

The Impact of the COVID-19 Pandemic on a Nuclear Medicine Department in Riyadh, Saudi Arabia

Layal K Jambi¹, Fahad Almutairi², Abdulrahman Saeed Alotaibi², Aliyah K Alshaya¹, Ohoud M Alharbi¹, AlShoug O Alqahtani¹, Wadha Alyami¹, Hanan M Alyafei¹, Abdulrahman Alhawass³

¹Radiological Sciences Department, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia; ²Radiology and Medical Imaging Department, King Saud University Medical City, Riyadh, Saudi Arabia; ³Radiology and Medical Imaging Department, College of Medicine, Riyadh, Saudi Arabia

Correspondence: Layal K Jambi, Radiological Sciences Department, College of Applied Medical Sciences, King Saud University, P.O. Box 145111, Riyadh, 4545, Saudi Arabia, Tel +966553101005, Email Ljambi@ksu.edu.sa

Introduction: The Coronavirus disease (COVID-19) pandemic which is an infectious disease caused by the SARS-CoV-2 virus had a profound impact on healthcare services worldwide, including the field of nuclear medicine. Understanding these effects is essential to optimize service delivery and patient management during future health crises.

Purpose: This study aimed to assess the trends, demographic patterns, and pandemic-related impacts on diagnostic nuclear medicine procedures over four years at King Saud University Medical City (KSUMC), Riyadh, Saudi Arabia.

Methods: A retrospective analysis was conducted on four years of data (2019–2022) from the Nuclear Medicine Department at King Saud University Medical City (KSUMC). The analysis included inpatients, outpatients, pre-admission, emergency cases, and business center outpatients. All diagnostic nuclear medicine procedures performed during this period were included, while therapeutic procedures were excluded. A total of 24,455 cases were reviewed, ensuring patient privacy through anonymous data collection.

Results: The study revealed a significant gender distribution, with female patients comprising 69.4% of the total sample. The most frequently performed procedure was DEXA (Dual-energy X-ray absorptiometry), followed by cardiac procedures and Positron Emission Tomography (PET) scans. Outpatient admissions accounted for 87.0% of the total, while inpatient admissions accounted for 11.5%. The number of outpatient visits decreased during the COVID-19 pandemic due to lockdown measures and patients' fear of visiting hospitals. Most procedures were conducted post-corona, with pre-corona procedures accounting for 38.6%. The pandemic also disrupted supply chains and distribution channels, impacting the availability of essential tracers like ^{99m}Tc/⁹⁹Mo and ¹³¹I.

Discussion: The study highlights the significant gender distribution in patient demographics and the impact of the COVID-19 pandemic on nuclear medicine procedures at a single center in Riyadh, Saudi Arabia. The decrease in outpatient visits during the pandemic emphasizes the need for improved healthcare utilization and patient behavior. The disruptions in the supply chain underscore the importance of ensuring a stable and reliable supply of essential tracers during similar health crises.

Keywords: COVID-19, pandemic, nuclear medicine, radiology, medical imaging

Introduction

Coronavirus Disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first identified in Wuhan, China, in December 2019. The virus rapidly spread across the globe and was declared a pandemic by the World Health Organization (WHO) in March 2020. By the end of 2023, more than 770 million confirmed cases and nearly 7 million deaths had been reported worldwide, with significant variation in mortality depending on geography, healthcare infrastructure, and population vulnerability.¹

The overall case fatality rate has been estimated at approximately 0.9–1.1%, but rates ranged from <0.3% in well-resourced healthcare systems to >3% in resource-limited regions. Cumulative attack rates exceeded 20,000 cases per

100,000 population in parts of Europe and the Americas, while repeated waves of infection were driven by emerging variants of concern such as Alpha, Delta, and Omicron, which strained healthcare resources and contributed to fluctuating incidence and hospitalization rates.¹

Although COVID-19 primarily presents as an acute respiratory illness, it is now widely recognized as a multisystem disease. Respiratory involvement remains central, with disease ranging from mild pneumonia to severe acute respiratory distress syndrome (ARDS), driven by alveolar injury, inflammatory cascades, and endothelial dysfunction, which may also lead to chronic pulmonary fibrosis in survivors.²

Beyond the lungs, COVID-19 affects the endocrine system via angiotensin-converting enzyme 2 (ACE2) receptor expression in endocrine tissues, resulting in complications such as thyroiditis, adrenal dysfunction, and poor glycemic control, particularly in individuals with pre-existing diabetes.³

The cardiovascular system is also affected, with myocarditis, arrhythmias, thromboembolic events, pericarditis, and heart failure reported, driven by direct viral injury, systemic inflammation, and hypercoagulability.⁴

Neurological complications include anosmia, ageusia, encephalitis, stroke, and peripheral neuropathies, reflecting viral neurotropism, systemic inflammation, and microvascular injury.⁵

