Radiology

ORIGINAL RESEARCH • THORACIC IMAGING

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

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Conflicts of interest are listed at the end of this article.

See also the editorial by Lee in this issue.

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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 coordinated a survey between May and July 2020 regarding CT utilization, protocols, and radiation doses from 62 health care sites in 34 countries across five continents for CT examinations performed in patients with 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 and dose length product). Descriptive statistics and generalized estimating equations were performed.

Results: Data from 782 patients (median age, 59 years [interquartile range, 15 years]) from 54 health care sites in 28 countries were evaluated. Less than one-half of the health care sites used CT for initial diagnosis of COVID-19 pneumonia and three-fourths used CT for assessing disease severity. CT dose index varied based on CT vendors (7–11 mGy; $P < .001$), number of detector rows (8–9 mGy; $P < .001$), year of CT installation (7–10 mGy; $P = .006$), and reconstruction techniques (7–10 mGy; $P = .03$). Multiphase chest CT examinations performed at 20% of sites (11 of 54) were associated with higher dose length product compared with single-phase chest CT examinations performed in 80% of sites (43 of 54) ($P = .008$).

Conclusion: CT use, scan protocols, and radiation doses in patients with coronavirus disease 2019 pneumonia showed wide variation across health care sites within the same and between different countries. Many patients were imaged multiple times and/or with multiphase CT scan protocols.

Online supplemental material is available for this article.

Beyond health care, the coronavirus disease 2019 (COVID-19) pandemic has had a ripple effect on the financial and social well-being of the wealthiest to the most underprivileged sections and parts of the world (1–5). Most health care and government policymakers agree that screening of both suspected and asymptomatic populations 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, for COVID-19. Also, the high false-negative rate of reverse transcription polymerase chain reaction in early disease and its inability to assess disease severity and progression have led to the growing use of cross-sectional imaging, such as

Abbreviations

COVID-19 = coronavirus disease 2019, $CTDI_{vol}$ = volume CT dose index, DLP = dose length product

Summary

CT use, scan protocols, and radiation doses in patients with coronavirus disease 2019 pneumonia show wide variation across health care sites within the same and between different countries.

Key Results

- Of 62 health care sites in 34 countries, 76% of sites used CT to assess severity of coronavirus disease 2019 pneumonia, whereas 22% used CT for initial diagnosis.
- CT dose index for chest CT varied by vendor (7–11 mGy; $P < .001$), number of detector rows (8–9 mGy; $P < .001$), year of CT installation (7–10 mGy; $P = .006$), and reconstruction technique (7–10 mGy; $P = .03$).
- Single-phase noncontrast CT was reported in 86% of countries, whereas multiphase CT was reported in 14% of countries.

CT, for diagnosis and assessment of disease severity, progression, complications, and treatment response (8). Although a few single-center studies (9,10) reported use of chest CT for diagnosis and work-up of patients with COVID-19 pneumonia, a recent survey suggested that only a few sites use reduced-dose scan protocols (with lower radiation dose compared with routine or general chest CT protocol) for imaging patients with known or who are suspected of having COVID-19 (8). Despite reports on chest radiography and nonionizing radiation–based imaging with US (11,12), CT remains the preferred imaging modality in COVID-19 pneumonia.

Because more than 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, to date, 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 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 COVID-19 pneumonia.

Materials and Methods

Approvals and Disclosures

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

Survey Protocol

The two-part survey included a questionnaire and fillable form for scan parameters and dose-related information in patients with known or who were suspected of having COVID-19 pneumonia. A medical physicist, CT technologist, and/or radiologist filled the survey details. In the questionnaire, we requested that participating health care sites answer the following 12 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 health care 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, applied tube current or vendor-specific image quality parameter for automatic exposure control, 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 health care sites with multiphase scan protocols). For multiphase CT protocols, specific type of phase with and without contrast enhancement was recorded (such as noncontrast, postcontrast arterial, venous, and/or delayed phases). For each phase, we instructed the participating health care 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 examination.

