Radiology

Variations in CT Utilization, Protocols, and Radiation Doses in COVID-19 Pneumonia: Results from 28 Countries in the IAEA Study

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Key Results

1. Of 62 healthcare sites in 34 countries, 76% of sites used CT to assess severity of COVID-19 pneumonia and while 22% used CT for initial diagnosis.
2. $CTDI_{vol}$ for chest CT varied by vendor (7-11mGy, $p<0.001$), number of detector rows (8-9mGy, $p<0.001$), year of CT installation (7-10mGy, $p=0.006$), and reconstruction technique (7-10mGy, $p=0.03$).
3. Single phase noncontrast CT was reported in 86% of countries, whereas multi-phase CT was reported in 14% of countries.

Summary statement: CT use, scan protocols, and radiation doses in patients with COVID-19 pneumonia show wide variation across healthcare sites both within the same and between different countries.

Abbreviations

COVID-19: coronavirus disease 2019, RT-PCR: reverse transcription polymerase chain reaction, IAEA: International Atomic Energy Agency, AEC: automatic exposure control, CTDI: CT dose index, DLP: dose length product, IQR: interquartile range, FBP: Filtered back projection, IR: Iterative reconstruction

See also the editorial by Lee.

Abstract

Background: There is lack of guidance on specific CT protocols for imaging patients with coronavirus disease 2019 (COVID-19) pneumonia.

Purpose: To assess international variations in CT utilization, protocols, and radiation doses in patients with COVID-19 pneumonia.

Materials and Methods: In this retrospective data collection study, the International Atomic Energy Agency (IAEA) coordinated a survey between May and July 2020 regarding CT utilization, protocols, and radiation doses from 62 healthcare sites in 34 countries across five continents for CT exams performed in COVID-19 pneumonia. The questionnaire obtained information on local prevalence, method of diagnosis, most frequent imaging, indications for CT, and specific policies on use of CT in COVID-19 pneumonia. Collected data included general information (patient age, weight, clinical indication), CT equipment (CT make and model, year of installation, number of detector rows), scan protocols (body region, scan phases, tube current and potential), and radiation dose descriptors (CT dose index ($CTDI_{vol}$) and dose length product (DLP)). Descriptive statistics and generalized estimating equations were performed.

Results: Data from 782 patients (median age (interquartile range) of 59(15) years) from 54 healthcare sites in 28 countries were evaluated. Less than one-half of the healthcare sites used CT for initial diagnosis of COVID-19 pneumonia and three-fourth used CT for assessing disease severity. $CTDI_{vol}$ varied based on CT vendors (7-11mGy, $p<0.001$), number of detector-rows (8-9mGy, $p<0.001$), year of CT installation (7-10mGy, $p=0.006$), and reconstruction techniques (7-10mGy, $p=0.03$). Multiphase chest CT exams performed in 20% of sites (11 of 54) were associated with higher DLP compared with single-phase chest CT exams performed in 80% (43 of 54 sites) ($p=0.008$).

Conclusion: CT use, scan protocols, and radiation doses in patients with COVID-19 pneumonia showed wide variation across healthcare sites within the same and different countries. Many patients were scanned multiple times and/or with multiphase CT scan protocols.

Introduction

Beyond healthcare, the coronavirus disease 2019 (COVID-19) pandemic has rippled the financial and social wellbeing of the wealthiest to the most underprivileged sections and parts of the world [1-5]. Most healthcare and government policymakers agree that screening of both suspected and asymptomatic population with early isolation, contact tracing, and quarantine slows the transmission of this highly contagious virus [6,7]. But disparities exist in the availability of the preferred diagnostic test, reverse transcription polymerase chain reaction (RT-PCR) for COVID-19. Also, the high false-negative rate of RT-PCR in early disease and its inability to assess disease severity and progression have led to the growing use of cross-sectional imaging such as CT for diagnosis and assessing disease severity, progression, complications, and treatment response [8]. Although a few single-center studies reported use of chest CT for diagnosis and work-up of patients with COVID-19 pneumonia [9,10], a recent survey suggested that only a very few sites use reduced-dose scan protocols (with lower radiation dose compared to routine or general chest CT protocol) for imaging patients with the suspected or known disease [8]. Despite reports on chest radiography and non-ionizing radiation-based imaging with ultrasonography [11,12], CT remains the preferred imaging modality in COVID-19 pneumonia.

Because >95% of patients with COVID-19 infection survive and the use of X-ray radiation-based CT is high, it is important to understand the utilization of CT and its associated radiation doses in different institutions. To our knowledge, there are no comprehensive studies on CT utilization, scan protocols, and radiation doses on an international level in patients with COVID-19 infection. Therefore, the Radiation Protection of Patients unit of the International Atomic Energy Agency (IAEA) coordinated a study of CT use in patients with COVID-19 pneumonia. The purpose of this study was to assess international variations in CT utilization, protocols, and radiation doses in patients with coronavirus disease 2019 (COVID-19) pneumonia.

Materials and Methods

Approvals and Disclosures

The participating healthcare sites shared fully anonymized data on patients with COVID-19 pneumonia in compliance with their institutional review boards. Human Insurance Portability and Accountability Act (HIPAA) was not applicable as there was no patient or scan data from the United States. Only de-identified data were collected as part of a voluntary survey coordinated by the IAEA. To ensure maximum patient privacy since some parts of the world had very few cases, we did not capture information on patient gender. The requirement for obtaining informed consent was waived. None of the coauthors have any financial disclosures related to the study. One study coauthor (MKK) has received research grants from Siemens Healthineers and Riverain Tech and serves on the medical advisory board of Globus Medical Inc. (Danvers, MA) for unrelated research projects.

