PRACTICAL CHALLENGES WITH IMAGING COVID-19 IN BRAZIL: MITIGATION IN AND BEYOND THE PANDEMIC

Mônica O. Bernardo1,2, Fatemeh Homayounieh3, Shadi Ebrahimian3, Juliana Santana de Melo Tapajós4,5, Luiz Cláudio de Moura Carvalho6, Ricardo Varella7, Helen Jamil Khoury8 and Mannudeep K. Kalra3,∗

1Pontifícia University Catholic of São Paulo, São Paulo, Brazil
2Hospital Miguel Soeiro—UNIMED, Sorocaba, São Paulo, Brazil
3Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA
4Hospital SAMEL Manaus, Amazonas, Brazil
5Hospital Delphina Rinaldi Abdel Aziz, Manaus, Amazonas, Brazil
6Hospital Universitário Júlio Muller, Cuiabá, Mato Grosso, Brazil
7Hospital Unimed Vitória, Vitoria, Espírito Santo, Brazil
8Hospital das Clínicas—Federal University of Pernambuco, Recife, Pernambuco, Brazil

∗Corresponding author: mkalra@mgh.harvard.edu

Received 19 April 2021; revised 23 June 2021; editorial decision 21 July 2021; accepted 21 July 2021

Computed tomography (CT) provides useful information in patients with known or suspected COVID-19 infection. However, there are substantial variations and challenges in scanner technologies and scan practices that have negative effect on the image quality and can increase radiation dose associated with CT. Objective: In this article, we present major issues and challenges with use of CT at five Brazilian CT facilities for imaging patients with known or suspected COVID-19 infection and offer specific mitigating strategies. Methods: Observational, retrospective and prospective study of five CT facilities from different states and regions of Brazil, with approval of research and ethics committees. Results: The most important issues include frequent use of CT, lack of up-to-date and efficient scanner technologies, over-scanning and patient off-centring. Mitigating strategies can include updating scanner technology and improving scan practices.

INTRODUCTION

COVID-19 took the world and Brazil by a storm as the pandemic surged from Wuhan, China in late 2019 and engulfed the globe claiming over 2.5 million lives and disrupting lives and livelihood everywhere(1). As vaccine supply and vaccinations ramp up, new variants, most notably from the UK, South Africa and Brazil have raised concerns over efficacy of vaccines to curtail or control the spread of infection from emerging variants(2). Despite the disruptions caused by the COVID-19 pandemic, medicine made tremendous progress, particularly in development and testing of several effective vaccines and artificial intelligence-based applications in imaging.

Imaging, specifically with computed tomography (CT), continues to play a critical role in management of patients with known or suspected COVID-19 pneumonia(3, 4). The initial days of pandemic saw substantial use of CT for rapid screening of patients with suspected COVID-19 infection in the face of paucity of reverse transcription-polymerase chain reaction (RT-PCR) assays and high disease prevalence(5). Many organisations and regulatory bodies recommended against routine use of CT for diagnosis of COVID-19 pneumonia due to low sensitivity and specificity of findings in early disease(5–7).

CT continues to be the ‘go-to’ method for diagnosis of COVID-19 pneumonia as well as for assessing disease severity, complications and treatment response. Beyond lungs, CT is also frequently used to assess vascular complications of COVID-19 infection in the brain, pulmonary arteries and the abdomen. In Brazil too, CT is frequently requested by the physicians for assessing diagnosis, severity and complications of COVID-19 pneumonia.

Our multicentre studies from Brazil and several other countries reported substantial variations in CT technology, scanning practices and radiation doses when it comes to imaging patients with known or suspected COVID-19 pneumonia(5, 8). Over the course of our studies involving multiple sites in Brazil, we identified several challenges with the use of CT that will have implications both within and beyond the current pandemic. Many but not all these issues can be mitigated with proper practice and optimisation steps. This article presents major issues and challenges with use of CT at a sample of Brazilian sites for
imaging patients with known or suspected COVID-19 infection. It offers specific mitigating strategies, offers steps for quality improvement and reinforces the justification.

