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Original Article/Research

The impact of the COVID-19 pandemic on the use of diagnostic imaging examinations in the Brazilian unified healthcare system (SUS)

Carlos Eduardo Bonacossa de Almeida [a], Richard W Harbron [b,c], Paulo Roberto Valle Bahia [d], Ana Cristina Murta Dovales [a,*]

[a] Instituto de Radioproteção e Dosimetria, Comissão Nacional de Energia Nuclear, Av. Salvador Allende 3773, Barra da Tijuca, Rio de Janeiro, RJ, 22783-127, Brazil
[b] Institute of Health & Society, Newcastle University, Sir James Spence Institute, Royal Victoria Infirmary, Newcastle upon Tyne, NE1 4LP, United Kingdom
[c] Radiation Protection Group, European Organisation for Nuclear Research (CERN), 1211 Geneva 23, Switzerland
[d] Departamento de Radiologia, Faculdade de Medicina, Universidade Federal do Rio de Janeiro, Rua Professor Rodolpho Paulo Rocco, 255, Cidade Universitária, Rio de Janeiro, RJ, 21941-913, Brazil

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ABSTRACT

Objectives: To assess the impact of the COVID-19 pandemic on the volumes of use of diagnostic imaging examinations in the Brazilian Unified Health System (SUS), the only healthcare provider for approximately 160 million people.
Methods: We collected the monthly numbers of diagnostic imaging examinations in the years 2019, 2020, and 2021 from a database provided by SUS. Data were collected by specific type of examination across different imaging modalities, both for the outpatient (elective and emergency) and inpatient settings.
Results: There was a large reduction in the annual volume of almost all types of diagnostic imaging examinations in SUS in 2020, compared to 2019. Decreases were generally greater among outpatients than in the hospital setting, in which the annual volume of use of most modalities was similar or even higher in 2021 than in the pre-pandemic period. Computed tomography (CT) was the only modality for which use increased in 2020 compared to 2019. In contrast to other types of examinations, the use of chest CT was much higher in both 2020 and 2021 than in the preceding years. The relative changes in diagnostic imaging use in SUS started around March-April 2020, when the pandemic began to get worse in Brazil, and tended to correlate to COVID-19 incidence in Brazil over the following months.
Conclusions: The COVID-19 pandemic had a large impact on the use of diagnostic imaging examinations in the SUS. Policies and actions are needed to alleviate the resulting potential adverse health effects and to optimize the use of diagnostic tests in the future.

Lay summary

The COVID-19 pandemic had great economic and social impacts, profoundly affecting people's lives worldwide. One of the consequences of the restrictive policies established to mitigate viral dissemination was a decline in the use of healthcare services worldwide. In this study, we show a large reduction in the use of most types of diagnostic imaging examinations in the Brazilian Unified Healthcare System (SUS) following the pandemic onset. When compared to 2019, there were about 20.5 million fewer outpatient procedures in 2020, while this deficit was around 7.2 million in 2021. This decrease may have hampered the detection and treatment of various diseases, leading to future potential adverse health outcomes. On the other hand, there was a great increase in the use of computed tomography (CT), driven mainly by the rise in the number of chest CT scans, even among children and young adults, which raises concerns about the potential risks of cancer induction due to exposure to ionizing radiation.

Introduction

In December 2019, Chinese authorities announced a pneumonia outbreak in the Wuhan district. The disease was later attributed to a new type of coronavirus (Severe Acute Respiratory Coronavirus 2, SARS-CoV-2) and named COVID-19 (coronavirus disease 2019). COVID-19

* Corresponding author.
E-mail addresses: adovales@ird.gov.br, adovales@uol.com.br (A.C. Murta Dovales).

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rapidly spread outside China and was declared a pandemic by the World Health Organization (WHO) on March 11, 2020 [1]. Following this, national and local governments around the world set up policies to mitigate viral dissemination [2]. Medical authorities recommended that non-urgent elective consultations, exams, and surgeries be rescheduled [3, 4]. In addition, the fear of being contaminated led many patients to avoid attending medical services, even when in need. As a result, the number of medical visits and admissions, and the volumes of diagnostic and therapeutic procedures rapidly underwent a large decline in the following weeks in many healthcare services. More than a year later, these services have still not returned to normal levels [5–8]. Medical care related to the diagnosis, prognosis, and treatment of COVID-19 increased, however. Intensive care units reached nearly full occupancy and there was a shortage of key supplies - including ventilators and personal protective equipment [9].

Diagnostic medical imaging was one of the most affected areas. Total imaging volumes greatly declined in 2020 compared to 2019, mainly in the outpatient setting. Mammography, nuclear medicine, and magnetic resonance imaging were among the most affected modalities [10–12]. Nevertheless, the use of imaging examinations for the diagnosis and management of COVID-19, particularly chest computed tomography (CT) increased [13–16].

Changes in the use of medical imaging examinations may have a great impact on public health. The detection and treatment of various diseases may be hampered, raising concerns regarding potential adverse population health outcomes. Conversely, the well-known problem of overuse of medicine [17, 18] may have worsened during the COVID-19 pandemic. In particular, the potential over- or misuse of CT scans raises concerns about the potential risks of cancer induction due to exposure to ionizing radiation [19–23].

Most reports on the impact of the COVID-19 pandemic on diagnostic imaging usage have focused on the changes in imaging volumes in local or regional healthcare services, mainly in developed countries. In addition, most of these studies were limited to evaluating the first few weeks after the beginning of the pandemic. In contrast, there is only scarce information on nationwide time trends and only a few papers described the changes in imaging according to specific type of examinations, especially in the medium or long term.

Quantifying and characterizing real-world changes in the use of medical imaging may help governments and medical organizations make decisions to minimize the associated potential health impacts on the population.

Brazil is one of the largest and most populous countries in the world. It has been severely affected by the COVID-19 pandemic, recording more than 20 million cases and 600,000 deaths by October 2021 [24, 25]. Health assistance in Brazil is provided mainly by the Brazilian Unified Health System (SUS), which is the only healthcare care provider for approximately 160 million people [26].

The aim of this work was to evaluate the temporal trends of the changes induced by the COVID-19 pandemic in diagnostic imaging volumes across different types of examinations and patient care locations in SUS, in the period 2019–2021.