Survey

The two-part survey included a questionnaire and fillable form for scan parameters and dose-related information in patients with known or suspected COVID-19 pneumonia. A medical physicist, CT technologist, and/or radiologist filled the survey details. In the questionnaire, we requested participating healthcare sites to answer the following twelve questions:

1. How many patients of COVID-19 pneumonia has your hospital seen?
2. What is the preferred mean of diagnosis of COVID-19 in your hospital?

3. What is the most frequently used imaging test for patients with COVID-19 pneumonia?
4. Do you use CT for initial diagnosis of patients with suspected COVID-19 infection?
5. How often do you use CT for outpatients with COVID-19 infection?
6. Do you use CT to assess severity of COVID-19 infection?
7. Do you perform CT in all hospital-admitted patients with COVID-19 pneumonia?
8. How often do you use CT for follow-up of COVID-19 infection?
9. Does your hospital follow a written policy regarding use of CT for COVID-19 pneumonia?
10. Do you have a dedicated CT protocol for COVID-19 patients?
11. How many CT scanners does your hospital have?
12. Which is the most frequently used CT protocol in patients with COVID-19 pneumonia?

We requested the healthcare sites with use of CT in COVID-19 infection to provide the following de-identified information: clinical details (patient age in years, body weight in kilograms, and clinical indications for each CT), CT scanner information (name of hospital with the CT scanner, scan vendor, scanner name, number of detector-rows, and year of installation), scan parameters (number of scan phases, body region, scan start and end locations, helical or axial scan mode, use of fixed tube current vs automatic exposure control (AEC), applied tube current or vendor-specific image quality parameter for AEC, tube potential, detector configuration, pitch, gantry rotation time, reconstructed section thickness of prospective or initial transverse CT images , and filtered back-projection or iterative reconstruction technique), and radiation dose descriptors (separate volume CT dose index - $CTDI_{vol}$ and dose length product - DLP for each acquired phase in healthcare sites with multiphase scan protocols). For multiphase CT protocols, specific type of phase with and without contrast enhancement were recorded (such as non-contrast, post-contrast arterial, venous, and/or delayed phases). For each phase, we instructed the participating healthcare sites to provide separate $CTDI_{vol}$ and DLP values. For patients with more than one CT examination, clinical, scan parameters and dose-related information were recorded separately for each exam.

One radiologist (MKK with >15 years of experience in CT radiation dose research) and two medical physicists (JV, OH) created the survey data collection form in Microsoft EXCEL (2019, version 1902, Microsoft, Redmond, WA). A study coauthor (JV) distributed the survey data collection to the national project counterparts of the IAEA via email correspondence. The survey was conducted between May-July 2020. Completed survey responses were received via secured email communication and then shared with coauthors using a secure file transfer system.

Participation of each contacted country was voluntary. The selection and number of participating sites at the local level was determined by the national project counterparts based on local case prevalence and availability of qualified personnel for recording survey responses. Sites used retrospective or prospective patient data since the beginning of COVID-19 pandemic.

Healthcare Sites and Patients

Each participating hospital was requested to provide the above-mentioned fillable information on at least 10-20 adult patients, who underwent CT with a suspected or known COVID-19 pneumonia. To avoid data truncation and assess CT usage in each patient, we requested sites to provide data on all initial and follow-up CT exams since their suspected or known COVID-19 pneumonia. Sites from countries (8 sites from 6 countries) with less than 10 patients were excluded from the data analyses. Since very few sites (5/34 sites; <5% of the data) provided information related to CT examination of body regions other than chest, to obtain statistically meaningful data, statistical analysis was limited to only chest CT exams.

Statistical Analysis

All sites provided the data in Microsoft Excel files. Descriptive statistics and pivot tables were created for data analyses from Microsoft Excel (2019, version 1902, Microsoft, Redmond, WA). Responses to the survey questionnaire were summarized as pie-charts with the percentage of participating healthcare sites in each response category. Radiation dose descriptors $CTDI_{vol}$ and DLP were summarized as median and interquartile range for different healthcare sites in the participating patients. For patients with multiphase chest CT and/or multiple CT exams, we separately calculated cumulative DLP (sum across all CT phases/exams) and median $CTDI_{vol}$ (across multiple phases/exams). In addition, we performed generalized estimating equations (SPSS Statistics for Windows, version 26; IBM, Armonk, NY) with $CTDI_{vol}$ and DLP as outcomes. Patients' age, continent, clinical indications, scan phases, year of CT installation, CT vendors, and reconstruction techniques were the key predictors and coded patient identification number and scanner types were covariates for the generalized estimating equation models. To find the distribution of CT use and compare radiation doses in patients with different ages, patients were arbitrarily classified into four age groups (20-39 years, 40-59 years, 60-79 years and ≥80 years). A p-value less than 0.05 was considered as a statistically significant difference.

Results

Survey Questionnaire

Responses to survey questionnaire from 62 healthcare sites from 34 countries are summarized in the video clip (Movie [online]). Most sites (63%, 39/62 sites) had a substantial burden of patients (sites with >100 patients with known or suspected COVID-19 infection at the time of data collection) (question 1). Most sites (60%, 37/62) indicated use of either antigen or antibody tests as the primary method of diagnosis (question 2) of COVID-19 infection; other sites used CT (22%, 14/62) or radiography (18%, 8/62) as primary methods of diagnosis. Several sites (52%, 32/62 sites; question 4) reported use of CT for diagnosis of COVID-19 pneumonia in 26-50% of patients. Chest radiography was the most commonly performed imaging test in 60% of sites for diagnosis and follow-up of patients (37/62 sites; question 3). Use of CT in hospital-admitted patients with COVID-19 (63%, 39/62 sites) was more than in outpatients (23%, 14/62 sites; question 5, 7).