One radiologist (M.K.K., with >15 years of experience in CT radiation dose research) and two medical physicists (J.V., O.H.) created the survey data collection form in Microsoft Excel (version 1902, Microsoft). A study coauthor (J.V.) distributed the survey data collection to the national project counterparts of the International Atomic Energy Agency via e-mail correspondence. The survey was conducted between May and July 2020. Completed survey responses were received via secured e-mail communication and then shared with coauthors by 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 the COVID-19 pandemic.

Health Care Sites and Patients

Each participating hospital was requested to provide the above-mentioned fillable information for at least 10–20 adult patients who underwent CT with known or who were suspected of having COVID-19 pneumonia. To avoid data truncation and to assess CT usage in each patient, we requested that sites provide data on all initial and follow-up CT examinations since their suspected or known COVID-19 pneumonia diagnosis. Sites from countries (eight sites from six countries) with fewer than 10 patients were excluded from the data analyses. Because very few sites (five of 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 examinations.

Statistical Analysis

All sites provided the data as Microsoft Excel files. Descriptive statistics and pivot tables were created for data analyses by using Microsoft Excel. Responses to the survey questionnaire were summarized as pie charts with the percentage of participating health care sites in each response category. Radiation dose descriptors $CTDI_{vol}$ and DLP were summarized as median and interquartile range for different health care sites in the participating patients. For patients with multiphase chest CT and/or multiple CT examinations, we separately calculated cumulative DLP (sum across all CT phases and examinations) and median $CTDI_{vol}$ (across multiple phases and examinations). In addition, we performed generalized estimating equations (SPSS Statistics for Windows, version 26; IBM) with $CTDI_{vol}$ and DLP as outcomes. Patients' ages, 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 to 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 .05 was considered to represent statistical significance.

Results

Survey Questionnaire

Responses to survey questionnaires from 62 health care sites from 34 countries are summarized in Movie 1 (online). Most sites (63%, 39 of 62) had a substantial burden of patients (sites with >100 patients with known or who were suspected of having COVID-19 infection at the time of data collection) (question 1). Most sites (60%, 37 of 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 of 62) or radiography (18%, 8 of 62) as primary methods of diagnosis. Several sites (52%, 32 of 62; 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 of 62 sites; question 3). Use of CT in hospital-admitted patients with COVID-19 (63%, 39 of 62 sites) was greater than that used with outpatients (23%, 14 of 62 sites; questions 5 and 7).

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

Variations in Median $CTDI_{vol}$ and DLP across Health Care Sites

De-identified data from 782 patients (median age, 59 years [interquartile range, 15 years]) were collected from 54 health care sites in 28 countries (Fig 1). There were eightfold variations in median $CTDI_{vol}$ and 10-fold variations in median DLP across multiple participating health care sites from the same country (Table 1). Most patients underwent a single CT examination (71%; 557 of 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 $CTDI_{vol}$ (8–9 mGy; P = .41) and DLP (299–344 mGy · cm; P = .84) between chest CT examinations performed in different continents (Table 3). However, because of the 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 = .03).

Scanners and Scan Parameters

Both median $CTDI_{vol}$ (7–11 mGy; P < .001) and DLP (280–439 mGy · cm; P = .018) differed across CT scanners from the four major vendors (Table 3). CT scanners installed between 2016 and 2020 (median, 7 mGy [interquartile range, 6 mGy]) and 2006 and 2010 (median, 8 mGy [interquartile range, 5 mGy]) were