Materials and methods

Data on the number and distribution of diagnostic imaging examinations in SUS were gathered from an online open access database provided by the Information Technology Department of SUS (DATASUS) [27]. This database contains anonymous information on publicly funded medical procedures in Brazil, set aside for outpatients or inpatients. Data were collected for the entire country, for each month of years 2019, 2020 and 2021, for all the catalogued diagnostic imaging modalities (general radiography - XR, ultrasonography - US, computed tomography - CT, magnetic resonance imaging- MRI and nuclear medicine – NM). Dental radiology, dual-energy X-ray absorptiometry (DEXA) and mammography, which are listed by SUS among general radiography examinations, were considered as independent modalities. Interventional radiology procedures were not included in the study. Imaging procedures for each modality were grouped according to imaged body part or specific type of examination. Chest CT scans were also grouped by patient care location (inpatient, elective or emergency, which also includes accidents and other types of lesions) and age (0–4, 5–9, 10–14, 15–19, 20–39, 40–59, 60–79 and 80 years or more).

The monthly number of new COVID-19 cases in Brazil was obtained by the adding the daily new cases in each month, as reported by the Our World in Data website [24].

Changes in the annual or monthly number of examinations in 2020 or 2021, relative to 2019 were calculated as: (Nf - Ni)/Ni, where Ni and Nf were the number of examinations in 2019 and 2020 or 2021, respectively.

Z-test for two proportions (pooled version) was used to assess the statistical significance of the differences between monthly and annual proportions of imaging examinations in 2019 compared to 2020 or 2021 across different modalities, patient care locations, and patient age. The monthly or annual proportion of each type of examination was defined as the rate of examinations per SUS dependent population, namely the Brazilian population that depends only on SUS for healthcare services [28]. Statistical significance was considered for P values <0.05 (two--tailed). All analyses were performed using Excel (Microsoft Inc).

Results

Table 1 shows the annual numbers of diagnostic imaging examinations across different modalities in SUS, in the years 2019, 2020, and 2021, and the relative variations in the periods 2019–2020 and 2019–2021. Data are shown separately for outpatients and inpatients. Almost all types of examinations across different modalities had lower volumes of use in 2020, compared to 2019, in both patient care locations. Decreases were greater in the outpatient setting, in which there were around 20.5 million fewer procedures performed in SUS in 2020 compared to 2019, while in 2021 this deficit was around 7.2 million examinations. In contrast, in 2021, the volume of most types of diagnostic imaging examinations has returned to pre-pandemic or even higher levels in the inpatient setting, except mainly for nuclear medicine procedures. The only modality for which annual use increased in both 2020 and 2021, compared to 2019, was CT, with chest CT standing out as the type of examination with the greatest increases in both outpatients and inpatients.

In the first two months of 2020, the number of outpatient examinations in each diagnostic imaging modality tended to be similar or even slightly higher than it was in 2019 (Fig. 1A). This scenario markedly changed in March-April 2020, when there was a great decrease in the volume of all diagnostic imaging modalities, at the same time as the COVID-19 pandemic began to worsen in Brazil. In April 2020, the monthly numbers of XR, US, CT, MRI, and NM outpatient examinations were around 49%, 66%, 25%, 51%, and 57% lower than in the same month in 2019. Dental X-rays, DEXA, and mammography were the modalities with the greatest relative monthly decreases (89%, 74%, and 79%, respectively). These relative differences gradually narrowed over the following months, but another drop in the use of most diagnostic imaging modalities occurred by the end of 2020, accompanying the second wave of the pandemic in Brazil. However, by the end of 2021, the volume of exams among SUS outpatients has returned to levels of the pre-pandemic period for most modalities. In sharp contrast, the decrease in the overall number of CT scans among SUS outpatients in March/April 2020 was smaller. The use of this imaging modality significantly increased in the following months, but there were some periods of decreasing trends closely accompanying the decreases in COVID-19 incidence.

A drop in the monthly usage of most imaging modalities – except CT – was also observed in the inpatient setting (Fig. 1B), mainly in April 2020 (-16%, -21%, -16%, and -43%, respectively, for XR, US, CT, MRI,

Table 1
Annual number of diagnostic imaging examinations (N) stratified by imaging modality and type of procedure (or imaged body part) in 2019, 2020, and 2021, and the relative changes in 2020 and 2021, compared to 2019 (%).

Table 1: Annual number of diagnostic imaging examinations (N) stratified by imaging modality and type of procedure (or imaged body part) in 2019, 2020, and 2021, and the relative changes in 2020 and 2021, compared to 2019 (%).