In the Kingdom of Saudi Arabia (KSA), the first confirmed COVID-19 case was reported on March 2, 2020. By mid-April 2022, official records documented 752,188 confirmed cases and 9,062 deaths, although excess mortality estimates suggest a wider range of 14,000–99,000 deaths. Crude infection rates decreased from approximately 12 cases per 1,000 population in 2020–2021 to 3 cases per 1,000 in 2022–2023. The case fatality rate for March 2020–April 2022 was 1.21%, equating to 25.38 deaths per 100,000 population, among the lowest globally. Mortality risk factors included older age, male sex, diabetes, hypertension, and cardiovascular comorbidities.⁶

A seroprevalence study in July 2020 found that ~11% of the Saudi population had antibodies against SARS-CoV-2, with regional variation from 1.8% to 24.5%.⁶ The pandemic has had substantial consequences for medical imaging services worldwide, including nuclear medicine. Several international and regional surveys reported marked reductions in patient volumes and procedure availability due to lockdowns, patient hesitancy, and reallocation of healthcare resources.^{7–9}

In Saudi Arabia, Alelyani et al documented a significant decline in imaging case volumes across the Aseer region.¹⁰ Similarly, global studies reported not only reduced nuclear medicine activity but also supply chain disruptions, delayed PET/CT examinations, and limitations in radiopharmaceutical availability.^{11–13} These challenges necessitated rapid departmental restructuring to maintain essential diagnostic and therapeutic services while adhering to infection control guidelines.^{14,15}

Nuclear medicine remains a vital discipline in the management of cardiovascular, oncological, and neurological diseases. Using advanced modalities such as Positron Emission Tomography (PET) and Single-Photon Emission Computed Tomography (SPECT), it provides unique insights into molecular and functional processes, enabling precise diagnosis, therapeutic planning, and longitudinal monitoring. During the COVID-19 pandemic, however, reduced utilization, shifting procedure priorities, and evolving operational protocols created new challenges and opportunities for the field.^{16,17}

This study investigates the specific impact of the COVID-19 pandemic on the Nuclear Medicine Department at King Saud University Medical City (KSUMC), Riyadh, Saudi Arabia. The objectives were:

1. To evaluate changes in patient volume across pre-pandemic, pandemic, and post-pandemic phases.
2. To assess changes in the types of nuclear medicine procedures performed during these periods.

By addressing these aims, this study contributes to a more comprehensive understanding of how the pandemic influenced nuclear medicine utilization in a major tertiary center in Saudi Arabia. The findings will provide valuable insights for healthcare providers and policymakers to enhance resilience, resource allocation, and preparedness in nuclear medicine services during future health crises.

Materials and Methods

A retrospective analysis was conducted on records from the Nuclear Medicine Department at King Saud University Medical City (KSUMC), covering a four-year period from 2019 to 2022. The study encompassed all diagnostic nuclear medicine procedures, including inpatients, outpatients, pre-admission, emergency cases, and business center clients, while therapeutic nuclear medicine procedures were excluded.

The disease of interest was Coronavirus Disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). To ensure diagnostic accuracy, the reference standard for confirming COVID-19 cases was the reverse transcription–polymerase chain reaction (RT-PCR) assay performed on nasopharyngeal or oropharyngeal swab specimens, as recommended by the World Health Organization (WHO) and the Saudi Ministry of Health during the study period. In cases where RT-PCR was not available or where repeat testing was indicated, confirmation was supplemented by clinical evaluation, radiological imaging (eg, chest CT findings consistent with COVID-19 pneumonia), and serological antibody testing, in line with institutional protocols and national guidelines. Patients were classified as COVID-19 positive only when a definitive laboratory confirmation (RT-PCR or equivalent gold-standard molecular testing) was documented in the electronic medical records.

Eligibility Criteria

All patients undergoing any diagnostic nuclear medicine imaging procedure during the study timeframe were eligible.

- **Inclusion criteria:** Adult patients (≥ 18 years) with complete demographic and procedural records.
- **Exclusion criteria:** Therapeutic nuclear medicine procedures and records with missing demographic or procedural data. Incomplete datasets were excluded to maintain data integrity.

Collected Variables

Data were extracted from the hospital information system and included:

- Demographics: sex, age (restricted to ≥ 18 years).
- Admission type: outpatient, inpatient, pre-admission, emergency, or business center.
- Procedure details: procedure name, category, and date.
- Time period classification: procedures were grouped into three phases:
 - Pre-COVID-19: Aug 2019 - Feb 2020
 - During COVID-19: Mar 2020 - Sep 2020
 - Post-COVID-19: Oct 2020 - Apr 2021

The dataset comprised 24,455 anonymized cases, ensuring confidentiality and compliance with ethical standards.

