

Our multicenter study demonstrates several upsides and downsides of CT usage in COVID-19 pneumonia in Brazil. Three-fourths of our patients had either one or two CT exams for their COVID-19 workup. Use of three or more CT exams was limited to those with typical findings of COVID-19 pneumonia. Second, most chest CT exams had findings typical for COVID-19 pneumonia, which imply CT usage in patients with high pretest probability of disease. This finding is consistent with those in a recent
Table 5. Distribution of artefacts in patients with CT findings typical, indeterminate, atypical or negative for COVID-19 pneumonia. Table presents a number of CT exams and percentage of all exams in the parenthesis. Denominator for all calculated percentage is the total number of CT exams (841). The last column represents the effect of artefacts on ability to evaluate CT exams (Optimal for all lobes/suboptimal in all lobes/suboptimal in lung apices/suboptimal in other parts of lungs).

| Artefacts                      | Typical findings | Indeterminate findings | Atypical findings | Negative findings | Total | Effect on evaluation |
|--------------------------------|------------------|------------------------|------------------|------------------|-------|---------------------|
| No artefacts                   | 311 (37%)        | 94 (11%)               | 18 (2%)          | 51 (6%)          | 474 (56%) | 474/0/0/0           |
| Respiratory motion             | 195 (23%)        | 111 (13%)              | 21 (2%)          | 17 (2%)          | 344 (41%) | 126/31/11/176       |
| Cardiac pulsations             | 3 (<1%)          | 2 (<1%)                | 1 (<1%)          | 1 (<1%)          | 7 (1%)   | 6/0/0/1             |
| Streak artefacts               | 10 (1%)          | 1 (<1%)                | 1 (<1%)          | 0 (0%)           | 12 (1%)  | 7/2/0/3             |
| Too much noise                 | 3 (<1%)          | 0 (0%)                 | 1 (<1%)          | 0 (0%)           | 4 (<1%)  | 2/1/0/1             |
| Total                          | 522 (62%)        | 208 (25%)              | 42 (5%)          | 69 (8%)          | 841 (100%) | 615/34/11/181       |

Figure 1. Box and whisker plots of median and interquartile ranges CTDIvol (A) and DLP (B) for chest CT with optimal and suboptimal image quality. There were significant statistical differences in CTDIvol ($P = 0.014$) but not in DLP ($P = 0.078$) for patients with optimal and suboptimal diagnostic quality. Weights of patients with suboptimal evaluation of entire lungs (median weight 70 kg, IQR 25 kg) were significantly lower than those with optimal evaluation (median weight 83 kg, IQR 30 kg) ($P < 0.001$).

survey on CT practices where the use of CT for screening COVID-19 infection was limited$^{[14]}$. Third, all participating sites performed a single-phase, non-contrast chest CT. Fourth, there was less than 2-fold variation in both CTDIvol and DLP across the six participating sites despite variations in CT scanner models (four vendors) and slice profile (16–64 section, multidetector CT scanners). The minor variation in radiation doses contradicts 2–8-fold variations reported in a recent study$^{[14]}$. Fifth, female patients
with lower body weight received lower radiation doses (both CTDI\text{vol} and DLP) than male patients. Sixth, younger patients (<40 years) did not receive higher radiation doses as compared with older patients. This finding compares favorably over prior international study that demonstrated higher but statistically insignificant radiation dose in younger patients as opposed to older patients\(^\text{(14)}\).

The main downside of CT usage and practice in Brazil was the use of higher radiation doses (median CTDI\text{vol} 7–13 mGy) for chest CT in patients with known or suspected COVID-19 pneumonia\(^\text{(17–19)}\). For example, Zarei \textit{et al.} reported ultra-low-dose CT protocol with 0.2–0.5 mGy CTDI\text{vol} on 128-section CT with iterative reconstruction technique\(^\text{(17)}\). Li \textit{et al.} reported 2.5-mGy CTDI\text{vol} for chest CT in COVID-19 patients with AEC and iterative reconstruction\(^\text{(18)}\). Hamper \textit{et al.} reported CTDI\text{vol} of 0.9 ± 0.3 mGy for low-dose chest CT exams on two scanners equipped with iterative reconstruction techniques\(^\text{(19)}\). Another study reported the use of high-pitch, low-kV with selective photon shield (100 kV with tin filter) and iterative reconstruction to achieve 0.6-mGy CTDI\text{vol} for chest CT in COVID-19 pneumonia on a third-generation, dual-source CT scanner\(^\text{(20)}\), compared with other studies with higher radiation doses were likely related to less advanced scanners and lack of iterative or advanced reconstruction techniques at our participating sites. Nonetheless, other studies without use of advanced scanners and reconstruction techniques have reported use of lower radiation dose in non-COVID settings. Bankier and Tack recommended CTDI\text{vol} of 4–6 mGy for smaller or average-sized patients for routine or standard chest CT\(^\text{(21)}\). Since only a handful of CT exams (4/841, <1%) in our study were too noisy to interpret, there is likely an opportunity to reduce radiation dose for chest CT in our sites. Although radiation doses varied across the participating sites, they were not related to patient size or scanner technology (16- or 64-section scanners). Radiation dose also did not vary between the initial and follow-up chest CT exams. Likewise, all sites used 120 kV as tube potential regardless of body weight, while other publications recommend frequent use of lower tube potential (<120 kV) for chest CT in non-obese patients\(^\text{(21, 22)}\). These observations imply the need for a structured or stratified weight-based chest CT protocol for optimizing radiation dose at the participating sites (Table 6).

