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MODALITY-BASED (UC, CT, MRI, PET-CT) IMAGING

ORIGINAL ARTICLE

Did radiation exposure increase with chest computed tomography use among different ages during the COVID-19 pandemic? A multi-center study with 42028 chest computed tomography scans

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PURPOSE

To determine whether radiation exposure increased among different ages with chest computed tomography (CT) use during the coronavirus disease-2019 (COVID-19) pandemic.

METHODS

Patients with chest CT scans in an 8-month period of the pandemic between March 15, 2020, and November 15, 2020, and the same period of the preceding year were included in the study. Indications of chest CT scans were obtained from the clinical notes and categorized as infectious diseases, neoplastic disorders, trauma, and other diseases. Chest CT scans for infectious diseases during the pandemic were compared with those with the same indications in 2019. The dose-length product values were obtained from the protocol screen individually.

RESULTS

The total number of chest CT scans with an indication of infectious disease was 21746 in 2020 and 4318 in 2019. Total radiation exposure increased by 573% with the use of chest CT for infectious indications but decreased by 19% for neoplasia, 12% for trauma, and 43% for other reasons. The mean age of the patients scanned in 2019 was significantly higher than those scanned during the pandemic (64.6 vs. 50.3 years). A striking increase was seen in the 10–59 age group during the pandemic ($P < 0.001$). The highest increase was seen in the 20–29 age group, being 18.6 fold. One death was recorded per 58 chest CT scans during the pandemic. Chest CT use was substantially higher at the beginning of the pandemic.

CONCLUSION

Chest CT was excessively used during the COVID-19 pandemic. Young and middle-aged people were exposed more than others. The impact of COVID-19-pandemic-related radiation exposure on public health should be followed carefully in future years.

KEYWORDS

COVID-19 pandemic, CT, pneumonia, radiation, thoracic

The World Health Organization declared the coronavirus disease-2019 (COVID-19) as a pandemic on March 11, 2020.[1] While the disease has an asymptomatic or milder course in children and young adults, it is relatively mortal in those over 65.[2-4] Men have an increased risk of mortality compared with women.[3]

There was no clear consensus on the diagnosis of the disease in the early stage of the pandemic, so imaging methods were widely used for detection.[5] After the development of test kits, real-time reverse transcriptase polymerase chain reaction (RT-PCR) became the standard diagnostic test for COVID-19.[6] Currently, imaging is not indicated for patients suspected to have COVID-19 with mild clinical features.[7] Over 95% of patients with COVID-19 infection

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survive, and radiation exposure limits even the usage of basic X-ray-based methods in thoracic imaging.[8] However, RT-PCR has disadvantages, such as limited availability, false negative results, and a relatively long test-to-result time.[9,10] Additionally, RT-PCR tests only verify the presence of the virus without suggesting the course and severity of the disease.[11,12]

Chest X-rays are not sensitive regarding the detection of viral pneumonia.[7] However, chest computed tomography (CT) scans play a key role for patients suspected to have COVID-19 pneumonia and contribute to an accurate diagnosis in the triage phase.[13] The decision to isolate the patient is an urgent issue, and CT rules out pneumonia within seconds.[7,13] Furthermore, CT can reveal the presence of pneumonia and can predict the prognosis by indicating the degree of pulmonary involvement and vascular complications.[12] Despite these benefits, it contains relatively high radiation, leading to an increase in the cumulative dose of the patients which are exposed.[13,14]

Radiation does not affect all age groups equally. Young people are more radiosensitive and have an increased risk of cancer with excessive use of CT scans.[15] Demonstration of the increased radiation exposure among different age groups during the pandemic may be useful to highlight potential radiation-induced diseases.

The present study tries to determine whether radiation exposure increased among different ages with chest CT use during the COVID-19 pandemic.