Chest CT was commonly used for assessing disease severity (76%; 46/62 sites; question 6) and for routine follow-up of patients with COVID-19 pneumonia in 51% of sites (32/62 sites; question 8). Half of the sites had dedicated CT protocol for imaging patients with COVID-19 infection (question 10). Non-contrast chest CT (67%; 41/62 sites; question 12) was the most common protocol followed by reduced-dose non-contrast chest CT with radiation dose less than the routine or general chest CT protocol (20%, 12/62 sites). Most healthcare sites stated availability of multiple CT scanners for imaging patients with COVID-19 (>2 CT scanners; 71%; 44/62 sites; question 11) installed after 2010 (85%; 34/50 responses).

Variations in median $CTDI_{vol}$ and DLP across healthcare sites

De-identified data from 782 patients (median age (IQR) of 59(15) years) was collected from 54 healthcare sites in 28 countries (Figure 1). There were 8-fold variations in median $CTDI_{vol}$ and 10-fold variations in median DLP across multiple participating healthcare sites from the same country (Table 1). Most patients underwent a single CT examination (71%; 557/782). Extent of change in $CTDI_{vol}$ and DLP with the number of CT examinations per patient is summarized in Table 2.

There were no differences in the median $CTDI_{vol}$ (8-9mGy; $p=0.41$) and DLP (299-344mGy.cm; $p=0.84$) between chest CT examinations performed in different continents (Table 3). But due to frequency of multiple follow-up chest CT, cumulative DLPs for patients in Latin America (503 mGy.cm) was higher compared with the corresponding values from the other three continents (306-382 mGy.cm) ($p=0.03$).

Scanners and Scan Parameters

Both median $CTDI_{vol}$ (7-11mGy, $p<0.001$) and DLP (280-439mGy.cm, $p=0.018$) differed across CT scanners from the four major vendors (Table 3). CT scanners installed between 2016-2020 (median (IQR)– 7(6) mGy) and 2006-2010 (median (IQR)– 8(5) mGy) were associated with lower $CTDI_{vol}$ as compared with scanners installed between 2011-2015 (median (IQR)– 10(7) mGy) ($p=0.006$). The corresponding median DLP values were not different (255-390mGy.cm; $p= 0.075$) (Table 3).

Scanners with >64-detector-rows were associated with lower $CTDI_{vol}$ (8-9mGy; $p<0.001$) and median DLP (285-334mGy.cm; $p=0.002$) as compared with those with ≤64-detector-rows. CT examinations performed with iterative reconstruction (in 33/54 healthcare sites) enabled image generation were associated with lower radiation doses as compared with those with conventional filtered back projection method (in 21/54 healthcare sites) (median (IQR) $CTDI_{vol}$ was 7(6) vs. 10(7) mGy and DLP – 305 vs. 523mGy.cm) ($p=0.03$ and $p=0.01$, respectively). The inferior extent of scan volume was at the lung bases in 47% (370/782) of patients, at the adrenal glands in 41% (322/782) of patients. The information on scan range was not available in some patients (12%, 90/782).

Distribution of median $CTDI_{vol}$ and DLP

Table 4 and Figure 2 summarize the distribution of median $CTDI_{vol}$ and DLP across different uses of chest CT in the participating countries. Most common indication for 1183 chest CT exams performed in 782 patients was follow-up of findings related to known or suspected COVID-19 pneumonia (n=551 chest CT exams; median $CTDI_{vol}$ 9mGy; median DLP 341mGy.cm) followed by initial diagnosis of suspected COVID-19 infection (n=461; median $CTDI_{vol}$ 8mGy; median DLP 278mGy.cm), complications (n=107; median $CTDI_{vol}$ 7mGy; median DLP 332mGy.cm) and other or non-specified clinical conditions (n=64; median $CTDI_{vol}$ 8mGy; median DLP 413mGy.cm). There was a difference in $CTDI_{vol}$ and DLP for chest CT exams performed for different clinical indications ($p<0.001$). Although patients ≥80 years were scanned with lower $CTDI_{vol}$ (8mGy) and DLP (325mGy.cm) as compared to patients in other age groups (<80 years: 6mGy and 229mGy.cm), these differences in doses were not significant (p= 0.737-0.942).

Median $CTDI_{vol}$ for single- and multiple-phase chest CT were significantly different due to change in acquisition parameters such as tube current for delayed phase as compared to initial non-contrast and arterial phases (single-phase-8mGy; multiple-phase-6mGy; $p<0.001$). Median DLP values was lower with a single phase (315mGym.cm) to three scan phases (1310mGy.cm, p=0.008). Radiation doses for single- and multi-phase chest CT exams are summarized in Figure 3. Single-phase, non-contrast chest CT was the most commonly reported protocol in 24/28 countries (43/54 healthcare sites), whereas multiphase CT were performed in 4/28 countries (11/54 healthcare sites). Only one hospital (1/54) acquired dual-phase contrast enhanced CT in arterial and venous phases without the non-contrast phase. There was no difference in $CTDI_{vol}$

(8-9mGy) across non-contrast, arterial, venous, and delayed phases (p=0.0.61) although median DLP values varied (300-386mGy.cm) (p=0.041) (Figure 4).

Discussion

Our study on variations in CT utilization, protocols, and radiation doses demonstrates a lack of guidance on CT protocols contributing to variable CT practices in COVID-19 pneumonia across different healthcare sites. CT was most often used to assess disease severity and less commonly for assessing suspected COVID-19 pneumonia and in outpatient settings. Several sites reported adoption of written policies on use of CT in COVID-19 pneumonia and preferential use of chest radiography over chest CT. About 29% of the patients (225/782) had 2-8 chest CT exams in less than one month. Multiphase scan protocols and their association with higher radiation dose were concerning in 11/54 healthcare sites from 4/28 countries in our study.

Healthcare sites varied CT protocols: some adopted a single-phase, non-contrast protocol and performed only one chest CT exam, some used reduced-dose chest CT protocol, and, likewise, some reduced radiation dose for follow-up chest CT compared with the baseline exam. Only 1/28 countries reported median $CTDI_{vol}$ <3mGy for chest CT exams. Conversely, lower dose chest CT exams on newer scanners (installed between 2016-2020) and those with iterative reconstruction suggest proper scanner use.