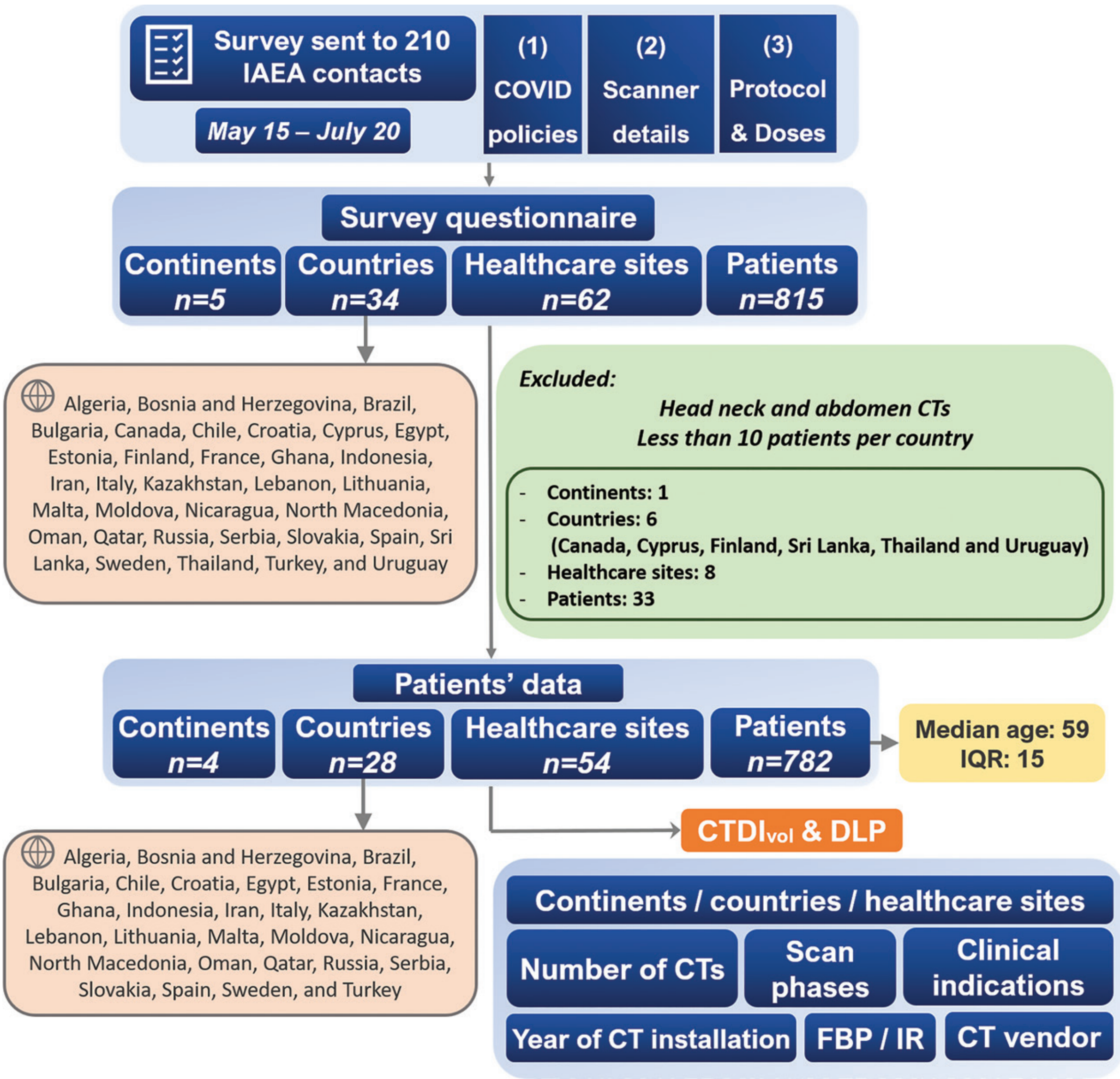

Figure 1: Flow diagram summarizes recruitment of different participants in survey along with exclusion criteria. COVID = coronavirus disease, $CTDI_{vol}$ = volume CT dose index, DLP = dose length product, FBP = filtered back projection, IAEA = International Atomic Energy Agency, IR = iterative reconstruction.

associated with lower $CTDI_{vol}$ compared with scanners installed between 2011 and 2015 (median, 10 mGy [interquartile range, 7 mGy]) (P = .006). The corresponding median DLP values were not different (255–390 mGy · cm; P = .075) (Table 3).