Methods

Study design

This retrospective study was approved by the University of Health Science Turkey, Dr. Behçet Uz Pediatrics and Surgery Training and Research Hospital Clinical Research Ethics Committee (approval number: 2021/02.25-513). Written informed consent was obtained before CT acquisition. It was conducted in two third-level referral pandemic hospitals (center 1, an adult hospital serving about 3 million adults annually in outpatient services; and center 2, a children's hospital serving about 0.5 million children annually in outpatient services). All patients with chest CT in the 8-month period of the pandemic between March 15, 2020, and November 15, 2020, and the same dates of the preceding year were included. The first case was reported in our country on March 11, 2020. Chest CT scans performed on dates other than in these ranges and non-chest CT scans were excluded.

Main points

- During the coronavirus disease-2019 pandemic, excess use of chest computed tomography (CT) caused increased radiation exposure.
- A sharp rise in chest CT use was seen in young people.
- At the beginning of the outbreak, CT use was higher.

The patients' diagnoses were obtained from the hospital registration system using International Classification of Diseases-10 codes. The indications of chest CT examinations were determined from the clinical notes as follows: infectious disease, neoplastic disorders, trauma, or other diseases (the majority of other diseases were vascular diseases, including pulmonary thromboembolism, aortic aneurysm, and dissection). Chest CT scans performed with the indication of infectious diseases were used in the statistical analysis, as the study's aim was to determine the radiation exposure related to the imaging of infections, mainly of COVID-19. The patients' demographic information and the date of examination were recorded. Those below the age of 18 were defined as children. Each chest CT scan was counted separately when a patient had more than one.

Calculation of radiation dose

The standard-dose non-contrast CT was used for infectious indications. The intravenous contrast (350 mg/mL iodine) was administered at a dose of 1 mL/kg of body weight if there was any suspicion of vascular disease, hilar, or mediastinal mass. The scanners and acquisition protocols for standard-dose non-contrast CTs were as follows: center 1 used a 128-slice CT scanner (SOMATOM Definition AS, Siemens, Erlangen, Germany), with a tube voltage of 120 kVp, a maximum tube current of 100 mA with automated exposure control, gantry rotation time of 0.5 s, pitch factor of 1.0, acquisition slice thickness of 0.6 mm; and center 2 used a 32-slice CT scanner (SOMATOM go.Now, Siemens, Erlangen, Germany), with a tube voltage of 110 kVp, a maximum tube current of 100 mA with automated exposure control, gantry rotation time of 1 s, pitch factor of 1.0, acquisition slice thickness of 1 mm. The total tube output during one scan was recorded from the patient's protocol screen as the dose-length product (DLP). The effective radiation doses (mSv) were calculated using the following formula: DLP × conversion factor = effective dose, where age-specific conversion factors used were: 0.039 (0–1 year), 0.026 (1–5 years), 0.018 (5–10 years), and 0.014 (>10 years old).[16]

Statistical analysis

Two years' data were compared using the Statistical Package for the Social Sciences (SPSS™) version 20.0 (IBM Corp., Armonk, NY, USA). In descriptive statistics, continuous variables were reported with mean ± standard deviation, while categorical variables were presented with numbers and percentages as n (%). In the examination-based analysis, Pearson's chi-squared test was used for the comparison of chest CT use by indications. Demographic data were found to be normally distributed by the Kolmogorov–Smirnov test. The ages of the patients scanned with an indication of infectious diseases in 2019 were compared with those scanned with the same indication in the pandemic using the t-test. Ages were grouped by decades. The gender and age groups of the patients were compared using Pearson's chi-squared test. Chest CT use with an indication of infectious disease in the centers in 2019 was compared with chest CT use with the same indication in the centers in 2020 using Pearson's chi-squared test. The ages of the patients who had repeated chest CT scans with an indication of infectious diseases in 2020 were compared with the ages of the patients who had a single chest CT scan with an indication of infectious diseases in the same period using the t-test. A P value of <0.05 was statistically significant.

Results

A total of 36502 patients were included in the study. There were 19557 men and 16945 women. The mean age was 54.9 ± 19.9 years. The total number of chest CT scans was 42028.