RECOMMENDATIONS ON IMAGING USE IN COVID-19

The initial hype on the role of imaging, chest CT in particular, for screening patients with suspected COVID-19 pneumonia was swiftly voted down in a number of follow-up imaging studies and guidelines from national and international bodies(5, 7, 9–12). These guidelines reinforced the fact that negative imaging does not rule out COVID-19 infection and a positive imaging does not confirm the infection in absence of RT-PCR assay or other antigen or antibody tests(5, 6, 10). In line with other national and international organisations including the World Health Organization (WHO), the Brazilian College of Radiology (CBR) issued recommendations on imaging use in COVID-19(5, 7, 9–13). The CBR reaffirmed that CT has no place in screening or initial diagnosis of COVID-19. These guidelines and recommendations are important since inappropriate or overuse of CT is associated with an unjustified radiation exposure as well as of infection transmission to radiology and transportation staff involved in imaging.

In some parts of the world, the lack of RT-PCR assays and other immunoassays coupled by high disease prevalence has necessitated use of CT for screening COVID-19 patients. Conversely, respectable authorities in thoracic imaging such as the Fleischner Society recommends use of chest CT in patients with moderate or severe disease, high-risk individuals with suspected infection, in those with complications, as well as for assessing treatment response or lack thereof(14). The CBR too advocates for rational use of CT in hospital-admitted patients with symptoms and a need to obtain specific clinical information(13). Furthermore, the CBR goes a step beyond the Society’s guidelines and recommends a low-dose scanning protocol without use of contrast media unless determined otherwise by the radiologist(13). The sense of radiologists’ oversight is exemplary of their role in ensuring appropriate scanner use.

Most hospital-admitted patients with known COVID-19 pneumonia receive chest radiographs due to their convenience as a bedside procedure, ease of disinfection and higher availability at lower cost and radiation dose compared with chest CT. Such patients often receive serial chest radiographs to monitor for disease evolution, complications and status of central lines and tubes. Despite their multiplicity, chest radiographs are still associated with a fraction of radiation dose associated with a single chest CT on most scanners. A prior study across a wide spectrum of adult body habitus reported an average effective dose of 3.2 mSv for chest CT and 0.04 mSv for a single posteroanterior chest radiograph(15).

STRENGTHS OF CT PRACTICES

As part of joint project with the International Atomic Energy Agency, we collected information on the use of CT in patients with known or suspected COVID-19 pneumonia from different geographic sites in Brazil(8). Sites for survey and scanner data on use of chest CT in 533 patients included five CT facilities from North, Northwest, Southeast and Midwest regions of Brazil. The survey was performed between 15 May 15 and 20 July 2020. The survey information on CT doses and scan parameters was filled out by a radiologist and/or radiologic technologist.

Radiology staff and services in Brazil and world over have and will continue to play an indispensable role in the COVID-19 pandemic, especially when it comes to caring for the sickest and those at highest risk. Like our colleagues from other medical specialty, radiology staff has had to adjust, adapt and deliver critical services at a risk to their own safety and practices. In addition, our survey highlighted several positive aspects of radiology departments in use of CT for patients with suspected and known COVID-19 infection. The most important strength pertained to use of written policies on the use of chest CT in patients with COVID-19 infection. Second, most patients had only one or two chest CTs (∼85%), which considering the often-protracted course of disease in intensive care unit-admitted patients, reveals a low contribution toward high cumulative radiation dose.

Third, most patients (95%) had a single-phase, non-contrast-enhanced chest CT in compliance with the CBR recommendations for patients with COVID-19 pneumonia. If all scan parameters are held constant, single-phase CT is associated with substantially lower dose as compared with scans performed with two or more phases. Fourth, all sites reconstructed chest CT images at thin-section width with high-spatial frequency kernels (such as lung kernel) to improve image resolution for evaluating lung findings. Fifth, regardless of the scan vendor and detector-rows (16–64), all sites used automatic exposure control (AEC) to adapt tube current to patient size. Finally, all sites adopted measures for protecting CT staff and patients from transmission of COVID-19 infection.

LIMITATIONS AND MITIGATION OF CT IN COVID-19 INFECTION

Besides the strengths of radiology practices, our multicentre studies revealed limitations in our practices,
which are neither unique nor unsolvable. This section stratifies these limitations and offers mitigation strategies.