	SUS OUTPATIENTS					SUS INPATIENTS				
	N			change		N			change	
PROCEDURE	2019	2020	2021	2019-2020	2019-2021	2019	2020	2021	2019-2020	2019-2021
General radiography (XR)	**56,164,111**	**44,307,831**	**49,032,802**	**-21.1%**	**-12.7%**	**6,938,064**	**6,714,401**	**7,421,136**	**-3.2%**	**7.0%**
Extremities or joints	23,595,955	18,983,525	21,778,221	-19.5%	-7.7%	1,368,271	1,326,107	1,392,934	-3.1%	1.8%
Chest	18,771,250	15,060,765	16,112,094	-19.8%	-14.2%	4,692,410	4,528,035	5,112,436	-3.5%	9.0%
Chest AP	9,396,013	6,980,115	7,768,519	-25.7%	-17.3%	3,454,323	3,418,167	3,972,894	-1.0%	15.0%
Chest AP + LAT	7,834,839	6,918,664	7,033,987	-11.7%	-10.2%	1,108,780	946,170	963,988	-14.7%	-13.1%
Spine	5,791,670	3,918,648	4,589,989	-32.3%	-20.7%	92,370	74,079	67,444	-19.8%	-27.0%
Abdomen/pelvis	4,005,916	3,711,359	3,945,852	-7.4%	-1.5%	718,717	738,008	802,670	2.7%	11.7%
Head/neck	3,992,839	2,629,674	2,601,972	-34.1%	-34.8%	64,377	46,881	44,220	-27.2%	-31.3%
Other	6,481	3,860	4,674	-40.4%	-27.9%	1,909	1,291	1,432	-32.4%	-25.0%
Ultrasonography (US)	**19,417,264**	**14,334,061**	**18,293,216**	**-26.2%**	**-5.8%**	**2,180,403**	**2,044,690**	**2,233,129**	**-6.2%**	**2.4%**
Abdomen	3,258,481	2,210,362	2,767,230	-32.2%	-15.1%	455,263	375,299	382,993	-17.6%	-15.9%
Transvaginal	3,043,269	2,203,104	2,819,140	-27.6%	-7.4%	73,547	68,578	69,584	-6.8%	-5.4%
Obstetric	2,514,560	2,300,238	2,445,983	-8.5%	-2.7%	385,836	373,718	393,039	-3.1%	1.9%
Urinary system/prostate	1,694,763	1,292,819	1,643,252	-23.7%	-3.0%	184,891	172,434	186,848	-6.7%	1.1%
Joints	1,642,751	1,143,052	1,566,718	-30.4%	-4.6%	33,114	31,049	36,052	-6.2%	8.9%
Vascular color doppler	1,594,229	1,215,003	1,629,333	-23.8%	2.2%	322,992	317,740	378,767	-1.6%	17.3%
Echocardiogram	1,577,282	1,123,306	1,445,549	-28.8%	-8.4%	545,647	538,996	606,723	-1.2%	11.2%
Transthoracic echocardiography	1,534,525	1,093,538	1,406,266	-28.7%	-8.4%	525,600	522,061	584,537	-0.7%	11.2%
Breast (bilateral)	1,407,064	1,005,092	1,302,966	-28.6%	-7.4%	6,540	5,719	6,356	-12.6%	-2.8% *
Corneal pachymetry	1,242,596	881,363	1,323,778	-29.1%	6.5%	---	---	---	---	---
Other	1,442,269	959,722	1,331,912	-33.5%	-7.7%	172,573	161,157	172,767	-6.6%	**0.1%** *
Computed tomography (CT)	**5,961,415**	**6,332,359**	**7,899,360**	**6.2%**	**32.5%**	**2,180,093**	**2,725,569**	**3,299,578**	**25.0%**	**51.4%**
Abdomen/pelvis	2,166,313	2,193,062	2,691,423	1.2%	24.2%	828,074	904,763	1,021,954	9.3%	23.4%
Head/neck	2,069,711	1,798,320	2,016,315	-13.1%	-2.6%	771,341	786,207	884,209	1.9%	14.6%
Chest	891,569	1,608,528	2,172,665	80.4%	143.7%	379,424	813,591	1,142,241	114.4%	201.0%
Spine	633,118	545,415	698,389	-13.9%	10.3%	127,157	132,630	150,293	4.3%	18.2%
Extremities	176,973	163,809	204,421	-7.4%	15.5%	72,113	80,766	92,875	12.0%	28.8%
Other	23,731	23,225	26,147	-2.1%	10.2%	1,984	7,612	8,006	283.7%	303.5%
Magnetic resonance imaging (MRI)	**1,411,701**	**1,197,276**	**1,490,023**	**-15.2%**	**5.5%**	**167,587**	**165,522**	**182,569**	**-1.2%**	**8.9%**
Spine	495,683	404,954	501,012	-18.3%	1.1%	40,458	38,157	43,543	-5.7%	7.6%
Head	332,642	271,726	337,121	-18.3%	1.3%	75,747	72,013	77,367	-4.9%	2.1%
Skull	284,780	232,711	287,839	-18.3%	1.1%	64,314	61,657	66,735	-4.1%	3.8%
Limbs	332,373	272,881	327,149	-17.9%	-1.6%	8,244	8,003	8,990	-2.9% *	9.0%
Abdomen	229,633	226,626	289,424	-1.3%	26.0%	39,426	43,606	47,735	10.6%	21.1%
Chest	21,370	21,089	26,317	-1.3% *	23.1%	3,712	3,743	4,934	0.8% *	32.9%
Nuclear Medicine (NM)	**459,352**	**361,889**	**405,752**	**-21.2%**	**-11.7%**	**20,400**	**15,201**	**14,075**	**-25.5%**	**-31.0%**
Heart	263,071	198,097	223,648	-24.7%	-15.0%	8,613	5,811	5,293	-32.5%	-38.5%
Myocardial perfusion scintigraphy	258,373	193,596	218,458	-25.1%	-15.4%	7,836	5,355	4,851	-31.7%	-38.1%
Bone or extremities	139,337	125,412	138,424	-10.0%	-0.7% *	4,823	3,988	3,733	-17.3%	-22.6%
Full body scintigraphy	128,531	115,713	128,823	-10.0%	0.2% *	4,270	3,351	3,114	-21.5%	-27.1%
Kidney scintigraphy	27,927	19,086	22,251	-31.7%	-20.3%	990	728	768	-26.5%	-22.4%
Other	29,017	19,294	21,429	-33.5%	-26.2%	5,974	4,674	4,281	-21.8%	-28.3%
Dental radiology	**2,879,648**	**894,628**	**1,139,341**	**-68.9%**	**-60.4%**	---	---	---	---	---
Dual-energy X-ray absorptiometry (DEXA	**568,077**	**389,035**	**487,772**	**-31.5%**	**-14.1%**	---	---	---	---	---
Mammography	**4,182,881**	**2,539,612**	**3,468,050**	**-39.3%**	**-17.1%**	---	---	---	---	---
Mammography (bilateral screening)	3,811,460	2,245,599	3,119,802	-41.1%	-18.1%	---	---	---	---	---
ALL EXAMINATIONS	**91,044,449**	**70,356,691**	**82,216,316**	**-22.7%**	**-9.7%**	**11,486,547**	**11,665,383**	**13,150,487**	**1.6%**	**14.5%**

a. All changes between 2019 and 2020 or 2021 are statistically significant ($p<0.05$) except when marked with (*).

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and NM, compared to April 2019). However, these decreases were much lower than among outpatients and there was a rapid return to the pre-pandemic or higher volumes of examinations. Furthermore, the use of most imaging modalities in this setting slightly increased by the end of 2020, accompanying a great increase in the number of COVID-19 cases in Brazil. However, the monthly volume of most types of procedures in this setting slightly dropped from mid-2021 onwards following a similar downward trend in COVID-19 incidence. By the end of 2021 the monthly number of examinations of most imaging modalities among inpatients has returned to levels similar to those of the pre-pandemic period. CT use, in contrast, remained at levels higher than in 2019.