In 2019, 12212 patients had chest CT, comprising 6466 men and 5746 women. The mean age was 61.1 ± 18.6 years. The total number of chest CT scans was 13832. In 2020, 24290 patients had chest CT, comprising 13091 men and 11199 women. The mean age was 51.8 ± 19.9 years. The total number of chest CT scans was 28196 (Table 1).

Chest CT examinations were grouped by indication. The numbers of chest CT scans with different indications were as follows: 4318 (31.22%) infectious diseases, 3654 (26.42%) neoplasia, 2020 (14.6%) trauma, and 3840 (27.76%) other diseases in 2019; and 21746 (77.12%) infectious diseases, 2794 (9.91%) neoplasia, 1644 (5.83%) trauma, and 2012 (7.14%) other diseases in 2020. Chest CT use with an indication of infectious disease was five times higher in 2020 than in the preceding year. The number of chest CT scans with indications of neoplasia, trauma, and other diseases decreased by 24%, 19%, and 48%, respectively, in 2020. Chest CT use with an indication of infectious diseases was significantly higher in 2020 (P < 0.001) (Table 2). The mean effective radiation doses per scan with an indication of infectious diseases were 3.15 ± 1.73 mSv and 3.58 ± 1.56 mSv in 2019 and 2020, respectively. The total radiation exposure of chest CT scans with an indication of infectious diseases was 13586.28 mSv in 2019, while it was 77867.24 mSv in 2020, an increase of 5.73 times in the pandemic. The total radiation exposure of chest CT scans for neoplastic diseases, trauma, and other reasons decreased by 19%, 12%, and 43%, respectively (Table 3). The data of 24915 (88.36%) chest CT scans in 2020 were accessible to determine the referring clinics. They were mostly ordered from the emergency departments with a rate of 77.58%, followed by infectious diseases, medical oncology, and chest diseases with rates of 8.89%, 5.41%, and 2.90%, respectively.

The demographic data of the patients who underwent chest CT with the indication of infectious disease in 2019 and during the pandemic were also compared. There was no significant difference by gender (P = 0.202). The mean ages of the patients with chest CT in 2019 and 2020 were 64.6 ± 19.1 and 50.3 ± 20, respectively. The difference was statistically significant (P < 0.001). A dramatic increase in chest CT use was found in the 10–59 age group (P < 0.001). The highest increase was 18.6 times and seen in the 20–29 age group (Table 4). The number of chest CT examinations increased 5.1 times in the adult hospital and 4.1 times in the children's hospital. The difference in the rate of increase between the two hospitals was not statistically significant (P = 0.081).

There were 18534 patients with 21746 chest CT scans in the infectious disease group in 2020, of whom 373 died, a mortality rate of 2.01%. One death was recorded per 58 chest CT scans during the pandemic. Chest CT use was substantially higher at the beginning of the pandemic. The numbers of chest CT scans were 631 in April 2019 and 606 in May 2019, while they were 3537 and 2353 in the same months of 2020, respectively. Chest CT use was relatively stable in 2019. However, chest CT use traced a zigzag pattern in the pandemic, and it decreased permanently after a second peak in August 2020 (Figure 1).

The number of patients who underwent repeated chest CT with an indication of infectious diseases was 548 in 2019 and 2301 in 2020, respectively. The maximum number of repetitions was 12 in 2019 and 17 in 2020 for a single patient (Table 5). The demographic data of the patients who, in 2020, had repeated chest CT scans with the indication of infectious disease were compared with those who had single chest CT scans with the same indication. The mean ages of repeated and non-repeated patients' groups were 55.7 ± 19.5 and 48 ± 19.8, respectively. The mean age of the patients who had repeated chest CT was significantly higher than that of the patients who had a single chest CT scan in 2020 (P < 0.001).

Table 1. Characteristics of the patient population

Parameters	Number of patients who had chest CT in 2019 n = 12212 (%)	Number of patients who had chest CT in 2020 n = 24290 (%)	Total n = 36502
Men	6466 (52.9%)	13091 (53.9%)	19557
Women	5746 (47.1%)	11199 (46.1%)	16945
Mean age (± SD)	61.1 (± 18.6)	51.8 (± 19.9)	54.9 (± 19.9)

CT, computed tomography; SD, standard deviation.