CT in initial diagnosis

Although several organisations including the CBR have stated that chest CT should not be used in the initial diagnosis of COVID-19 infection\textsuperscript{13}, like the practice in many countries, Brazil too suffers from a lack of adequate serological testing for patients with suspected COVID-19 infection. The lack of serological testing necessitated use of chest CT in many sites in Brazil (3/5 CT facilities included in our study)\textsuperscript{8}. While use of CT in initial diagnosis of COVID-19 infection is justified in hospital-admitted patients, high-risk patients and those with suspected complications or moderate to severe disease\textsuperscript{13, 14}, there is little evidence to justify a routine use of CT as a screening test in low-risk outpatients and those with mild disease. In the latter group, CT may be false negative and/or non-specific. Frequent and unindicated use of CT increases the risk of infection transmission in radiology and transport staff besides exposing the patients to unnecessary radiation dose and risks from incidental unrelated findings.

Mitigation

A significant ramp up in serological testing would be preferable to the use of CT. However, given the global challenges in both developed and developing countries such as Brazil, access to serological testing though improved from the early pandemic days remains inadequate in most countries. This puts the onus on the referring physicians and the radiologists to follow guidance from the CBR, WHO and other respected organisation and restrict or avoid frequent use of CT and chest radiography as a mean for initial diagnosis of COVID-19 infection.

Recommendation

CT facilities or hospitals should monitor and limit routine use of chest CT for screening or initial diagnosis of COVID-19 infection in patients with low risk or mild disease.

Multiple CT for follow-up

Most surveyed hospitals (3/5) reported frequent use of CT in hospital-admitted patients with COVID-19 pneumonia in order to assess disease severity, complications and follow-up imaging findings for change or resolution. In total, 60% of the patients had two or more chest CTs. In at-risk patients such as those with comorbidities such as diabetes, heart disease or immunocompromised status, use of CT is justified and recommended\textsuperscript{14}. However, routine use of CT for assessing change or resolution of radiologic findings or COVID-19 pneumonia or for predicting disease outcome is not recommended\textsuperscript{14}. Multiple CTs increase the cumulative radiation dose and healthcare costs. Unfortunately, none of the participating sites reduced radiation doses for follow-up CT as compared with the baseline CT.

Mitigation

Repeat or follow-up chest CTs should only be performed in specific circumstances such as in patients with unexplained clinical deterioration, complications and unexplained lack of improvement in patient condition. Routine use of CT for assessing resolution of radiologic finding should be avoided. When needed, for assessment of treatment response and for non-vascular complications, radiation doses for follow-up CT must be reduced to relative to the initial baseline chest CT. Users can simply reduce the tube current for follow-up chest CT to accomplish such dose reduction. Physicians should not forget that chest radiography is a more convenient, portable, accessible, cheaper and lower radiation dose method compared with chest CT. Routine follow-up of patients with chest CT and radiography should be avoided unless the patient deteriorates, demonstrates lack of improvement or develops complications. For assessing treatment response, often chest radiographs are sufficient and multiple CTs should be avoided.

Recommendation

Avoid routine use of follow-up or multiple chest CTs in patients with known COVID-19 pneumonia. When necessary, follow-up chest CTs should be performed with modification of scan parameters to reduce radiation doses relative to baseline examination.

Planning scan acquisition

First, review of over 800 chest CT examinations from the five participating sites revealed that respiratory motion artefacts occur in ~40% of patients. Motion artefacts can limit evaluation of lung findings and require additional CT images that increases radiation dose to the patients. High incidence of respiratory motion artefacts may be related to slow scanning speed or an inability to follow or comply with breathhold instructions.

Second, 80% of chest CTs in patients with known or suspected COVID-19 infection at the surveyed sites were off-centred relative to CT gantry isocentre\textsuperscript{16}. Off-centring can increase image noise and radiation dose\textsuperscript{17}. Although the actual cause for off-centring was not specifically investigated, it is possible that
a reduction in close patient contact may have contributed to such high frequency of off-centring.

Third, all sites extended the scan coverage to the adrenal glands instead of lung bases\(^8\). Since there is no literature to support an increased incidence of adrenal abnormality in a benign infectious disease such as COVID-19 pneumonia, extension to adrenal glands increases the scan length and radiation dose associated with chest CT.