Fig. 2A shows the variation in the monthly number of CT examinations of different body parts among SUS outpatients in the years 2019–2021. There was a drop in the monthly number of CT scans of almost all parts of the body when COVID-19 cases began to rise up in Brazil, in April 2020 (-27%, -41%, -49%, and -41% for the abdomen/pelvis, head/neck, spine, and extremities, respectively, compared to 2019). This decline was soon reversed by an increasing trend in outpatient CT examinations of all body parts over the following months, although there were also some periods of decreasing use. In contrast, the use of chest CT scans greatly increased from March 2020 up to mid-2021, when it significantly decreased. Monthly variations in the number of CT scans for inpatients are shown in Fig. 2B. For all body parts, except the chest, there was only a subtle reduction in the relative number of CT scans in 2020, most pronounced in April, which was soon reversed to levels similar or slightly higher than those of 2019. In contrast, the use of chest CT greatly increased from February-March 2020 onwards in this patient group, being around 4.3-fold higher in March 2021 than in the same month in 2019. However, inpatient use of chest CT decreased in the second semester of 2021, but by the end of the year it was still around 2-fold higher than in 2019.

The use of chest CT scans among SUS patients remained relatively stable over 2019 in elective, emergency and inpatient settings (Fig. 3). In contrast, these examinations greatly increased from March 2020 onwards for all three categories. Changes over the study period closely correlates with COVID-19 incidence in Brazil and were not very different

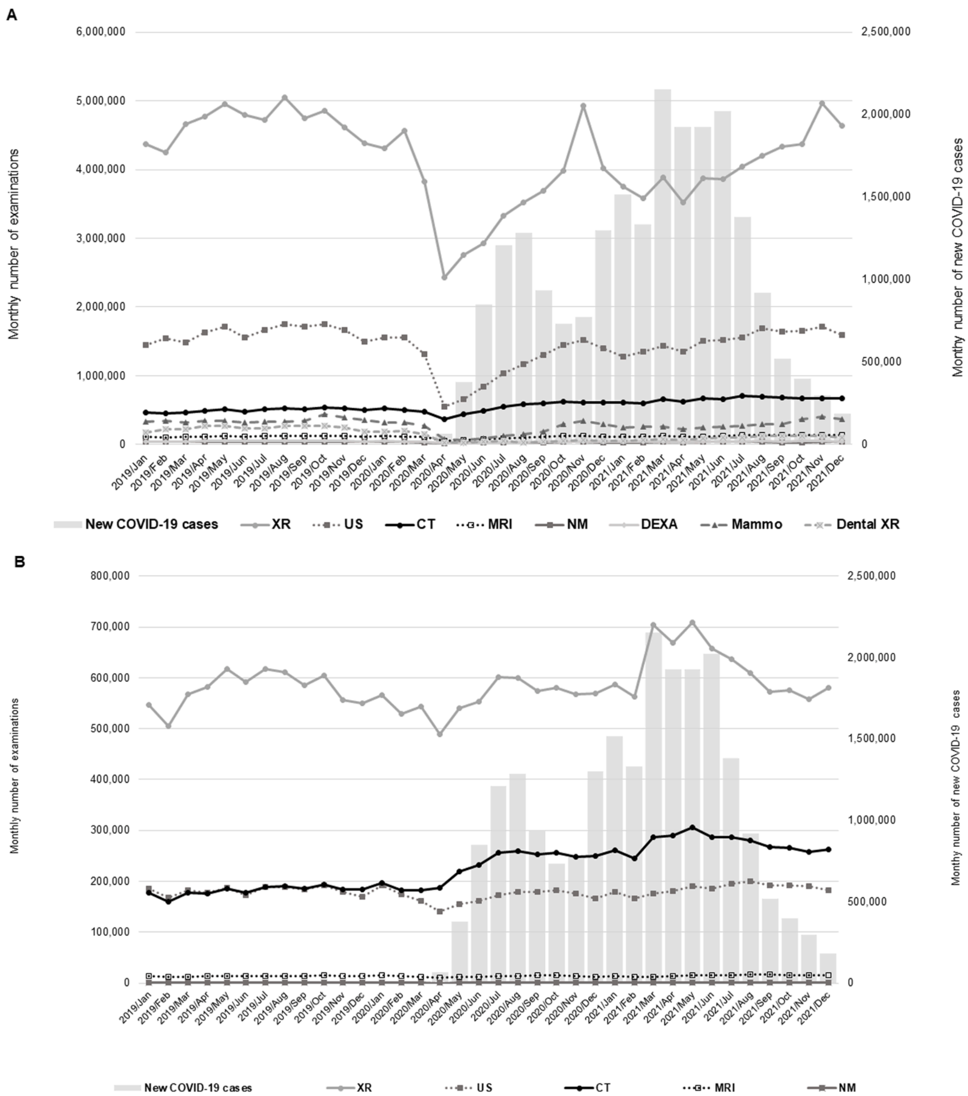

Fig. 1. Monthly number of diagnostic imaging examinations among SUS outpatients **(A)** and inpatients **(B)** in the years 2019, 2020 and 2021, according to imaging modality. XR: general radiography, US: ultrasonography; CT: computed tomography; MRI: magnetic resonance imaging; NM: nuclear medicine; DEXA: dual-energy X-ray absorptiometry.

among patient care locations. Most chest CT scans were done in the outpatient setting all over the study period, but the greatest relative increase was in the emergency setting, in which the number of chest CT scans increased by around 6.9-fold between March 2019 and March 2021.

The increased use of elective chest CT examinations in 2020 and 2021, compared to 2019, was observed for all age groups of SUS outpatients (Table 2). The greatest relative increase was for patients aged 20–39 years (almost 3-fold between 2019 and 2021). Increases were lower but significant in children and young adults (around 41%, 36%, 71% and 116% for the groups aged $\leq$ 4, 5–9, 10–14 and 15–19 years, respectively, between 2019 and 2021).

Discussion

Our study showed a large reduction in the use of most types of diagnostic imaging examinations in SUS in 2020, compared to 2019. More than 20 million fewer procedures were done among SUS outpatients in 2020. In 2021 the deficit was smaller, but reached around 9 million fewer examinations than in 2019. In the inpatient setting, there was also a significant drop in 2020, smaller than among outpatients, which was completely reversed in 2021 for most types of examinations. The main exception was CT, for which use greatly increased in all patient care locations, driven mainly by the rise in the numbers of chest CT scans in all patient age groups. The changes in diagnostic imaging use in SUS started around March-April 2020, when the COVID-19 pandemic began to worsen in Brazil, and tended to correlate to COVID-19 incidence in Brazil over the following months [24, 25].