Use of CT in most sites participating in our study was compliant with guidance from several notable organizations and societies which discourage use of screening CT in absence of paucity of RT-PCR or serological assays [13-17]. Conversely, our study identified several areas of concern including those stemming from frequent report on the use of CT for initial diagnosis of suspected COVID-19 pneumonia. Although CT is justified in high disease prevalence sites with low availability of antigen or antibody assays for the coronavirus, overuse of CT remains an important concern. Although recommendations from the Fleischner Society support use of CT for follow-up and complications in COVID-19 pneumonia, they do not provide guidance on frequency of its use, specific scan protocols and the need to reduce dose for follow-up CT examinations [16].

Use of contrast-enhanced chest CT is justified in patients with suspected vascular complications and superimposed necrotizing infection, however, most other pulmonary opacities in COVID-19 pneumonia can be assessed with a single-phase, non-contrast phase chest CT. As opposed to abdomen-pelvis CT, there is little justification for multiphase CT of the chest for most clinical indications in and beyond COVID-19 pneumonia [8,18].

There are no specific recommended or target doses in patients with COVID-19 pneumonia, but when evaluation is limited to lung parenchyma, a $CTDI_{vol}$ <3mGy, as recommended for low dose chest CT for lung cancer screening may be sufficient for COVID-19 pneumonia [8]. There are studies on use of high-resolution and ultra-high-resolution chest CT in patients with COVID-19 pneumonia, most studies related to acquisition technique for scanning these patients describe use of non-contrast reduced-dose CT protocol [10, 19-22]. These studies describe use of high-pitch, selective photon shield with tin filter, low tube current and/or tube potential to obtain low-dose CT without loss of diagnostic information related to COVID-19 pneumonia [20]. However, several fold variations in $CTDI_{vol}$ and DLP in chest CT exams at participating sites in our study often from the same country and city makes dose optimization difficult. Another cause of concern pertains to higher $CTDI_{vol}$ associated with scanners installed between 2011 and 2015 as compared with older scanners prior to 2011. Such differences in $CTDI_{vol}$ (about 3mGy) might not clinically meaningful and might be related to variations in patient sizes, protocol types, scan parameters. These differences highlight the importance of CT protocol optimization, which is as important as access to latest scanners and dose reduction technologies.

Differences in DLP associated with chest CT across sites could be related to differences in $CTDI_{vol}$, scan range (particularly, in the inferior anatomic coverage of lung base versus adrenal glands), and/or number of acquired scan phases. This implies an urgent need for optimization of scan protocols and radiation doses for chest CT examinations and not only limited to imaging of patients with COVID-19 pneumonia.

Our study has limitations. Some clinical indications or usage of CT might have been missed due to the limited sample size of 10-20 patients per site. The study was also a retrospective data collection on practices and protocols related to use of CT in patients with COVID-19 pneumonia. Not all healthcare sites and countries participated, so generalization was limited. The accuracy of our results is subject to errors and variations in manually recorded data from different sites. Due to logistic and data privacy issues, we did not obtain CT image datasets or assess image quality with different CT protocols used at the participating sites. We lacked data on clinical features and disease severity, particularly from sites with multiple follow-up CT examinations. Therefore, we could not assess the justification of follow-up CT exams in patients with COVID-19 pneumonia. We could not adequately assess justification of multiple CT exams in some patients since the provided information stated follow-up or worsening of symptoms. Also, we did not obtain RT-PCR results due to the anticipated lack of access to these tests and their results at several sites, particularly from the developing countries. Also, there was a relative heterogeneity in the number of patients contributed by each site based on disease prevalence and availability and access to data at the time of the ongoing pandemic.

In summary, our international, multicenter study on practices, protocols and radiation doses suggests frequent CT usage in assessment of disease severity, complications, and follow-up in patients with COVID-19 with a several fold variations in number of scan phases, CT examinations per patient, and associated radiation dose descriptors. We identify an urgent need for a dedicated task force to establish specific guidelines and recommendations on the frequency of CT and specific scan protocols to minimize the effects of cumulative radiation exposure from multiple CT and multiphase CT protocols.

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Table 1. Summary of median (interquartile range) age in years, weight in kg, $CTDI_{vol}$ in mGy and DLP in mGy.cm for data from 782 patients (median age (interquartile range) 59 (15) years) from 54 healthcare sites in 28 countries