Scanners with more than 64 detector rows were associated with lower $CTDI_{vol}$ (8–9 mGy; $P < .001$) and median DLP (285–334 mGy · cm; P = .002) compared with those with 64 or more detector rows. CT examinations performed with iterative reconstruction–enabled (in 33 of 54 health care sites) image generation were associated with lower radiation doses compared with those with conventional filtered back projection method (in 21 of 54 health care sites) (median $CTDI_{vol}$, 7 mGy [interquartile range, 6 mGy] vs 10 mGy [interquartile range, 7 mGy] and DLP was 305 mGy · cm vs 523 mGy · cm) (P = .03 and P = .01, respectively). The inferior extent of scan volume was at the lung bases in 47% (370 of 782) of patients or at the adrenal glands in 41% (322 of 782) of patients. The information on scan range was unavailable in some patients (12%, 90 of 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 examinations performed in 782 patients was follow-up of findings related to known or suspected COVID-19 pneumonia (551 chest CT examinations; median $CTDI_{vol}$, 9 mGy; median DLP, 341 mGy · cm) followed by initial diagnosis of suspected COVID-19 infection (n = 461; median $CTDI_{vol}$, 8 mGy; median DLP, 278 mGy · cm), complications (n = 107; median $CTDI_{vol}$, 7 mGy; median DLP, 332 mGy · cm) and other or nonspecified clinical conditions (n = 64; median $CTDI_{vol}$, 8 mGy; median DLP, 413 mGy · cm). There was a difference in $CTDI_{vol}$ and DLP for chest CT examinations performed for different clinical indications (P

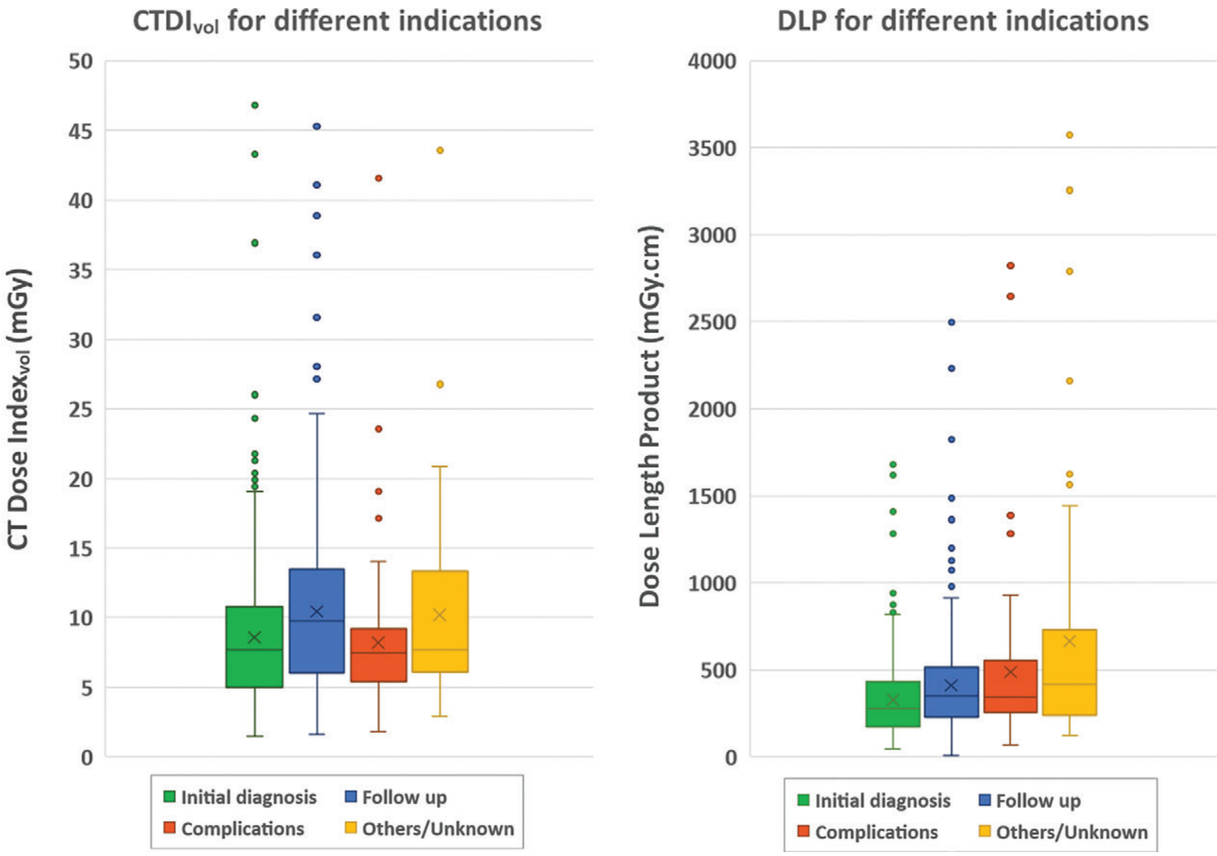

Figure 2: Box and whisker plots show, *A*, volume CT dose index ($CTDI_{vol}$) and, *B*, dose length product (DLP) for patients who underwent chest CT for different clinical indications. Lines and crosses within boxes represent median and mean values. Superior and inferior aspects of each box represent first and third quartile of doses.