Decreases in the use of healthcare services during the COVID-19 pandemic have been well documented [6]. Diagnostic medical imaging was one of the most affected areas. As expected, outpatient procedures, used primarily for non-urgent routine indications, were the most affected during the pandemic, while emergency and inpatient examinations that generally cannot be postponed were less affected. Naidich *et al.* [10] showed a 24.8% reduction in outpatient imaging in the first 16 weeks of 2020 in a large healthcare system in the United States, while in the inpatient setting this reduction was around 4.2%. Maximum decrease rates were 94% for mammography, 85% for NM, 74% for MRI, 64% for US, 46% for CT and 22% for XR, in week 16. Parikh *et al.* [11] evaluated imaging use in an integrated healthcare system of over 150 locations in the United States. Outpatient and inpatient volumes had maximum decreases of 68% and 31%, respectively, while emergency procedures decreased by 48%, compared to normal practice. Mammography was the most affected modality, with a 93% decrease

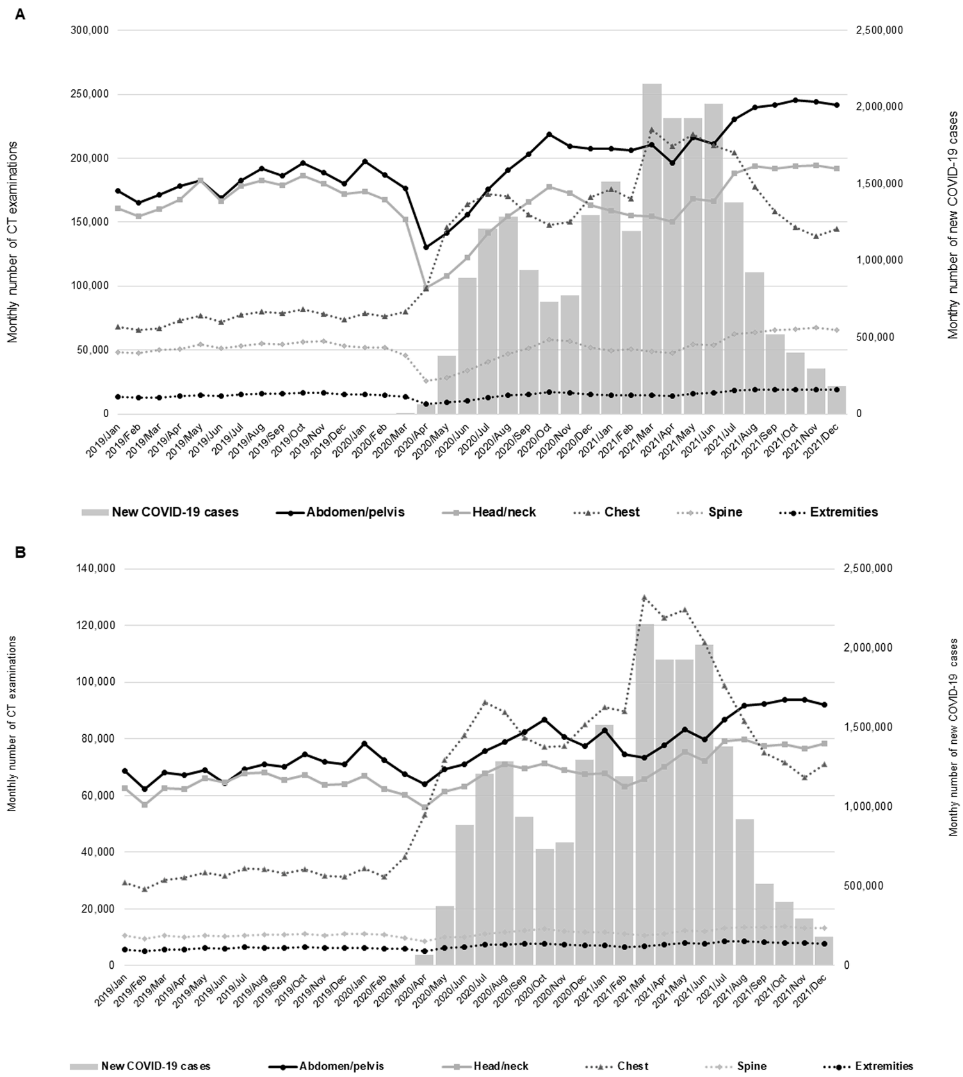

Fig. 2. Monthly number of CT examinations among SUS outpatients **(A)** and inpatients **(B)** in the years 2019, 2020 and 2021, according to imaged body part.

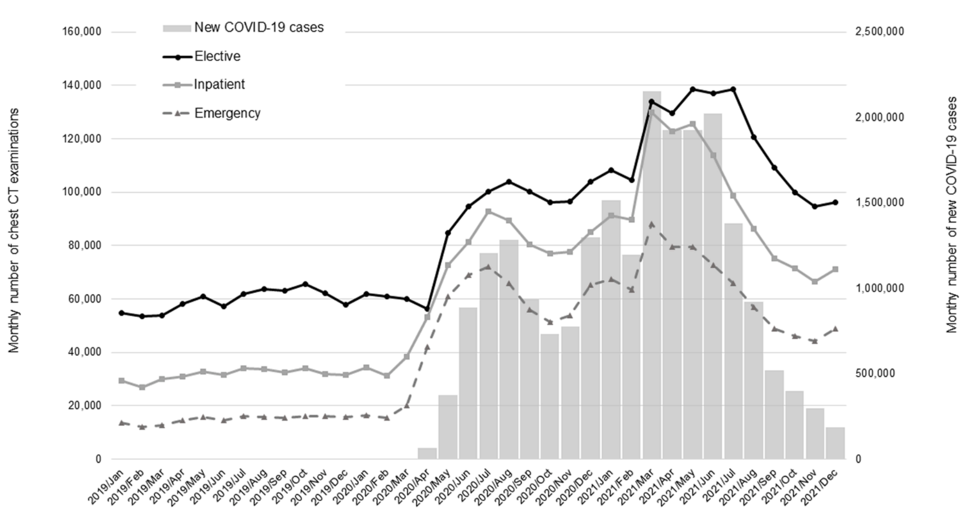

Fig. 3. Monthly numbers of chest CT examinations among SUS outpatients in the years 2019, 2020 and 2021 according to patient care location.