**Mitigation**

To reduce the incidence of motion artefacts related to patient factors, it is important to provide and demonstrate the breath-hold to patients who can follow instructions. Good instructions can improve patient compliance with breath-hold instructions and reduce presence and/or severity of motion artefacts. Often manual instructions provide better breath-hold compliance than pre-recorded instructions on the scanners\(^18\). Technologists and/or radiologists should assess the patients for their ability to hold breath prior to their imaging. For those unable to comply with instructions, the choice of scanner and scan parameters can help increase scan speed and mitigate or reduce motion artefacts.

To address the issue of off-centring, CT technologists must first understand that patient off-centring in CT is a frequent and consequential occurrence. They must make efforts to centre the patient in gantry isocentre while minimising prolonged patient contact. Radiologists can help improve the quality of patient positioning by constructive feedback to the technologists on chest CTs performed with considerable off-centring during interpretation. Improved patient centring in the scanner isocentre helps in optimum calculation of tube current with AEC techniques as well as in balanced distribution of image noise in the entire cross-section of the anatomy.

To reduce scan length and associated radiation dose, scan coverage for non-contrast chest CT in patients with COVID-19 pneumonia should only cover the lungs from the apices to the lung bases unless a concurrent CT of abdomen is requested.

**Recommendations**

Improved patient instructions on breath-holding for chest CT and proper patient centring in the scanner gantry can improve image quality, reduce artefacts and avoid excess radiation dose from repeat scanning or uninterpretable images. Routine extension of scan length to include adrenal glands should be avoided when performing chest CT in patients with COVID-19 pneumonia.

**Choice of scan parameters**

Survey and data from the five sites revealed that applied scan parameters and radiation doses did not vary based on number of CT examinations, patient’s size, age or the extent of motion artefacts in the acquired CT datasets (Figure 1). There was no change in scan parameters and radiation dose between the baseline and follow-up CT examinations or between younger and older patients. Despite use of AEC techniques at the participating sites, there were no substantial differences in patients with small or large body habitus. About 60% of chest CTs were performed at 120 kVp regardless of patient size or age. All sites performed chest CTs with 0.8 s or slower gantry rotation speed and at pitch less than 1:1; these parameters increase scan duration and frequency of motion artefacts in patients who cannot hold their breath for the duration of their examination.

**Mitigation**

Prior studies have reported that scan parameters can be modified to reduce radiation dose for baseline and follow-up evaluation of lung findings\(^18\). Lack of change in radiation dose despite AEC use underscore the importance of proper application of AEC such as with the use of proper image quality parameter [such as high noise index (GE Healthcare) and standard deviation (Canon Medical Systems) or lower-quality reference mAs (QRM, Siemens Healthineers)]. Application of AEC on equipment of some vendors require use of image quality parameter (noise index,
### Table 1. Summary of our five-site survey shows that most sites did a single-phase CT. There were substantial variations in radiation doses across the surveyed sites. Most sites used gantry rotation times of >0.5 s and therefore had higher probability of motion artefacts. [Data source modified from reference(8)].

| Site | No. of scan phase | CTDIvol (mGy) | DLP (mGy.cm) | Rotation times (s) | Tube voltage (kV) | Slice thickness (mm) |
|------|------------------|---------------|--------------|--------------------|-------------------|---------------------|
| Site a | 1 (1–2) | 9 (9–12) | 288 (247–394) | 0.625 (0.5–0.75) | 120 | 1 |
| Site b | 1 (1–1) | 7 (6–10) | 254 (170–341) | 0.8 (0.8–0.8) | 130 | 1 |
| Site c | 1 (1–1) | 10 (7–13) | 398 (273–500) | 0.75 (0.75–0.75) | 120 | 1 |
| Site d | 1 (1–1) | 6 (5–7) | 198 (163–226) | 0.8 (0.8–0.8) | 110 | 2 |
| Site e | 1 (1–1) | 9 (8–10) | 388 (310–431) | 0.4 (0.4–0.4) | 120 | 1 |

GE or standard deviation, Canon), which takes into account the specified pitch and section thickness, as well as the range of tube current between which the tube current can modulate. Patients with body weight <80 kg can be scanned at 100 kVp and those under 50 kg can be imaged with 80 kVp, even when using filtered back projection technique. Often a reduction in tube potential will require higher tube current, which is best accomplished by AEC technique. This ensures that the radiation doses do not drop so low that the diagnostic information is lost. Finally, to reduce the frequency and severity of motion artefacts, chest CTs must be performed with faster rotation time (0.5 s) and non-overlapping pitch (>1:1). When possible, a wider beam collimation enables faster table speed if all other parameters are held constant and can also help reduce motion artefacts. Faster scanning speed with good breath-hold instructions can help reduce frequency of motion artefacts. For chest only CTs, use of faster scan speed should provide sufficient diagnostic quality images in obese patients as well since high inherent tissue contrast with in normal and abnormal lung parenchyma is often not adversely affected by the presence of high image noise.