< .001). Although patients aged 80 years or older were scanned with lower $CTDI_{vol}$ (8 mGy) and DLP (325 mGy · cm) compared with patients in other age groups (<80 years, 6 mGy and 229 mGy · cm), these differences in doses were not significant (P = .737–.942) (Table 5).

Median $CTDI_{vol}$ for single- and multiple-phase chest CT was significantly different due to change in acquisition parameters such as tube current for delayed phase compared with initial noncontrast and arterial phases (single phase, 8 mGy; multiple phase, 6 mGy; $P < .001$). Median DLP values were lower with a single phase (315 mGy · cm) to three scan phases (1310 mGy · cm; P = .008). Radiation doses for single- and multiphase chest CT examinations are summarized in Figure 3. Single-phase noncontrast chest CT was the most commonly reported protocol in 24 of 28 countries (43 of 54 health care sites), whereas multiphase CT was performed in four of 28 countries (11 of 54 health care sites). Only one hospital (one of 54) performed dual-phase contrast-enhanced CT in arterial and venous phases without the noncontrast phase. There was no difference in $CTDI_{vol}$ (8–9 mGy) across noncontrast, arterial, venous, and delayed phases (P = .0.61) although median DLP values varied (300–386 mGy · cm) (P = .041) (Fig 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 coronavirus disease 2019 (COVID-19) pneumonia across different health care sites. CT was most often used to assess disease severity and less commonly to assess for patients suspected of having COVID-19 pneumonia and those 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 of 782) had two to eight chest CT examinations in less than 1 month. Multiphase scan protocols and their association with higher radiation dose were concerning in 11 of 54 health care sites from four of 28 countries in our study.

Health care sites varied on their CT protocols: some adopted a single-phase noncontrast protocol and performed only one chest CT examination, some used reduced-dose chest CT protocol, and, likewise, some reduced radiation dose for follow-up chest CT compared with the baseline examination. Only one of 28 countries reported median $CTDI_{vol}$ less than 3 mGy for chest CT examinations. Conversely, lower-dose chest CT examinations on newer scanners (installed between 2016 and 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 that discourage use of screening CT in absence of paucity of reverse transcription polymerase chain reaction or serologic assays (13–17). Conversely, our study identified several areas of

Table 1: Summary Data from 782 Patients from 54 Health Care Sites in 28 Countries

Country	No. of Patients	Age(y)*	Weight (kg)*	No. of CT Examinations	No. of Scan Phases	$CTDI_{vol}$ (mGy)*	DLP per Examination (mGy · cm)	Cumulative DLP for All CTs (mGy · cm)	Rotation Times (msec)	Tube Voltage (kV)	Slice Thickness (mm)	No. 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.— Unless otherwise specified, data are medians. Median age of patients included in data summary is 59 years (interquartile range, 15 years). Minimum-maximum (Min-max) volume CT dose index ($CTDI_{vol}$) and dose length product (DLP) refer to the minimum and maximum values across different health care sites from the same country.

* Data are means, with interquartile ranges in parentheses.

Table 2: Summary of Information in Patients with One or More Chest CT Examinations for Evaluation of Their COVID-19 Lung Infection

Characteristic	One CT Examination	Two CT Examinations	Three CT Examinations	Four CT Examinations	Five to Eight CT Examinations
No. of patients	557	124	65	18	18
Median age (y)	59 (26)	57 (25)	58 (29)	68 (14)	68 (20)
Median $CTDI_{vol}$ (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 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 first and last CTs	…	9 (10)	14 (12)	21 (13)	29 (25)
Stable $CTDI_{vol}$ in mGy‡	…	0 (18)	0 (4)	0 (1)	…
Decrease in $CTDI_{vol}$ (mGy)‡	…	1.1 (43)	1.1 (30)	4.2 (6)	3.6 (14)
Increase in $CTDI_{vol}$ (mGy)‡	…	0.6 (63)	0.7 (31)	1 (11)	0.3 (4)