between April 10th and 16th. NM decreased by 61%, MRI by 56%, US by 58%, CT by 47% and XR by 53%. Also in the United States, Doshi et al. [12] focused on the impact of the COVID-19 pandemic on outpatient imaging in a large, multicenter metropolitan healthcare system. Decreases were 88% for XR, 75% for CT, 73% for MRI, 80% for US, 90% for DEXA, and 85% for mammography. Direct comparison of these studies

Table 2
Monthly number of elective chest CT examinations among SUS outpatients in 2019, 2020 and 2021 according to patient age, and the relative change to 2019 (%).

Age	Year	Month January	February	March	April	May	June	July	August	September	October	November	December	All months
≤ 4	2019	397	347	349	398	441	399	454	402	368	371	381	334	4641
	2020	358	301	327	323	302	352	448	489	469	480	437	473	4759
	change (%)	-9.8%*	-13.3%*	-6.3%*	-18.8%	-31.5%	-11.8%*	-1.3%*	21.6%	27.4%	29.4%	14.7%*	41.6%	2.5%*
	2021	517	461	615	553	585	533	549	574	521	492	565	589	6554
	change (%)	30.2%	32.9%	76.2%	38.9%	32.7%	33.6%	20.9%	42.8%	41.6%	32.6%	48.3%	76.3%	41.2%
5–9	2019	285	299	277	342	352	307	337	355	321	323	339	282	3819
	2020	300	230	284	229	300	335	399	492	454	402	388	381	4194
	change (%)	5.3%*	-23.1%	2.5%*	-33.0%	-14.8%	9.1%*	18.4%	38.6%	41.4%	24.5%	14.5%*	35.1%	9.8%
	2021	456	368	464	384	484	435	447	434	438	410	432	425	5177
	change (%)	60.0%	23.1%	67.5%	12.3%*	37.5%	41.7%	32.6%	22.3%	36.4%	26.9%	27.4%	50.7%	35.6%
10–14	2019	385	404	398	428	423	412	466	462	440	444	400	394	5056
	2020	430	382	377	293	456	546	665	686	631	651	600	635	6352
	change (%)	11.7%*	-5.4%*	-5.3%*	-31.5%	7.8%*	32.5%	42.7%	48.5%	43.4%	46.6%	50.0%	61.2%	25.6%
	2021	676	610	731	695	806	794	803	777	713	654	675	689	8623
	change (%)	75.6%	51.0%	83.7%	62.4%	90.5%	92.7%	72.3%	68.2%	62.0%	47.3%	68.8%	74.9%	70.5%
15–19	2019	783	735	769	741	755	699	748	778	764	821	771	678	9042
	2020	723	709	774	640	1090	1355	1492	1529	1410	1365	1333	1409	13,829
	change (%)	-7.7%*	-3.5%*	0.7%*	-13.6%	44.4%	93.8%	99.5%	96.5%	84.6%	66.3%	72.9%	107.8%	52.9%
	2021	1523	1356	1644	1692	1956	1934	2099	1730	1552	1422	1364	1271	19,543
	change (%)	94.5%	84.5%	113.8%	128.3%	159.1%	176.7%	180.6%	122.4%	103.1%	73.2%	76.9%	87.5%	116.1%
20–39	2019	6240	5841	6037	6530	6764	6165	6792	6909	6920	7226	6821	6209	78,454
	2020	6559	6565	7065	9357	17,627	19,054	18,807	18,956	16,694	14,665	14,756	16,930	1,67,035
	change (%)	5.1%	12.4%	17.0%	43.3%	160.6%	209.1%	176.9%	174.4%	141.2%	102.9%	116.3%	172.7%	112.9%
	2021	18,098	16,113	22,955	22,573	25,062	25,637	24,839	19,538	15,460	13,175	11,814	12,331	2,27,595
	change (%)	190.0%	175.9%	280.2%	245.7%	270.5%	315.8%	265.7%	182.8%	123.4%	82.3%	73.2%	98.6%	190.1%
40–59	2019	19,366	19,223	19,180	20,773	21,555	20,356	21,971	22,809	22,344	23,273	22,040	20,633	2,53,523
	2020	21,749	21,514	21,472	21,478	33,237	36,265	37,283	38,251	36,401	34,446	34,681	37,994	3,74,771
	change (%)	12.3%	11.9%	11.9%	3.4%	54.2%	78.2%	69.7%	67.7%	62.9%	48.0%	57.4%	84.1%	47.8%
	2021	39,414	37,579	50,496	50,307	54,947	55,249	52,901	43,159	38,735	35,417	33,020	33,096	5,24,320
	change (%)	103.5%	95.5%	163.3%	142.2%	154.9%	171.4%	140.8%	89.2%	73.4%	52.2%	49.8%	60.4%	106.8%
60–79	2019	23,898	23,481	23,565	25,388	26,786	25,316	27,111	28,238	27,903	29,021	27,543	25,644	3,13,894
	2020	27,901	27,387	26,125	20,975	27,676	31,469	35,041	37,059	37,598	37,837	37,766	39,456	3,86,290
	change (%)	16.8%	16.6%	10.9%	-17.4%	3.3%	24.3%	29.3%	31.2%	34.7%	30.4%	37.1%	53.9%	23.1%
	2021	40,561	41,012	49,010	46,407	47,281	44,727	48,442	46,129	43,959	41,369	40,089	40,707	5,29,693
	change (%)	69.7%	74.7%	108.0%	82.8%	76.5%	76.7%	78.7%	63.4%	57.5%	42.5%	45.6%	58.7%	68.7%
≥ 80	2019	3284	3307	3318	3617	3849	3652	3848	3931	3942	4192	3889	3556	44,385
	2020	3995	3829	3738	2926	4172	5287	5963	6563	6488	6382	6398	6736	62,477
	change (%)	21.7%	15.8%	12.7%	-19.1%	8.4%	44.8%	55.0%	67.0%	64.6%	52.2%	64.5%	89.4%	40.8%
	2021	7051	7174	7926	7038	7562	7765	8411	8375	7903	6986	6647	7035	89,873
	change (%)	114.7%	116.9%	138.9%	94.6%	96.5%	112.6%	118.6%	113.1%	100.5%	66.7%	70.9%	97.8%	102.5%
All ages	**2019**	54,638	53,637	53,893	58,217	60,925	57,306	61,727	63,884	63,002	65,671	62,184	57,730	7,12,814
	2020	62,015	60,917	60,162	56,221	84,860	94,663	1,00,098	1,04,025	1,00,145	96,228	96,359	1,04,014	10,19,707
	change (%)	13.5%	13.6%	11.6%	-3.4%	39.3%	65.2%	62.2%	62.8%	59.0%	46.5%	55.0%	80.2%	43.1%
	2021	1,08,296	1,04,673	1,33,841	1,29,649	1,38,683	1,37,074	1,38,491	1,20,716	1,09,281	99,925	94,606	96,143	14,11,378
	change (%)	98.2%	95.2%	148.3%	122.7%	127.6%	139.2%	124.4%	89.0%	73.5%	52.2%	52.1%	66.5%	98.0%