Countries	Number of Patients	Age, years	Weight, kg	Number of CT exams	Number of scan phases	CTDIvol, mGy	DLP/exam, mGy.cm	Cumulative DLP for all CTs, mGy.cm	Rotation times, ms	Tube voltage, kV	Slice Thickness, mm	Number of sites	Min-Max $CTDI_{vol}$, mGy	Min-Max DLP, mGy.cm
C1	20	65 (31)	-	20	20	10(3)	431 (109)	431 (109)	0.6 (0)	120 (0)	1.3 (0)	1	-	-
C2	20	58 (29)	88 (13)	20	20	6(6)	244 (220)	244 (220)	0.6 (0.3)	110 (20)	1.1 (2.8)	2	2.4 - 27	81 - 966
C3	82	56 (26)	78 (22)	169	188	9(5)	323 (207)	493 (784)	0.8 (0.1)	120 (5)	1 (1)	5	3.6 - 18	83 - 1128
C4	63	61 (27)	75 (20)	95	104	12(5)	381 (167)	560 (446)	0.6 (0.3)	120 (20)	2.7 (3)	3	4.5 - 23	193 - 1281
C5	10	68 (43)	75 (16)	15	22	5(4)	392 (394)	662 (648)	0.5 (0.1)	100 (33)	1.5 (2)	1	-	-
C6	34	61 (24)	80 (30)	37	43	7(4)	256 (225)	282 (266)	0.5 (0)	110 (20)	1.5(2)	4	3.1 - 27	74 - 2231
C7	10	43 (22)	90 (40)	12	12	9(2)	325 (37)	356 (295)	0.8 (0.1)	120 (5)	4 (0.2)	1	-	-
C8	30	65 (16)	-	34	41	8(6)	299 (635)	314 (845)	0.8 (0.3)	130 (10)	1.5 (1.6)	3	4.8 - 19	102 - 1627
C9	42	66 (20)	80 (16)	57	58	4.7(4)	200 (150)	245 (146)	0.3 (0.2)	100 (20)	1.3 (1.4)	4	1.9 - 14	77 - 763
C10	19	45 (17)	-	19	19	4.6(2)	162 (90)	162 (90)	0.8 (0)	100 (0)	5 (0)	1	-	-
C11	20	58 (18)	-	20	20	5(3)	156 (93)	156 (93)	0.5 (0)	120 (0)	8 (0)	1	-	-
C12	20	69 (32)	-	27	27	5(0)	169 (40)	179 (148)	1 (0.2)	110 (0)	2 (0)	1	-	-
C13	25	58 (20)	-	29	30	6(4)	213 (130)	221 (136)	0.5 (0)	120 (0)	5 (0)	1	-	-
C14	20	34 (31)	-	52	52	17(7)	731 (228)	1762 (794)	0.6 (0)	120 (0)	5 (0)	1	-	-
C15	20	40 (26)	-	20	20	8(2)	321 (113)	321 (113)	0.8 (0)	120 (0)	3 (0)	1	-	-
C16	12	59 (24)	90 (45)	14	19	16(21)	786 (991)	786 (1398)	0.7 (0)	120 (0)	0.6 (1.4)	1	-	-
C17	14	76 (35)	-	14	14	6(3)	180 (96)	180 (96)	0.5 (0)	100 (0)	1.3 (0)	1	-	-
C18	59	58 (19)	80 (20)	66	73	7(5)	300 (261)	307 (316)	0.5 (0)	120 (0)	5 (0)	4	2.2 - 16	78 - 821
C19	15	47 (26)	71 (14)	15	15	11(6)	452 (279)	452 (279)	0.8 (0.3)	120 (0)	2 (0)	1	-	-
C20	28	55 (16)	76 (13)	48	48	12(9)	455 (245)	626 (353)	0.6 (0.0)	130 (10)	1.5 (3.5)	2	3.9 - 18	179 - 768
C21	10	58 (15)	80 (18)	10	10	8(6)	265 (256)	264 (256)	0.3 (0.1)	120 (35)	1 (0.5)	1	-	-
C22	32	43 (17)	80 (13)	35	49	8(3)	340 (282)	349 (259)	0.5 (0)	120 (14)	5 (3.5)	4	2.9 - 17	99 - 983
C23	50	70 (19)	85 (15)	206	217	9(9)	340 (339)	1239 (1162)	0.8 (0.3)	120 (0)	1 (0)	4	1.5 - 38	53 - 1409
C24	67	62 (20)	82 (19)	70	120	10(7)	473 (317)	473 (317)	0.5 (0)	120 (10)	5 (0)	2	3.2 - 24	188 - 921
C25	20	86 (10)	-	26	46	3.9(2)	211 (286)	221 (365)	0.5 (0)	105 (20)	0.6 (0)	1	-	-

C26	10	61 (23)	77 (50)	11	11	13(7)	415 (189)	462 (239)	0.5 (0)	120 (0)	2 (0.3)	1	-	-
C27	10	52 (17)	84 (12)	17	17	7(2)	323 (300)	539 (489)	0.4 (0)	100 (0)	0.9 (0.1)	1	-	-
C28	20	47 (29)	-	25	25	2(0)	76 (14)	76 (69)	0.8 (0.1)	120 (0)	5 (0)	1	-	-

Note.—Min-max $CTDI_{vol}$ and DLP refer to the minimum and maximum values across different healthcare sites from the same country. The data on rotation time, section thicknesses, and tube potential represent median (IQR: interquartile range; Min- Minimum; Max- Maximum; $CTDI_{vol}$: CT dose index; DLP: dose length product).

Table 2. Summary of information in patients with one or more chest CT exams for evaluation of their COVID-19 lung infection

Characteristics	1 CT exam	2 CT exams	3 CT exams	4 CT exams	≥ 5 CT exams (5-8)
Number of Patients	557	124	65	18	18
Median (IQR) age, years	59 (26)	57 (25)	58 (29)	68 (14)	68 (20)
Median (IQR) $CTDI_{vol}$, mGy*	8 (6)	9 (7)	11 (8)	10 (8)	7 (4)
Min – Max $CTDI_{vol}$, mGy	-	8 - 9	9 - 12	8 - 11	5 -11
Median (IQR) cumulative DLP, mGy.cm**	303 (260)	736 (641)	1207 (941)	1569 (1110)	1644 (1990)
Min - Max DLP, mGy.cm	-	320 - 392	338 - 454	289 - 461	154 – 450
Days between 1^{st}& last CTs (IQR)	-	9 (10)	14 (12)	21 (13)	29 (25)
Stable $CTDI_{vol}$ in mGy [number of patients]	-	0 [18]	0 [4]	0 [1]	-
Decrease $CTDI_{vol}$ in mGy [number of patients]	-	1.1 [43]	1.1 [30]	4.2 [6]	3.6 [14]
Increase $CTDI_{vol}$ in mGy [number of patients]	-	0.6 [63]	0.7 [31]	1 [11]	0.3 [4]

Note.—Min-max $CTDI_{vol}$ and DLP refer to the minimum and maximum values of median $CTDI_{vol}$ and DLP across patients with multiple CT exams. Rows with stable, decrease, or increase $CTDI_{vol}$ describe the differences in $CTDI_{vol}$ between initial and follow-up CT examinations. (Key: IQR- interquartile range; Min- Minimum; Max- Maximum; $CTDI_{vol}$: CT dose index; DLP: dose length product; COVID-19: Coronavirus disease 2019)

* $p = 0.04$ for differences in $CTDI_{vol}$ based on number of CT exams.