**Recommendations**

Proper scan parameters can help reduce radiation dose while improving diagnostic quality of chest CTs.

**Radiation doses**

Most scanners (at 4/5 surveyed sites) had 64-detector-rows or under and only offered filtered back projection technique of image reconstruction. Older scanners, particularly when the scan parameters are not adapted to obtain optimal scan duration, can be associated with higher frequency of motion artefacts from respiration and cardiac pulsations. Unfortunately, evaluation of radiation doses in our survey did not demonstrate lower radiation doses for patients scanned on 16- vs. 64-detector-row CT scanners. This discrepancy points to inconsistent selection of scan parameters across different scanner types.

A prior study has reported on radiation doses from five Brazilian CT facilities with median CT dose index volume (CTDIvol) of 9 mGy (interquartile range of 5 mGy) for a single phase, non-contrast chest CT(8). Prior studies in both COVID-19 pneumonia and other clinical indications for chest CT have reported that chest CT can be performed with a sufficient diagnostic quality at CTDIvol 4–6 mGy or less(5, 8, 19–22). A lack of national diagnostic reference levels (DRL) for CT in Brazil compounds the issue of higher than needed radiation doses(21). However, radiation doses in our survey were similar to a prior study on local institutional level DRLs from Brazil; the authors reported a chest CT DRL of 10 mGy(23). Radiation doses from our multicentre survey are summarised in Tables 1–3.

**Mitigation**

Deployment of modern, wider detector-array scanners with better detector efficiency, faster scanning speed and advanced image reconstruction techniques (such as iterative reconstruction or deep learning-based reconstruction techniques) can help lower radiation dose while improving diagnostic quality and reducing respiratory motion artefacts. At the same time, lack of radiation dose reduction on 64-detector-row CT scanners relative to older 16-detector-row scanners point to the need for optimising scan parameters so that potential of current scanners can be adequately utilised to optimise and reduce radiation dose. This observation along with the
Table 2. Table summarises the frequency of multiple CTs in patients with COVID-19 pneumonia and associated CTDI\textsubscript{vol} and DLP. In total, 60% of patients received more than one CT. [Data source modified from reference\textsuperscript{(8)}]. There was no significant difference in radiation doses for patients with three or four CT examinations ($P > 0.05$). Slightly lower radiation dose for patients with four CTs than those with three CTs may have resulted from use of some dose optimisation in patients with four chest CTs.

| Percentage of patients | Median CTDI\textsubscript{vol} (mGy) | Median of the total DLP (mGy.cm) |
|------------------------|-----------------------------------|----------------------------------|
| Patients with one CT   | 40%                               | 9 (6–11)                         | 271 (198–390)                  |
| Patients with two CTs  | 23%                               | 9 (6–11)                         | 493 (421–735)                  |
| Patients with three CTs| 29%                               | 8 (6–10)                         | 1003 (731–1247)                |
| Patients with four CTs | 6%                                | 10 (7–12)                        | 992 (894–1550)                 |
| Patients with five CTs | 2%                                | 6 (6–7)                          | 1087 (1022–1152)               |

Table 3. The table summarises lack of change in radiation dose (despite use of AEC) with change in body habitus and age.

| Percentage of patients | Median CTDI\textsubscript{vol} (mGy) | Median DLP (mGy.cm) |
|------------------------|-----------------------------------|---------------------|
| Median patient size    |                                    |                     |
| <78 kg                 | 49%                               | 9 (6–11)            | 271 (198–390)                  |
| \geq 78 kg             | 51%                               | 9 (6–11)            | 283 (216–398)                  |
| Median patient age     |                                    |                     |
| <56 y                  | 49%                               | 9 (6–10)            | 283 (210–401)                  |
| \geq 56 y              | 51%                               | 9 (6–11)            | 284 (211–406)                  |

The aforementioned issues in Brazil points to a serious need for raising awareness on issues related to CT image quality and radiation doses amongst the technologists and radiologists. Replacement of older scanners with newer more advanced CTs requires a considerable cost burden in a developing country. Until such upgrade, importance and education of dose optimisation strategies should be stressed. Teams of radiographers, radiologists and medical physicists can help in such optimisation efforts.