All changes between 2019 and 2020 or 2021 are statistically significant ($p<0.05$) except when marked with (*).

with ours is hampered by methodological differences. We analyzed elective and emergency examinations grouped as outpatient procedures and assessed monthly changes throughout 2020 and 2021, while the mentioned authors used different grouping of examinations and timeframes. In addition, different countries may have distinct healthcare organization and were not similarly affected by the pandemic. Nevertheless, all these studies reported that the volumes of imaging began to decline in March with maximum decreases around April 2020. Furthermore, maximum decreases in the monthly number of examinations among SUS outpatients in 2020 were not dissimilar from those reported in the United States.

Data on the use of diagnostic imaging examinations in the last months of 2020 and throughout 2021 are scarce, but largely compatible with ours. Fleckenstein *at al.* showed the severe effect of COVID-19 pandemic and related shutdown measures on overall provided medical care in Germany in the years 2020/2021, when the number of radiological examinations decreased significantly as compared to baseline data from 2018/19 [29]. Graham et al. reported that the COVID-19 pandemic continued to influence the volumes of nuclear medicine examinations across Europe in 2021 [30]. Also, a study from by the International Atomic Energy Agency reported that cardiac diagnostic testing did not rebound to pre-pandemic levels by April 2021, mainly in lower middle- and low-income countries [31].

The decrease in the volumes of diagnostic imaging examinations raises concerns about the potential future adverse health outcomes due to potential delays in the diagnosis and management of a number of diseases. In particular, delayed diagnosis of cancer may result in the loss of detection of early-stage tumors, increasing the risk of progression from curable to non-curable disease and increasing the potential future number of deaths. Mammography, CT, MRI, NM and US are routinely used as a direct or complementary modality for the diagnosis of a number of tumors, including breast, lung, thyroid and prostate. Actually, the average number of cancer diagnoses has dropped considerably since the pandemic period started in many countries, including Brazil [32]. One area that deserves special attention is breast cancer screening, as impressive decreases in the number of mammograms has been reported by many studies, leading to estimates of 7.9% to 9.6% increased deaths from breast cancer due to a 1-year delay in England [33]. In SUS, the use of mammography decreased by more than 80% in April and May 2020, compared to 2019. Although part of this drop was gradually reversed in the following months, by the end of 2021 the number of mammographic tests in SUS had not returned to previous levels. As a result, more than 1.6 and 0.7 million breast cancer screening exams left to be done in SUS in 2020 and 2021, respectively, compared to 2019. If we consider detection rates of 4.7 per 1000 examinations [34], this means that more than 10,000 breast cancer cases may not have been properly detected in SUS in 2020 and 2021. This scenario may be even worse if we consider a similar drop in mammograms paid by health plans and insurance in Brazil (supplementary healthcare system, SHS), in which another around 1.4 and 0.5 million exams were not done in 2020 and 2021, respectively, compared to 2019 (data not shown, available at https://www.gov.br/ans/pt-br/acesso-a-informacao/perfil-do-setor/dados-e-indicadores-do-setor).

Diagnostic imaging examinations have also crucial role in the diagnosis and management of many other health conditions, including cardiac illnesses. The impact of COVID-19 on heart disease is complex. Emergency admissions decreased during the worst months of the pandemic [35], while out-of-hospital cardiac arrests increased [36]. The overall impact appears to have been an increase in deaths from ischemic heart disease and hypertensive disease, most notably in areas worst hit by the pandemic [35, 37]. The 50–70% decrease in the number of cardiac imaging procedures and fluoroscopically guided cardiac interventions observed in Europe and the United States [38, 39] is similar to the decrease in transthoracic echocardiography and myocardial nuclear medicine procedures in Brazil between April 2019 and April 2020 (data on other procedures were unavailable). The associated delay in diagnosis and treatment likely contributed to increased heart disease mortality, although it is difficult to disentangle reduced imaging from other factors, including the impact of COVID-19 itself on the heart and reduce access to non-radiological procedures. Assuming the incidence of congenital heart disease (CHD) has remained unchanged, we can assume the decrease in cardiac x-ray imaging and interventions has led to a backlog of untreated conditions such as atrial septal defects and coarctations. Future research is required to determine the impact on CHD mortality and morbidity. Strategies to overcome the delays caused by the COVID-19 pandemic in the diagnosis and treatment of various health conditions are urgently needed. This may include efforts to prioritize needs and expansion of diagnostic imaging capabilities. In addition, the development of guidelines to prepare the Brazilian health system during and after crises in the health system are essential to mitigate future impacts.