** $p < 0.001$ for differences in cumulative DLP based on number of CT exams.

Table 3. Summary of median $CTDI_{vol}$ and DLP of chest CT exams from different continents, scanners from different CT vendors and year of installation

	Number of countries	Number of sites	Number of patients	Median (IQR) $CTDI_{vol}$, mGy	Median (IQR) DLP/exam, mGy.cm	Median (IQR) cumulative DLP, mGy.cm
Different Continents						
Africa	3	3	46	9 (6)	310 (245)	331 (289)
Asia	6	9	122	8 (6)	299 (350)	306 (414)
Europe	16	35	506	8 (7)	321 (292)	382 (475)
Latin America	3	7	108	9 (5)	344 (210)	503 (618)
p-value	-	-	-	*0.41*	*0.84*	*0.03*
Different vendors						
Canon	9	11	135	7 (6)	280 (220)	305 (306)
GE	11	13	186	9 (7)	307 (252)	354 (387)
Philips	8	10	135	11 (6)	439 (269)	672 (1032)
Siemens	14	22	326	7 (5)	280 (300)	363 (470)
p-value		-	-	*< 0.001*	*0.018*	*0.004*
Year of CT installation						
2006 – 2010	11	11	166	8 (5)	324 (240)	362 (447)
2011 – 2015	14	18	265	10 (7)	390 (255)	465 (405)
2016 – 2020	17	27	351	7 (6)	255 (256)	326 (516)
p-value	-	-	-	*= 0.006*	*0.075*	*0.13*

Note.—Cumulative DLP represents sum of DLP of initial and follow-up chest CT exams in each patient. Total number of countries and healthcare sites are greater than 28 and 54, respectively, since some countries and healthcare sites had >1 scanner. The numbers in parenthesis represent interquartile range (IQR). ($CTDI_{vol}$: CT dose index; DLP: dose length product).

Table 4. Median (interquartile range) $CTDI_{vol}$ and DLP for different clinical uses of chest CT in patients with COVID-19 in the participating countries (C)

Country	Initial Diagnosis $CTDI_{vol}$,mGy	Initial Diagnosis DLP, mGy.cm	Follow up $CTDI_{vol}$, mGy	Follow up DLP, mGy.cm	Complication $CTDI_{vol}$, mGy	Complication DLP, mGy.cm	Other indications $CTDI_{vol}$,mGy	Other indications DLP, mGy.cm
C1	10 (3)	431 (109)	-	-	-	-	-	-
C2	-	-	2.5 (1)	104 (60)	-	-	9 (10)	316 (329)
C3	9 (4)	314 (182)	10 (5)	347 (220)	10 (-)	339 (-)	12 (9)	473 (332)
C4	9 (6)	364 (168)	12 (5)	385 (166)	13 (-)	1290 (-)	16 (9)	613 (1745)
C5	5 (2)	203 (177)	4.1 (-)	447 (-)	4.7 (10)	269 (562)	6 (3)	586 (223)
C6	6 (4)	201 (179)	10 (16)	338 (781)	7 (3)	402 (559)	7 (-)	1425(-)
C7	9 (2)	325 (37)	9 (1)	315 (21)	-	-	-	-
C8	7 (4)	245 (85)	5 (-)	213 (-)	17 (-)	1409 (-)	16 (9)	1138 (2411)
C9	3.6 (2)	162 (49)	3.8 (9)	174 (278)	8 (2)	304 (69)	-	-
C10	-	-	4.6 (2)	162 (90)	-	-	-	-
C11	5 (5)	150 (91)	-	-	-	-	5 (3)	162 (95)
C12	5 (0)	167 (30)	5 (1)	204 (78)	-	-	-	-
C13	6 (4)	204 (148)	5 (-)	191 (-)	8 (-)	653 (-)	-	-
C14	18 (7)	712 (239)	17 (6)	688 (251)	-	-	-	-
C15	8 (2)	321 (113)	-	-	-	-	-	-
C16	-	-	17 (25)	786 (1118)	15 (-)	629 (-)	-	-
C17	6 (3)	185 (89)	4.3 (-)	148 (-)	-	-	-	-
C18	6 (7)	230 (265)	8 (5)	319 (223)	6 (5)	397 (499)	4.9 (2)	310 (317)
C19	11 (6)	452 (279)	-	-	-	-	-	-
C20	17 (3)	536 (131)	8 (6)	353 (264)	-	-	-	-
C21	-	-	8 (9)	198 (451)	8 (19)	282 (195)	-	-
C22	8 (2)	356 (222)	9 (5)	321 (193)	7 (6)	418 (634)	7 (2)	319 (377)
C23	10 (8)	357 (329)	9 (10)	338 (352)	4 (3)	227 (306)	10 (-)	1505 (-)
C24	-	-	11 (5)	466 (235)	6 (4)	540 (472)	-	-
C25	4 (2)	212 (295)	6 (3)	234 (340)	-	-	-	-
C26	17 (-)	486 (-)	12 (4)	364 (129)	12 (12)	411 (425)	-	-
C27	-	-	-	-	7 (2)	323 (300)	-	-
C28	2 (0)	74 (10)	2 (3)	81 (122)	8 (-)	262 (-)	-	-

Note.— ($CTDI_{vol}$: CT dose index; DLP: dose length product).