Recommendation

Substantial financial resources are required to update CT scanner technologies and reduce radiation dose while improving diagnostic quality.

SUMMARY

Routine use of CT for screening patients with suspected COVID-19 infection and for evaluating patients with mild disease is not recommended. Important strength of scanning practices in such patients include use of single, non-contrast chest CT and use of AEC to adapt radiation doses to patient body habitus and size. CT protocols must also be modified (faster scanning speed with fast gantry rotation speed and/or higher pitch) to reduce motion artefacts, which frequently limit evaluation of lung parenchyma. However, several limitations including longer than needed scan duration, patient adjustment and inadequate protocol adjustment call for immediate and long-term remediation steps in scanner use and technologies to improve image quality and reduce radiation dose.

ACKNOWLEDGEMENTS

We are grateful to our following colleagues for their help in data collection and manuscript review: Alair S. Santos, MD; Fernando A. Almeida, MD, Flávio Morgado, PhD\textsuperscript{1}, RenanG. Henschel, MD, and Débora Pinto\textsuperscript{1}, Danilo M. Sales, MD (Pontificia University Catholic of São Paulo, São Paulo, Brazil); Antônio A. Moscatelli, MD, Luiz M. Bellegard, MD, and Maria Cuter, MD (Hospital Miguel Soeiro–UNIMED, Sorocaba, São Paulo, Brazil); Homero Medeiros, MD, and Gabriela Buril, MD (Hospital das Clinicas–Federal University of Pernambuco, Recife, Pernambuco, Brazil); Juliana P. Carvalho, MD, and Vinicius P. Carvalho (Hospital Unimed Vitória, Vitoria, Espírito Santo, Brazil); and Luciano L. Tapajás, MD (Hospital Delphina Rinaldi Abdel Aziz, Manaus, Amazonas, Brazil).

CONFLICT OF INTEREST

A study coauthor received research funding from Siemens Healthineers and Riverain Tech Inc for unrelated research. Other co-authors have nothing to disclose.
REFERENCES

1. Johns Hopkins University & Medicine. Coronavirus Resource Center. Global Map [Internet] (Baltimore: JHU.edu) (2021) [cited 2021 Mar 17]. Available from: https://coronavirus.jhu.edu/map.html

2. Madhi SA, Bailie V, Cutland CL, Voysey M, Koen AL, Fairlie L, Padayachee SD, Dheda K, Barnabas SL, Bhorat QE, Briner C. Efficacy of the ChAdOx1 nCoV-19 Covid-19 vaccine against the B. 1.351 variant. New England Journal of Medicine 384(20), 1885–98 (2021).

3. Kanne, J. P ., Bai, H., Bernheim, A. et al. COVID-19 imaging: what we know now and what remains unknown. Radiology 9, 204522 (2021 Feb). https://doi.org/10.1148/radiol.2021204522.

4. Homayounieh, F., Babaei, R., Karimi Mobin, H. et al. Computerized tomography radiomics can predict disease severity and outcome in coronavirus disease 2019 pneumonia. J. Comput. Assist. Tomogr. 44, 640–646 (2020).

5. Kalra, M. K., Homayounieh, F., Arru, C. et al. Chest CT practice and protocols for COVID-19 from radiation dose management perspective. Eur. Radiol. 30, 6554–6560 (2020).

6. Simpson, S., Kay, F. U., Abbara, S. et al. Radiological Society of North America Expert Consensus Statement on reporting chest CT findings related to COVID-19. Endorsed by the Society of Thoracic Radiology, the American College of Radiology, and RSNA—Secondary Publication. J. Thorac. Imaging 35, 219–227 (2020).

7. Centers for Disease Control and Prevention. Interim Clinical Guidance for Management of Patients with Confirmed Coronavirus Disease (COVID-19) [Internet] (Atlanta: CDC) (2020) [cited 2021 Mar 18]. (Coronavirus Disease 2019 [COVID-19]). Available from: https://stacks.cdc.gov/view/cdc/89980

8. Homayounieh, F., Holmberg, O., Umarri, R. A. et al. Variations in CT utilization, protocols, and radiation doses in COVID-19 pneumonia: results from 28 countries in the IAEA Study. Radiology 298, E141–E151 (2021).