While decreases in the use of all diagnostic imaging modalities during the COVID-19 pandemic were largely reported, we and other authors observed increased use of CT, driven mainly by chest scans. Naidich et al. [13] showed that chest CT angiography increased among inpatients in a large healthcare system in the US in the first 16 weeks of 2020. Increased chest CT use in accordance with the local epidemic spreading was also reported in French [14] and Italian [16] radiological centers and by other authors in Brazil [15]. The increased use of chest CT during the COVID-19 pandemic is not unforeseen as the severe forms of the disease are largely associated to the extent of pulmonary involvement and chest CT has a recognized role in assessing severity and progression of the disease. Accordingly, the volumes of chest CT use in SUS closely tracked COVID-19 incidence in Brazil. The greater increase was in the emergency setting, followed by inpatient use. Nevertheless, the volume of elective chest CT examinations also greatly increased in the study period, suggesting it use for diagnosis purposes. The use of chest CT in the diagnosis of COVID-19 is controversial. Guidelines recommended against the use of chest scans for routine COVID-19 diagnostic of asymptomatic individual, because findings were considered non-specific, and normal CT imaging does not rule out the infection. CT scans are also not indicated for patients with mild features of COVID-19 unless they are at risk for disease progression. However, CT scanning provides faster results than the reverse-transcription polymerase chain reaction (RT-PCR), which is considered the gold standard diagnostic test for COVID-19. In addition, CT scans may be more readily available in some settings, allowing for rapid screening of patients particularly when COVID-19 non-imaging tests are limited [40, 41].

Even though the benefits of CT imaging in the diagnosis and management of a number of conditions are largely recognized, exposure to ionizing radiation during CT scans is associated with potential increased risk of subsequent cancer development [19–23]. As a result, the balance between the need for a CT scan and the associated risks must be considered (justification). Moreover, when properly justified, CT scanning protocols must be optimized to minimize patient radiation doses and risks. It has been proposed that chest CT of patients with suspected or confirmed COVID-19 should preferentially be performed using a single-phase, non-contrast, low-dose protocol, which are able to show most pulmonary opacities in COVID-19 associated pneumonia with lower risk than standard CT scans [40, 41]. We did not address chest CT indications or the selected protocols and associated doses. Notwithstanding, a study conducted by the International Atomic Energy Agency (IAEA) showed wide variation on CT use, imaging protocols and doses among patients with COVID-19 pneumonia across healthcare sites in 34 countries. Many services used CT as the preferred testing method, and multiphase chest CT scans in COVID-19 patients were not uncommon. Importantly, CT dose index (CTDI) varied 8 to 10-fold across the participating health care sites, suggesting the lack of optimization of these procedures. In addition, multiple chest CT examinations leading to increased cumulative doses among COVID-19 patients was reported [22].

Radiation associated risks are greater among the young, who have a higher sensitivity to the effects of radiation and longer life expectancy allowing for cancer to develop. In addition, children may receive radiation doses above the necessary if scans protocols are not properly adjusted for their smaller body size [23]. The distribution of chest CT scans according to patient age was not available for the SUS inpatient setting. Among outpatients, all age groups had more elective chest CT scans in 2020 and 2021 than in 2019. The largest increase was among patients aged 20–39 years. The risk of COVID-19 symptomatic disease, hospitalization and death increases with increasing patient age. Respiratory symptoms are not uncommon among the elderly, requiring frequent chest CT scans to monitor pulmonary changes. Conversely, children and young adults are usually asymptomatic or show milder symptoms, rarely demanding follow-up examinations [42]. The increased use of elective chest CT across all age groups in the outpatient setting in SUS may reflect the use of this examinations for diagnostic purposes and not in response to clinical worsening. This scenario may be at least partially driven by the limited availability of non-imaging tests in Brazil [25], at least in the first months of the pandemic onset. However, CT findings in pediatric COVID-19 are nonspecific and not helpful in differentiating SARS-CoV-2 infection from other childhood lower respiratory tract infections [42]. Even though radiation burden is not the main factor to be considered for determining the role of imaging in COVID-19 diagnosis and management, it should be taken into account. Estimates of the radiation doses delivered by pediatric chest CT scans in SUS are needed for a proper risk-benefit assessment of these examinations. Furthermore, it would be helpful to establish national guidelines to reduce the frequency of unnecessary CT and to help to optimize scan protocols in Brazil.

This study has a number of limitations. First, we did not investigate changes across different geographic regions across the country. Brazil is very large and shows great inequalities in the quantity and quality of health resources [26]. In addition, there were variations in the temporal and regional spread of the COVID-19 pandemic across the country and restrictive measures were imposed and relaxed at different moments in different regions [25]. Our analysis also did not include examinations undergone out of SUS. The SHS, although accessible to only 25% of the Brazilian population, has around half of the imaging machines, and may account for a similar or even greater annual number of imaging examinations than those carried out in SUS [26, 28, 43]. Notwithstanding, the use of diagnostic imaging in the SHS was also greatly affected by the pandemic (data not shown, available at https://www.gov.br/ans/pt-br/acesso-a-informacao/perfil-do-setor/dados-e-indicadores-do-setor). Another limitation is that our analysis focused on monthly changes and may not have detected variations within each month. In addition, we did not consider the impact of differences in the number of days in each month or the seasonality in the demand for healthcare, although our results suggest that these factors were not a major influence.

Our study has also many strengths. To our knowledge, no studies have assessed the impact of the COVID-19 pandemic on the use of diagnostic imaging examinations in such a large healthcare system as SUS. In addition, we analyzed the changes throughout the whole year 2020 and 2021. Conversely, most published studies relied on smaller local healthcare systems and focused on the first weeks of the pandemic, not describing long-term trends. Furthermore, we investigated changes by type of examination across different imaging modalities and both in the outpatient and inpatient care locations. Changes in the use of elective outpatient chest CT were also analyzed by patient age. Finally, this seems to be the first study addressing the impact of COVID-19 in imaging use in a LMIC country, in which imaging use and the impact of the pandemic may differ from developed countries. The real-world data on the use of radiological imaging in the COVID-19 pandemic here presented may help Brazilian health authorities and medical organizations in the planning of actions to alleviate the potential adverse health effects of the observed changes as well as to develop policies to improve the use of diagnostic tests in the future, both during and beyond pandemics.

Conclusions

The COVID-19 pandemic had a strong impact on the use of diagnostic imaging examinations in SUS. The great drop in the number of various types of diagnostic imaging procedures in 2020 and 2021 compared to 2019 could potentially lead to worsening health outcomes in Brazil in the coming years. On the other hand, the large and lasting increase in the use of chest CT scans raises concerns about the potential increased risks of radiation-induced cancer.

Ethical approval

Not required.

Patient consent

Not required.

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Declaration of Competing Interest

The authors declare that there are no conflicts of interest related to this study.

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