Table 5. Distribution of median (IQR - interquartile range) number of scan phases, $CTDI_{vol}$ and DLP in patients of different age group who underwent chest CT for known or suspected COVID-19 pneumonia

Age groups	20-39 years	40-59 years	60-79 years	≥80 years
Number of Patients	133	268	297	81
Number of CT exams	1 (1)	1 (1)	1 (1)	1 (1)
Median (IQR) weight, Kg	75 (18)	81 (20)	80 (18)	71 (16)
Number of Scan phases	1 (1)	1 (1)	1 (1)	1 (2)
Median (IQR) $CTDI_{vol}$, mGy	8 (6)	8 (7)	8 (6)	6 (5)
Median (IQR) DLP, mGy.cm	307 (271)	338 (296)	326 (279)	229 (190)

Note.—(For 3 patients ages were not provided.) ($CTDI_{vol}$: CT dose index; DLP: dose length product; COVID-19: Coronavirus disease 2019).

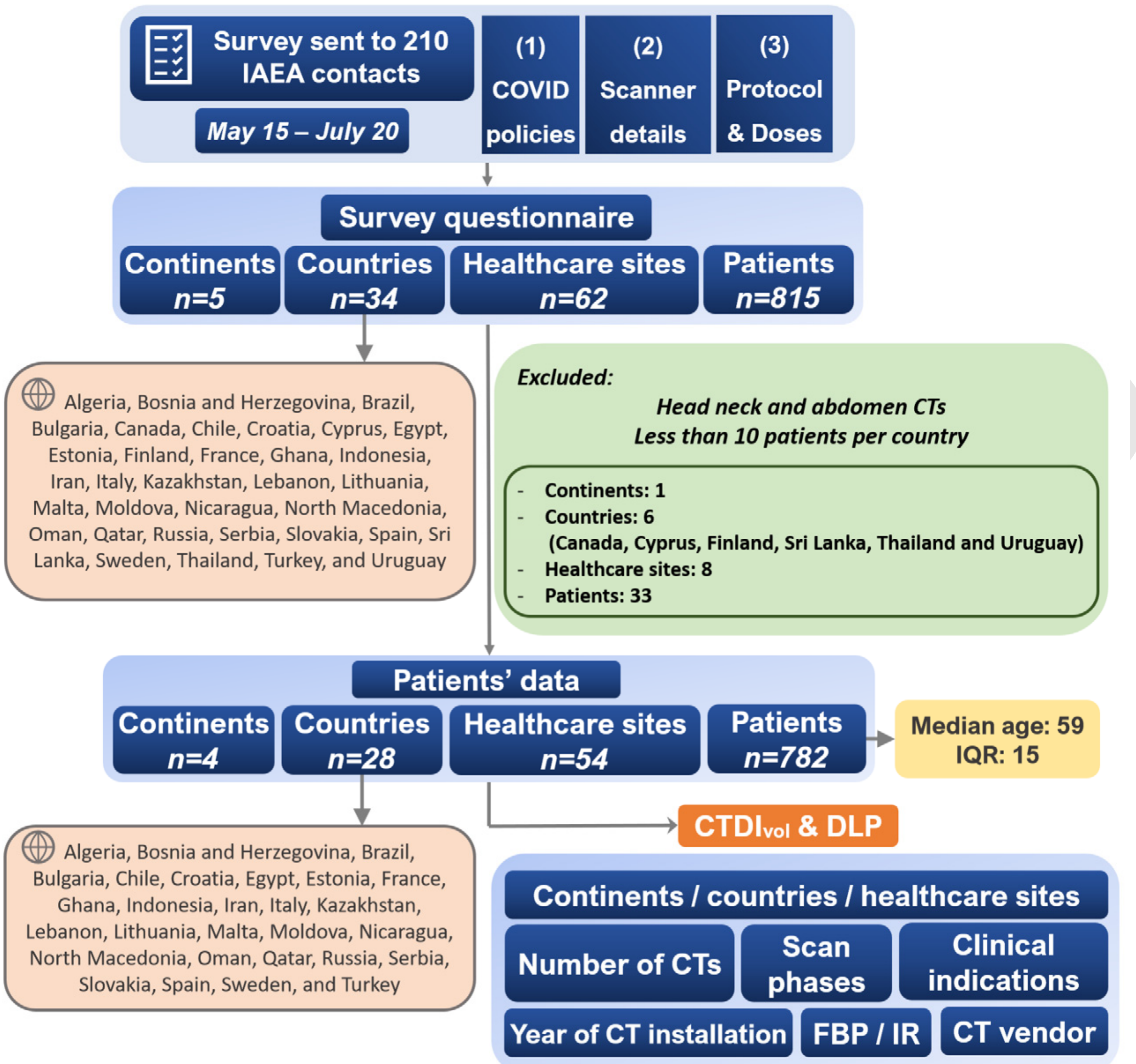

Figure 1. Flow diagram summarizing recruitment different participants in the survey along with the exclusion criteria. (IAEA: International Atomic Energy Agency; COVID: Coronavirus disease; $CTDI_{vol}$: CT dose index; DLP: dose length product; FBP: Filtered back projection; IR: Iterative reconstruction)