Note.—Unless otherwise specified, data are medians, with interquartile ranges in parentheses. Minimum-maximum (Min-max) CT volume dose index ($CTDI_{vol}$) and dose length product (DLP) refer to the minimum and maximum values of median $CTDI_{vol}$ and DLP across patients with multiple CT examinations. Rows with stable, decreased, or increased $CTDI_{vol}$ describe the differences in $CTDI_{vol}$ between initial and follow-up CT examinations. COVID-19 = coronavirus disease 2019.

* $P = .04$ for differences in $CTDI_{vol}$ based on number of CT examinations.

† $P < .001$ for differences in cumulative DLP based on number of CT examinations.

‡ Data in parentheses are numbers of patients.

Table 3: Summary of Median $CTDI_{vol}$ and DLP of Chest CT Examinations

Parameter	No. of Countries	No. of Sites	No. of Patients	Median $CTDI_{vol}$ (mGy)	Median DLP per Examination (mGy · cm)	Median Cumulative DLP (mGy · cm)
Different continent						
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	…	…	…	.41	.84	.03
Different vendor						
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	.018	.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	…	…	…	.006	.075	.13

Note.—Data in parentheses are interquartile ranges. Table is a summary of the data of volume CT dose index ($CTDI_{vol}$) and dose length product (DLP) examinations organized by continent, scanner from different CT vendors, and year of installation. Cumulative DLP represents sum of DLP of initial and follow-up chest CT examinations in each patient. Total number of countries and health care sites are greater than 28 and 54, respectively, because some countries and health care sites had more than one scanner.

concern, including those stemming from frequent report on the use of CT for initial diagnosis of patients suspected of having 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 suspected of having vascular complications and superimposed necrotizing infection. However, most other pulmonary opacities in COVID-19 pneumonia can be assessed with a single-phase noncontrast 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 $CTDI_{vol}$ less than 3 mGy, as

Table 4: Median $CTDI_{vol}$ and DLP for Different Clinical Uses of Chest CT in Patients with COVID-19 in the Participating Countries

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 (N/A)	339 (N/A)	12 (9)	473 (332)
C4	9 (6)	364 (168)	12 (5)	385 (166)	13 (N/A)	1290 (N/A)	16 (9)	613 (1745)
C5	5 (2)	203 (177)	4.1 (N/A)	447 (N/A)	4.7 (10)	269 (562)	6 (3)	586 (223)
C6	6 (4)	201 (179)	10 (16)	338 (781)	7 (3)	402 (559)	7 (N/A)	1425 (N/A)
C7	9 (2)	325 (37)	9 (1)	315 (21)	…	…	…	…
C8	7 (4)	245 (85)	5 (N/A)	213 (N/A)	17 (N/A)	1409 (N/A)	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)	…	…	…	…
^{11}C	5 (5)	150 (91)	…	…	…	…	5 (3)	162 (95)
C12	5 (0)	167 (30)	5 (1)	204 (78)	…	…	…	…
^{13}C	6 (4)	204 (148)	5 (N/A)	191 (N/A)	8 (N/A)	653 (N/A)	…	…
C14	18 (7)	712 (239)	17 (6)	688 (251)	…	…	…	…
C15	8 (2)	321 (113)	…	…	…	…	…	…
C16	…	…	17 (25)	786 (1118)	15 (N/A)	629 (N/A)	…	…
C17	6 (3)	185 (89)	4.3 (N/A)	148 (N/A)	…	…	…	…
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 (N/A)	1505 (N/A)
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 (N/A)	262 (N/A)	…	…

Note.—Data are medians, with interquartile ranges in parentheses. COVID-19 = coronavirus disease 2019, $CTDI_{vol}$ = volume CT dose index, DLP = dose length product, N/A = not available.