Table 2. Comparison of chest CT scans by indications by years

Indications	The number of chest CT scans		P value
	In 2019 n = 13832 (%)	In 2020 n = 28196 (%)	
Infectious diseases	4318 (31.22%)	21746 (77.12%)	<0.001
Neoplastic disorders	3654 (26.42%)	2794 (9.91%)	
Trauma	2020 (14.60%)	1644 (5.83%)	
Other diseases	3840 (27.76%)	2012 (7.14%)	

CT, computed tomography.

Discussion

The present study showed that radiation exposure increased significantly with chest CT during the COVID-19 pandemic. In the first year of the pandemic, compared with the preceding year, the increase in overall chest CT use to image infection was about five-fold. Interestingly, young adults were scanned more frequently, and the most prominent increase was observed in the 20–29 age group with 18.6 times. The number of repeated scans also increased 4.2 times during the pandemic. To the best of the authors' knowledge, this is the first study addressing increased radiation exposure by age groups with the increased use of chest CT in the COVID-19 pandemic.

Levin et al.[17] reported a logarithmic linear relationship between the infection fatality rate and age. The age-specific fatality rate was extremely low in children (0.002%) and increased to 0.4% at age 55, 1.4% at age 65, 4.6% at age 75, and 15% at age 85.[17] In a study by Grasselli et al.[18], older age and male gender were the independent risk factors for death. But COVID-19 infection was more common in middle-aged adults.[4] Moreover, chest CT was often used in triage during the pandemic.[13] These findings explain the more frequent use of chest CT among young and middle-aged people. Chest CT use was more common in men, both in 2019 and 2020. Only 2% of the patients with an indication of infectious disease who had chest CT in 2020 died. This rate (2.01%) was below than the expected mortality of the disease.[17] These results suggest redundant CT use carried out almost as a screening test.

The Fleischner Society did not recommend CT as a screening test and noted that CT should be used for moderate to severe disease with worsening respiratory status.[7] Still, several factors caused excessive CT use during the pandemic. Hospitalization was higher during the pandemic, and most (63%) of the centers used chest CT for hospitalized patients with COVID-19.[8] Chest CT was frequently used as an initial test because of the limited availability of RT-PCR test kits at the beginning of the pandemic. Early studies underlined false negative RT-PCR test results.[9,19] In the meta-analysis of Islam et al.[20], chest CT had a higher sensitivity than RT-PCR. The pooled sensitivity and specificity of chest CT were 87.9% and 80.0%, respectively.[20] The

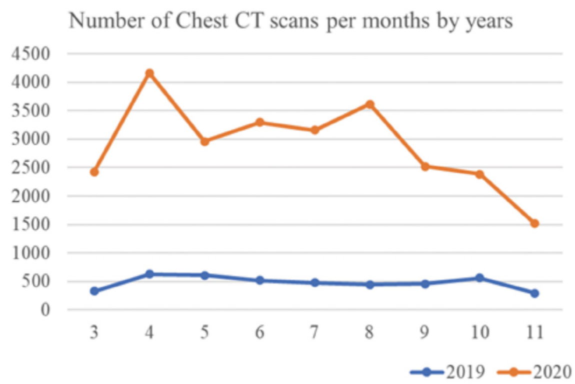

Figure 1. Comparison of the number of chest computed tomography scans with the indication of infectious diseases by months. *Showing half of 3rd and 11th months. CT, computed tomography.

Table 3. Change of total radiation exposure by indication

	Total radiation exposure (mSv)		
Indications	In 2019	In 2020	Change
Infectious diseases	13586.28 (31.36%)	77867.24 (78.23%)	+573%
Neoplastic disorders	11224.30 (25.91%)	9120.59 (9.16%)	–19%
Trauma	6405.92 (14.79%)	5648.76 (5.67%)	–12%
Other diseases	12104.27 (27.94%)	6904.10 (6.94%)	–43%
Total	43320.77	99540.69	+230%

mSv, millisievert.