Another cause for concern in our study was the presence of respiratory motion artefacts in more than...
Table 6. Distribution of CTDIvol, DLP and EED based on the frequency of chest CT usage at different participating sites. The values in table represent median and interquartile range (in the parenthesis).

| Weight (kg) | #CT = 1 (per patient) | #CT = 2 (per patient) | #CT = 3 (per patient) | #CT ≥ 4 (per patient) |
|------------|------------------------|------------------------|------------------------|------------------------|
|            | CTDIvol (mGy); DLP (mGy.cm); EED (mSv) | CTDIvol (mGy); DLP (mGy.cm); EED (mSv) | CTDIvol (mGy); DLP (mGy.cm); EED (mSv) | CTDIvol (mGy); DLP (mGy.cm); EED (mSv) |
| Site A     | 71 (20)                | 79 (22)                | 75 (20)                | 85 (20)                |
| Site B     | 9 (7)                  | 9 (6)                  | 10 (4)                 | 10 (1)                 |
| Site C     | 346 (196)              | 316 (139)              | 226 (149)              | 341 (65)               |
| Site D     | 457 (107); 6.4 (42.5)  | 306 (198); 4.3 (2.8)   | 226 (149); 3.2 (2.1)   | 341 (65); 4.8 (0.6)    |
| Site E     | 931 (0); 13.9 (0)      | 1151 (630); 11.5 (6.4) | 738 (493); 10.3        | 738 (493); 10.3        |
| Site F     | 12 (−)                 | 12 (−)                 | 12 (−)                 | 12 (−)                 |

Despite the similar distribution of pulmonary opacities across the participating sites, there was a 2.5-fold variation in the number of CT exams per patient, with two sites using one CT per patient and two sites performing 2–2.5 CT exams per patient. The sites with a higher number of CT exams per patient might have sicker, complicated or at higher risk patients than others. However, it was not clear if sites followed recent recommendations from the Brazilian College of Radiologists that discourage CT for screening purposes and support the use of low-dose CT protocols for COVID-19 infection\(^{(24, 25)}\). The use of low-dose CT protocols can also be challenging on older, legacy scanners and in the absence of a national consensus on reference dose levels (DRL) for CT in Brazil. Adoption of existing international guidelines\(^{(26)}\) or the creation
Table 7. Specific recommendations for radiation dose and image quality optimization.

| Issues                      | Recommendations                                                                                                                                 |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Initial CT dose optimization| Decrease CT usage for screening purposes in COVID-19  
Use AEC to adapt dose to patient size  
Use lower kV (80–100 kV) and lower mA for smaller patients  
Confine scan length to lung bases instead of adrenals  
Target CTDI_{vol} of 4–6 mGy as initial step toward optimization  
Update CT technology if feasible (i.e. iterative reconstruction) |
| Follow-up CT optimization   | Reduce routine use of follow-up CT  
Explore use of chest radiography for follow-up  
Use follow-up CT only in specific circumstances:  
• Suspected complications  
• Unexplained clinical deterioration  
• Unexplained lack of improvement in patient condition |
| Respiratory motion artefacts| Reduce dose for follow-up CT as compared to baseline CT  
Instruct patients to make effort for a good breath-hold  
Increase scanning speed  
• Increase pitch (≥1:1) and table speed  
• Faster gantry rotation time (<0.5 seconds)  
• Use wider beam collimation  
Invest in newer wide-area detector or dual-source CT scanners |

of national guidelines can help reduce the frequency of unnecessary CT and help reduce radiation dose. Reduction in unnecessary follow-up CT can also help minimize the risk of spreading the infection to healthcare personnel, including CT technologists who have to move, position, center and instruct the patient for their CT exams.

There are a few limitations in our study. Our study was retrospective evaluation of existing practices on use of CT in patients with known or suspected COVID-19 pneumonia. Information on exposure factors and radiation dose were recorded manually at each participating site since we do not have an automatic radiation dose monitoring or tracking program. Although radiologists double-checked all data entries, manual recording can lead to errors. We did not have access to variations in disease severity in patients and their outcomes, which could explain variations in CT usage across different patients and participating sites. Although there was a representation of scanners from four CT vendors, as anticipated from a resource-constrained, developing nation such as Brazil, the included scanners do not represent the state-of-the-art latest scanners capable of scanning patients with substantially lower radiation doses. This limitation can also be construed as a strength since our CT equipment are aligned with anticipated level of technology in developing countries. Due to the limited availability of RT-PCR assays for COVID-19 pneumonia in Brazil, we could not assess variations in radiation doses in patients with 'true positive COVID-19 pneumonia (with positive RT-PCR assay)' and 'true negative COVID-19 pneumonia (at least two negative RT-PCR assays)'. However, such limited access to RT-PCR assay is not infrequent in even the most developed countries in a setting of a high-prevalence pandemic. A limitation of our study was that each site CT exams were assessed by one radiologist. However, all participating radiologists had extensive interpretation experience (10–24 years). They also underwent mandatory training before evaluation of the included chest CT exams (10 hours) to avoid any bias and decrease inter-observer variations. Finally, we did not record the beam collimation or width, which is a key parameter for estimating table speed and scan duration.

In conclusion, there are substantial variations in scan practices and radiation doses with the use of chest CT in patients with known or suspected COVID-19 pneumonia. Patients with small body sizes or scanned on 64-slice CT scanners did not receive lower doses than those with greater body weights or scanned on 16-slice CT scanners. In addition, more than two-fifth (41%) of chest CT exams had respiratory motion artefacts. Our study identified several issues and proposed several recommendations on improving CT usage and protocols for patients with known or suspected COVID-19 pneumonia.
ABBREVIATIONS
CT, Computed tomography; COVID-19, Coronavirus Disease of 2019; IAEA, International Atomic Energy Agency; CTDIvol, Computed tomography dose index volume; DLP, Dose length product; kV, Kilovolt; kg, Kilogram; IQR, Inter quartile range; SD, Standard deviation

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