Table 5: Distribution of Median Number of Scan Phases, $CTDI_{vol}$, and DLP in Patients of Different Age Groups Who Underwent Chest CT for Known or Suspected COVID-19 Pneumonia

Variable	20–39 Years	40–59 Years	60–79 Years	≥80 Years
No. of patients	133	268	297	81
No. of CT examinations	1 (1)	1 (1)	1 (1)	1 (1)
Median weight (kg)	75 (18)	81 (20)	80 (18)	71 (16)
No. of scan phases	1 (1)	1 (1)	1 (1)	1 (2)
Median $CTDI_{vol}$ (mGy)	8 (6)	8 (7)	8 (6)	6 (5)
Median DLP (mGy · cm)	307 (271)	338 (296)	326 (279)	229 (190)

Note.—Unless otherwise specified, data are medians, with interquartile ranges in parentheses. For three patients, ages were not provided. COVID-19 = coronavirus disease 2019, $CTDI_{vol}$ = volume CT dose index, DLP = dose length product.

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-spatial-resolution and ultra-high-spatial-resolution chest CT in patients with COVID-19 pneumonia, but most studies related to acquisition technique for scanning these patients describe use of noncontrast 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, severalfold variations in $CTDI_{vol}$ and DLP in chest CT examinations at participating sites in our study, often from the same country and city, make dose optimization difficult. Another cause of concern pertains to higher $CTDI_{vol}$ associated with scanners installed between 2011 and 2015 compared with older scanners prior to 2011. Such differences in $CTDI_{vol}$

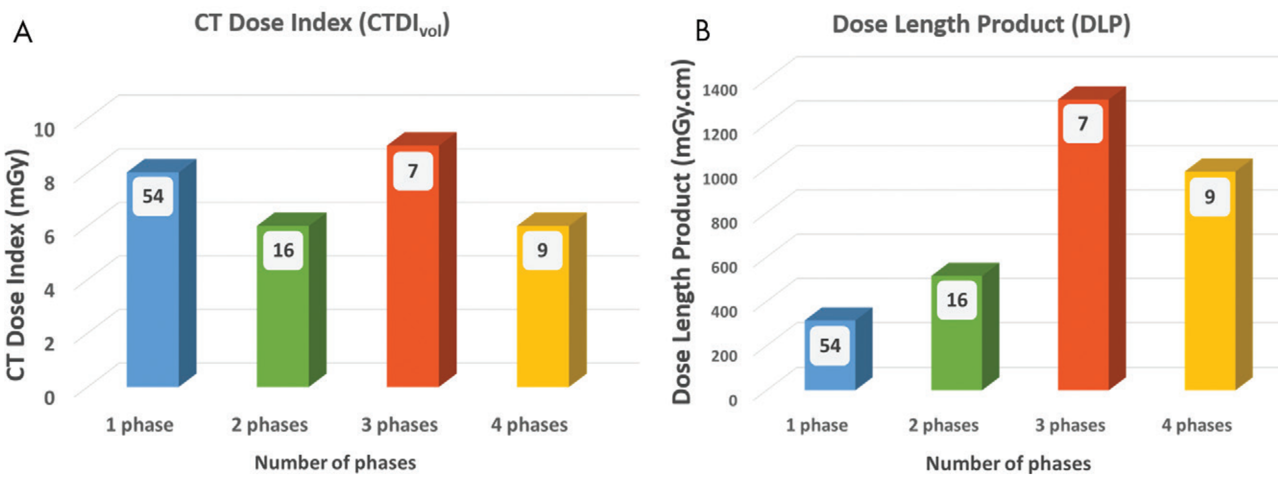

Figure 3: Bar diagrams summarize, *A*, median volume CT dose index ($CTDI_{vol}$) and, *B*, dose length product (DLP) of chest CT examinations with different numbers of scan phases. Lower DLP with four-phase CT protocols compared with three-phase CT was likely related to use of lower $CTDI_{vol}$ in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