9. American College of Radiology. ACR recommendations for the use of chest radiography and computed tomography (CT) for suspected COVID-19 infection [Internet] (Philadelphia: ACR) [update 2020 Mar 22; cited 2021 Mar 18]. Available from: https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Recommendations-for-Chest-Radiography-and-CT-for-Suspected-COVID-19-Infection

10. The Royal College of Radiologists. The role of CT in patients suspected with COVID-19 infection [Internet] (London: RCR) (2021) [published 2020 Mar 12; cited 2021 Mar 18]. Available from: https://www.rcr.ac.uk/college/coronavirus-covid-19-what-rcr-doing/clinical-information/rcr-position-role Ct-patients

11. Sociedad Espanola de Radiologia Medica. Guía básica de indicaciones de pruebas de imagen en la infección COVID-19 [Internet] (Madrid: SERAM) (2020) [cited 2021 Mar 18]. Available from: https://seram.es/images/site/Recomendaciones_imagen_SERAM_COVID_19.pdf

12. World Health Organization. Country & Technical guidance - Coronavirus disease (COVID-19) [Internet] (Washington: WHO) (2021) [cited 2021 Mar 18]. Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance

13. The Brazilian College of Radiology and Diagnostic Imaging. Recommendations for Using Imaging Methods for Patients Suspected of Having a COVID-19 Infection [Internet] (São Paulo: CBR) (2020) [cited 2021 Mar 17]. Available from: https://cbr.org.br/en/recomendacoes-de-uso-de-metodos-de-imagem-para-pacientes-suspeitos-de-infeccao-pelo-covid-19/

14. Rubin, G. D., Ryerson, C. J., Haramati, L. B. et al. The role of chest imaging in patient management during the COVID-19 pandemic: a multinational consensus statement from the Fleischner Society. Chest 158, 106–116 (2020).

15. Zhang, Y., Li, X., Segars, W. P. and Samei, E. Comparison of patient specific dose metrics between chest radiography, tomosynthesis, and CT for adult patients of wide ranging body habitus. Med. Phys. 41(2), 023901 (2014 Feb). https://doi.org/10.1118/1.4859315 PMID: 24506654; PMCID: PMC3985882.

16. Ebrahimi, S., Oliveira Bernardo, M., Alberto Moscatelli, A. et al. Investigating centering, scan length, and arm position impact on radiation dose across 4 countries from 4 continents during pandemic: mitigating key radioprotection issues. Phys. Med. 84, 125–131 (2021 Apr 21).

17. Li, J., Udayasankar, U. K., Toth, T. L. et al. Automatic patient centering for MDCT: effect on radiation dose. AJR Am. J. Roentgenol. 188, 547–552 (2007).

18. Bankier, A. A., O’Donnell, C. R. and Boiselle, P. M. Quality initiatives. Respiratory instructions for CT examinations of the lungs: a hands-on guide. Radiographics 28, 919–931 (2008).

19. Bankier, A. A. and Tack, D. Dose reduction strategies for thoracic multidetector computed tomography: background, current issues, and recommendations. J. Thorac. Imaging 25(4), 278–288 (2010). https://doi.org/10.1097/RTI.0b013e3181beeb49 PMID: 21042066.

20. Kalra, M. K., Maher, M. M., Toth, T. L. et al. Strategies for CT radiation dose optimization. Radiology 230, 619–628 (2004).

21. Singh, S., Kalra, M. K., Thrall, J. H. et al. Pointers for optimizing radiation dose in chest CT protocols. J. Am. Coll. Radiol. 8, 663–665 (2011).

22. Vanaudenhove, T., Van Muylem, A., Howarth, N. et al. CT diagnostic reference levels: are they appropriately computed? Eur. Radiol. 29, 5264–5271 (2019).

23. Narciso, L. D., Lima, N. W., Dartora, C. M. and da Silva, A. M. A contribution to the establishment of diagnostic reference levels in computed tomography in Brazil: In: World Congress on Medical Physics and Biomedical Engineering, Toronto, Canada . (Cham: Springer) pp. 737–740 (2015), 7–12 June 2015