Table 4. Comparison of chest CT scan numbers with the indication of infectious diseases

Parameters	The number of chest CT scans in 2019	The number of chest CT scans in 2020	Fold	*P* value
Men	2293	11778	5.1	**0.202**
Women	2025	9968	4.9	
Mean age (± SD)	64.6 (± 19.1)	50.3 (± 20)		<0.001
Age groups by tens				
1 (0–9)	68	72	1.1	
2 (10–19)	41	734	17.9	
3 (20–29)	171	3186	**18.6**	
4 (30–39)	187	3448	18.4	
5 (40–49)	327	3478	10.6	
6 (50–59)	618	3251	5.3	<0.001
7 (60–69)	915	3074	3.4	
8 (70–79)	978	2650	2.7	
9 (80–89)	801	1566	2	
10 (90–99)	212	281	1.3	
11 (100–110)	0	6	n/a	

CT, computed tomography; SD, standard deviation; n/a, non-applicable.

Table 5. The number of repetitions for patients who had multiple chest CT scans with the indication of infectious diseases

The number of repetitions	Number of patients who had multiple chest CT	
	In 2019	In 2020
2	370	1730
3–5	160	536
6–10	17	30
11+	1	5

CT, computed tomography.

other potential factors of increased CT use were the unknown course of the disease in the early stages of the pandemic, the tendency to immediately diagnose pneumonia, and peaks during the pandemic. In the present study, it was observed that CT scans were mostly used in the early period of the pandemic and had decreased by September 2020. The increased use of facial masks, which could decrease contagion, the accumulation of knowledge about the disease course, the increased availability of test kits, and the shortening of the RT-PCR test process may have reduced chest CT use later in 2020.

Another factor for the greater radiation exposure was the increased number of patients with repetitive scans. In the cohort of Cristofaro et al.[21], each patient positive for COVID-19 was scanned with chest CT an average of 2.78 times. The maximum repetition number was 10 between March and October 2020.[21] Yurdaisik et al.[22] showed that 43% of the patients had repetitive scans at the start of the pandemic. They did not find an age difference between the patients with single and multiple scans.[22] In the present study, the number of patients with repetitive scans increased by 4.2 times. The maximum repetition was 17 during the pandemic. Repeated CT scans were observed in older patients. Age correlated with severe disease course, which could have increased the requirement for rescans.

A significant decrease (57.4%) was seen in trauma admissions during the COVID-19 pandemic.[23] Head CT use due to traumatic brain injury decreased by about 40% in emergency departments during the pandemic.[24] Emergency surgeries were also reduced by 59%.[25] Netherland Cancer Registration data showed a 26% decrease in cancer diagnoses except for skin cancers within the first months of the pandemic.[26] Reprioritization of non-emergency services, including diagnostic specialists, and the lockdown of the population dramatically disrupted cancer referrals.[27] Deferrable, non-urgent procedures, even in oncologic practice, were delayed.[28,29] Chest imaging was encouraged to exclude COVID-19 risk for maximal safety before surgeries.[30] Chest CT was recommended for any patient needing emergency surgery and undergoing an abdominal CT scan in the early stage of the pandemic.[31] But the Royal College of Radiologists does not recommend routine preoperative CT screening. Instead, CT use should be limited, and preoperative chest CT should be considered only if positive CT findings would change the patient's immediate surgical management.[32] The Royal College of Surgeons advises an RT-PCR screening within 72 h of surgery for patients who are candidates for elective surgery.[33] While these factors reduced the use of chest CT for non-infectious reasons, COVID-19 screening increased radiation exposure. In the present study, the total radiation exposure decreased by 12% for trauma, 19% for oncological screening, and 43% for other reasons but increased by 573% for infectious diseases in two referral centers when compared with the preceding year. It can be speculated that the 573% increase in radiation exposure was highly related to the COVID-19 pandemic. The impact of the COVID-19 pandemic on radiation exposure should be followed carefully in future years, especially considering that middle-aged people were excessively exposed.