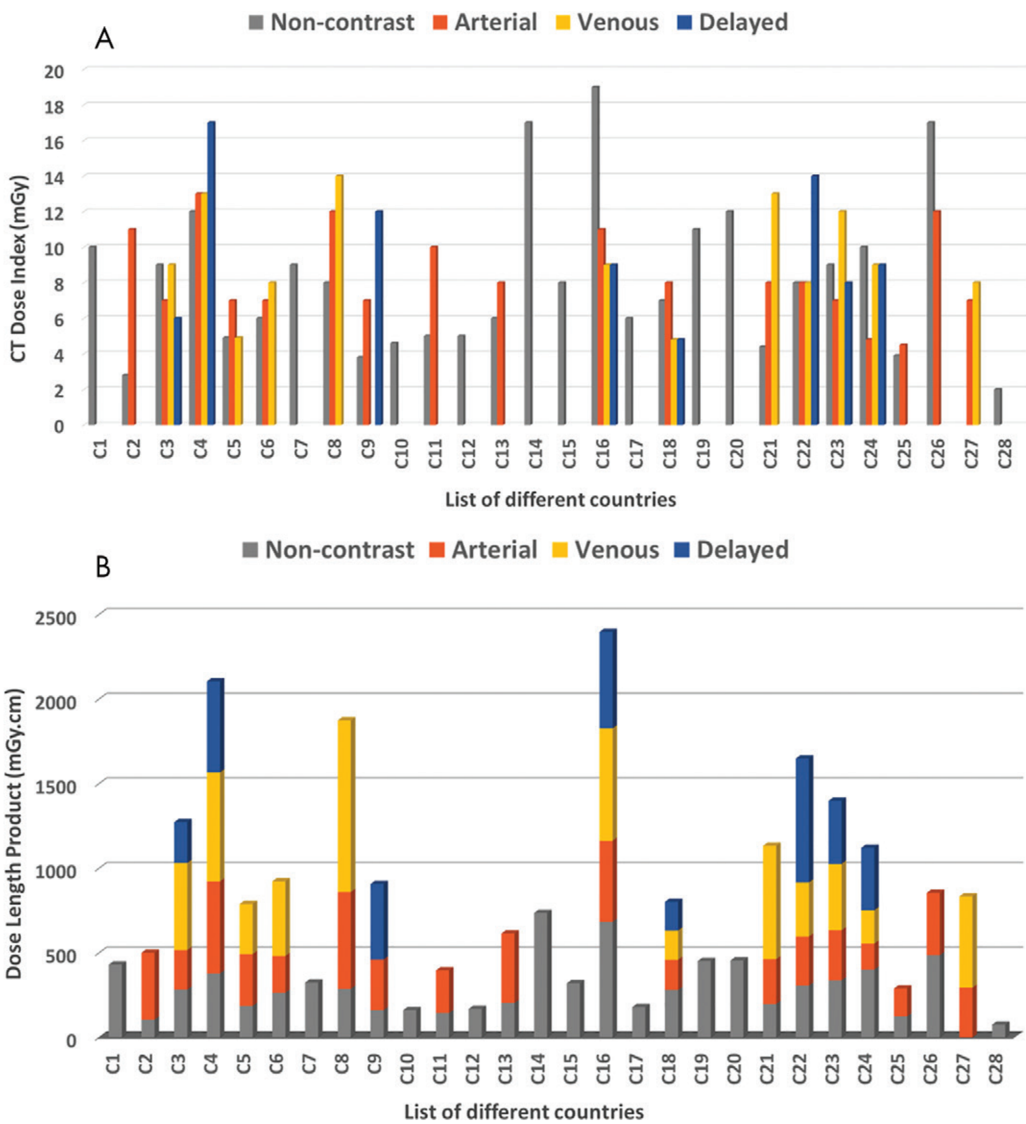

Figure 4: Bar diagrams summarize, *A*, median volume CT dose index ($CTDI_{vol}$) and, *B*, dose length product (DLP) for noncontrast, arterial, venous, and delayed phases of chest CT.

(about 3 mGy) might not be clinically meaningful and might be related to variations in patient sizes, protocol types, and scan parameters. These differences highlight the importance of CT protocol optimization, which is as important as access to the 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 vs 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 that are not only limited to the imaging of patients with COVID-19 pneumonia.

Our study had limitations. Some clinical indications or usage of CT might have been missed because of 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 health care 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. Because of logistic and data privacy issues, we did not obtain CT image data sets 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 examinations in patients with COVID-19 pneumonia. We could not adequately assess justification of multiple CT examinations in some patients because the provided information stated follow-up or worsening of symptoms. Also, we did not obtain reverse transcription polymerase chain reaction results because of 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 coronavirus disease 2019 with severalfold 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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