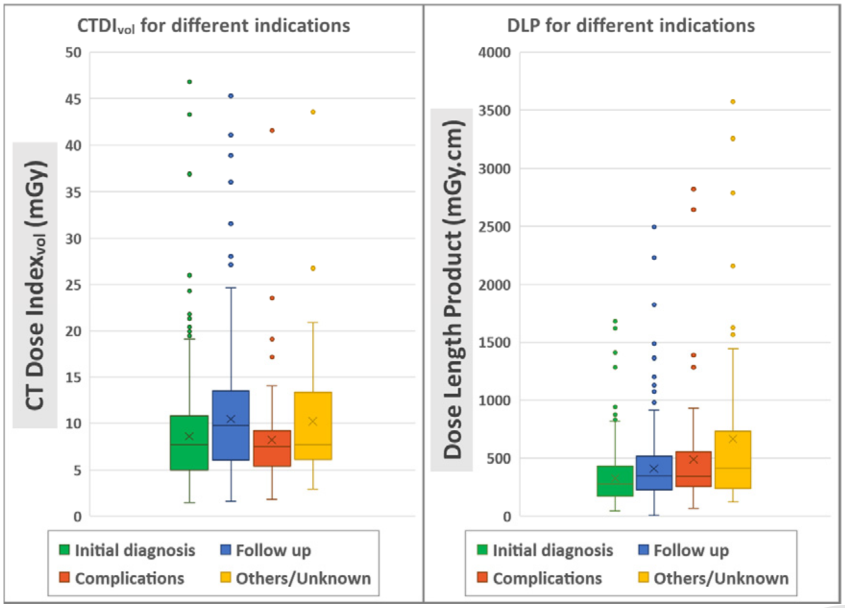

Figure 2. Box and whisker plots of, *A,* CT dose index (CTDIvol) and, *B,* dose length product (DLP) for patients who underwent chest CT for different clinical indications. The lines and crosses within the boxes represent median and mean values. The superior and inferior aspects of each box represent 1st and 3rd quartile of doses.

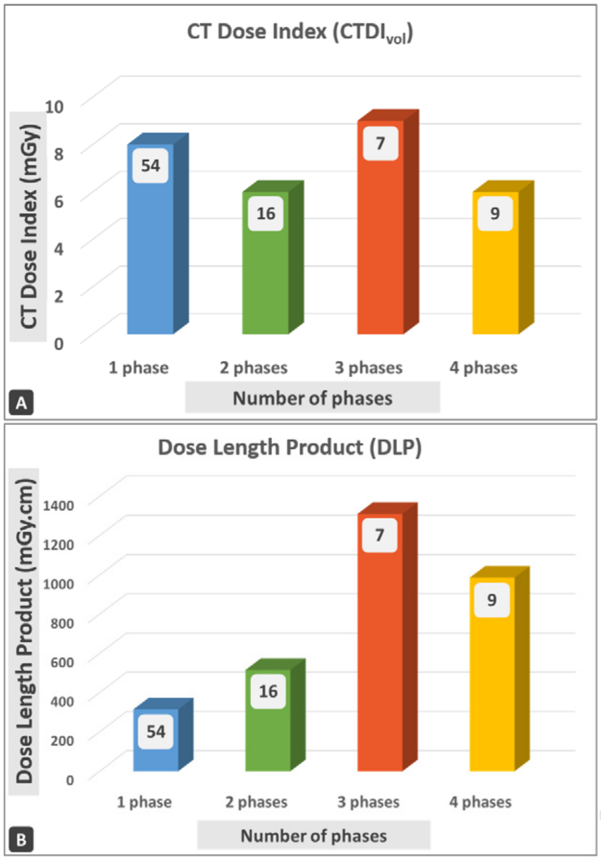

Figure 3. Bar diagrams summarize, *A,* median CT dose index ($CTDI_{vol}$) and, *B,* dose length product (DLP) of chest CT examinations with different number of scan phases. Lower DLP with 4-phase CT protocols as compared with the 3-phase CT was likely related to the use of lower $CTDI_{vol}$ in 4-phase protocols and/or lower scan length. All sites scanned one or more patients with 1 phase CT protocol. But 19 sites scanned patients with both single and multiphase protocols. Hence, the numbers of sites (as shown in white boxes) for different phases exceed the total number of participating sites.

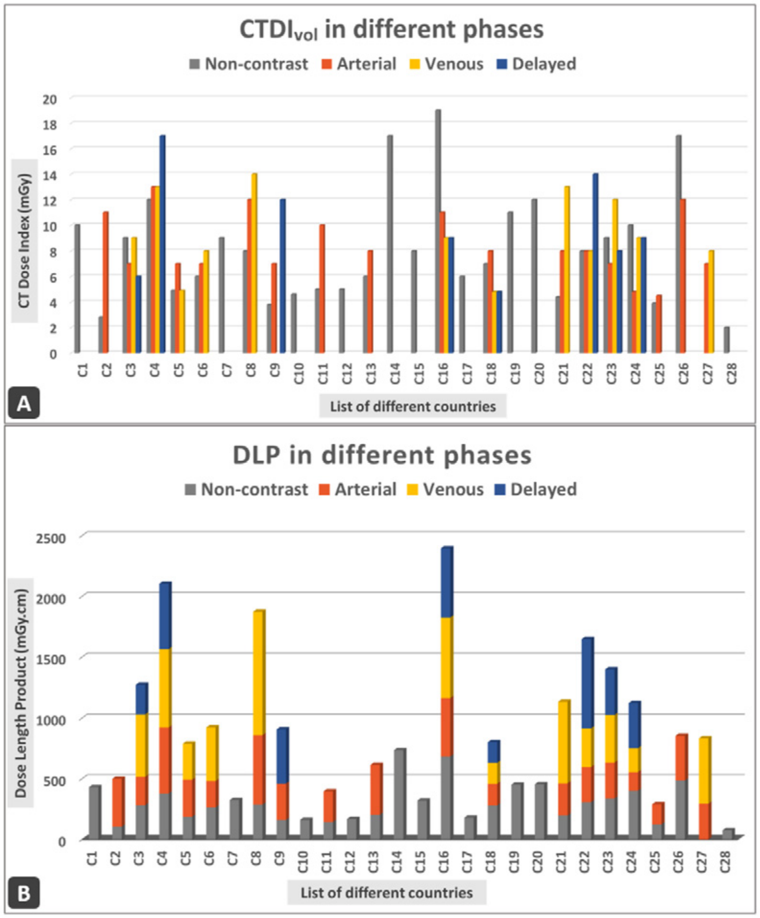

Figure 4. Bar diagrams summarize, *A,* median CT dose index ($CTDI_{vol}$) and, *B,* dose length product (DLP) for non-contrast, arterial, venous, and delayed phases of chest CT.