Using low-dose chest CT protocols has been a controversial issue during the pandemic. The Atomic Energy Study Group determined wide variations in CT use across the centers in 28 countries. Homayounieh et al.[8] reported that approximately half of the centers did not have a dedicated CT protocol for patients with COVID-19, and 20% of the centers used multiphase CT, which was found to be associated with higher radiation exposure. Approximately two-thirds of the centers used standard-dose CT without contrast, while 20% of the centers performed reduced-dose CT without contrast.[8] Kang et al.[14] proposed a dose reduction from a median effective dose of 1.81 mSv to 0.203 mSv without a significant decrease in the image quality. Tabatabaei et al.[13] compared standard-dose (6.60 ± 1.47 mSv) and low-dose (1.80 ± 0.42 mSv) CTs and found there was an excellent inter-reader agreement with Kappa scores of 0.81–0.84 in both standard- and low-dose examinations. But decreasing radiation dose increases the noise and limits the discrimination of ground glass opacity typical in COVID-19 pneumonia. Shiri et al.[34] reported diminished lesion detectability in about 60% of the cases with low-dose CT. The quality scores for all other patterns, including consolidation, crazy paving, nodular infiltrations, and bronchovascular thickening, decreased by reducing the radiation dose.[34] Variations in patient sizes and the lack of reduction technologies, such as current iterative reconstructions, also limited the usage of low-dose CT.[8] In the present study, the standard-dose CT was used to avoid underdiagnosis risk with dose reduction. The mean effective dose per scan was slightly elevated during the pandemic (3.58 mSv in 2020 vs. 3.15 mSv in 2019). The majority of chest CT scans (77.58%) were ordered from the emergency department, where the technologists are prone to scan longer. Therefore, increased scan length may have increased the mean effective dose per scan during the pandemic.

The International Commission on Radiological Protection (ICRP) approved three fundamental principles of radiological protection, namely justification, optimization, and the application of dose limits. "Justification" is a necessity before imaging. In justification, the process including radiation should be beneficial for the patient, and the expected benefits should compensate for the costs, including the radiation detriment. In optimization, the number of people exposed and the magnitude of individual procedures should all be kept as low as reasonably achievable (the ALARA principle).[35] The International Atomic Energy Agency recommends that the decision process of an imaging procedure should be shared between the referring physicians and the radiologists. The referring consultant should bring the medical aspect with the history of the patient, and the radiologist should consider the appropriateness of the request, urgency of the procedure, characteristics of the exposure, relevant information from any previous procedures, and alternative methods that do not use ionizing radiation.[36] Some suggestions for reducing radiation exposure are that the radiologists should take an active role in the decision-making process and national guidelines should be developed to clarify the roles of the radiologists and referring physicians, and the three principles of ICRP should be implemented.

There were several limitations of this study. The retrospective design had the potential for bias. The lack of PCR correlation may be a second limitation; however, this would not reduce the value of the study since the primary goal was to determine the increased radiation exposure during the pandemic. The PCR tests had not been performed for all patients with chest CT in 2020. Probably the most important limitation was that chest CT use may have been affected by local factors, such as the intense admissions of COVID-19 cases, peak periods, and insufficiencies in healthcare services, including the lack of experience of the clinicians. Therefore, the results might not be generalized. Still, this limitation can be justified by the lack of consistent and eligible guidelines on chest CT use, especially in the early period of the pandemic globally. In addition, the hospitalization ratio or rate of intensive care admission to suggest redundant CT use could not be reached. However, the mortality statistics that could suggest overuse in the study population were obtained.

In conclusion, chest CT was excessively used during the COVID-19 pandemic. Young and middle-aged people were exposed more than others. Awareness should be raised about radiation exposure with CT scans. The clinical benefits should outweigh the potential risks, and CT use should be kept low. The impact of the COVID-19 pandemic-related radiation exposure on public health should be followed carefully in future years.

Conflict of interest disclosure

The authors declared no conflicts of interest.

Data sharing statement

Data generated or analyzed during the study are available from the corresponding author by request via e-mail.

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