Nuclear Medicine Procedures and Indications

The study included a broad range of diagnostic nuclear medicine procedures, categorized as follows:

- **Bone scans:** detection of bone metastases, occult fractures, avascular necrosis.
- **Cardiac imaging (eg, MPI):** diagnosis and risk stratification of coronary artery disease.
- **PET scans:** for lymphoma, lung, colorectal, head and neck cancers, and others.
- **DEXA scans:** assessment of bone mineral density (BMD).
- **Thyroid imaging:** evaluation of hyperthyroidism and nodule characterization.
- **Lung perfusion scans:** primarily for pulmonary embolism assessment.
- **Renal scans (DTPA, MAG3):** evaluation of perfusion, function, and drainage.
- **Digestive system imaging:** eg, Meckel's scan, gastric emptying studies.

- **Brain/Nervous System Imaging**
- **Inflammatory/infection imaging:** eg, osteomyelitis, prosthetic joint infection.

Data Analysis

The data were compiled in Microsoft Excel and analyzed using IBM SPSS Statistics for Windows, Version 25.0.

- Descriptive statistics summarized categorical variables (sex, admission type, procedure type) as frequencies and percentages.
- Comparative analysis: Chi-square tests of independence were used to examine associations between categorical variables and COVID-19 phases. A p-value <0.05 was considered statistically significant. Cramér's V was reported to quantify effect size.
- Temporal analysis: Data were analyzed in 7-month intervals, corresponding to the defined phases of the pandemic at KSUMC. This interval was chosen to capture the temporal shifts in utilization patterns within each distinct stage of the pandemic response, while avoiding seasonal confounding. Although quarterly or annual analyses could provide additional insights, the 7-month segmentation allowed for direct comparison between the three pandemic phases.

Limitations of Statistical Approach

While chi-square testing was used to assess categorical associations, more advanced methods such as multivariable regression analysis could provide deeper insight into the relationships between variables and account for potential confounders. This approach is recommended for future multi-center studies.

Results

Descriptive Statistics

In the data analysis, several key findings emerged, shedding light on the demographic composition, admission patterns, procedural frequencies, and temporal variations within the Nuclear Medicine Department see [Table 1](#).

Firstly, regarding patient demographics, the results reveal a notable predominance of female patients, comprising 69.4% of the total sample, compared to male patients, representing 30.6%. This gender distribution suggests potential gender-specific healthcare needs or differential healthcare-seeking behaviors among the population served by the department.

Table 1 Distribution of Patients by Sex, Admission Type, Procedure Type, and Procedure Time Across Different Phases of the COVID-19 Pandemic

Category		N	Percent
Patient sex	Male	7474	30.6%
	Female	16981	69.4%
Admission type	Business centre outpatients	2	0.0%
	Pre-admission	143	0.6%
	Outpatient	21280	87.0%
	Inpatient	2819	11.5%
	Emergency	211	0.9%

(Continued)

Table 1 (Continued).

Category		N	Percent
Procedure Name	Cardiac	4063	16.6%
	Lung	267	1.1%
	Iodine and Inflammatory	515	2.1%
	Urinary System	1303	5.3%
	Digestive System	847	3.5%
	Brain/Nervous System	151	0.6%
	PET Scan	3261	13.3%
	Thyroid	942	3.9%
	Bone	2477	10.1%
	DEXA	10629	43.5%
Procedure time	Pre Corona	9449	38.6%
	During Corona	1499	6.1%
	Post Corona	13507	55.2%
Procedure time 7 months	Pre Corona 7 months	4799	19.6%
	During Corona 7 months	1499	6.1%
	Post Corona 7 months	3965	16.2%

In terms of admission types, outpatient admissions emerge as the most common, constituting a significant majority at 87.0%, followed by inpatient admissions at 11.5%. However, it's noteworthy that pre-admission and emergency admissions each represent less than 1% of the total cases. At the same time, business centre outpatients were not observed within our dataset, warranting further exploration or clarification.

Turning to procedural frequencies, the analysis highlights DEXA (Dual-energy X-ray absorptiometry) as the most frequently performed procedure, accounting for 43.5% of all procedures. This is followed by Cardiac procedures at 16.6% and PET scans at 13.3%, indicating variability in the utilization of diagnostic or therapeutic interventions within the department.

Examining procedural trends over time, we observe a clear temporal variation, with most procedures conducted during the post-corona period representing 55.2% of the total. Pre-corona procedures account for 38.6%, while the during-corona period has the lowest frequency at 6.1%. This temporal shift likely reflects the impact of the COVID-19 pandemic on healthcare utilization patterns, influenced by factors such as pandemic-related restrictions, patient behavior, and healthcare facility capacity.

Further granularity is provided by analyzing procedural frequencies within 7-month intervals within each period. Here, we found consistency with the overall trends, with the post-corona 7-month period exhibiting the highest frequency of procedures at 16.2%, followed by pre-corona 7-month procedures at 19.6%. The during-corona 7-month period remains consistent with the overall during-corona period frequency at 6.1%.

Comparative Analysis

Figure 1 illustrates the number of patients undergoing different nuclear medicine procedures across all periods analyzed in the study. The DEXA (Dual-energy X-ray absorptiometry) scan was the most frequently performed procedure, with 10,629 cases, highlighting its widespread use for osteoporosis screening and bone health assessment. Cardiac imaging

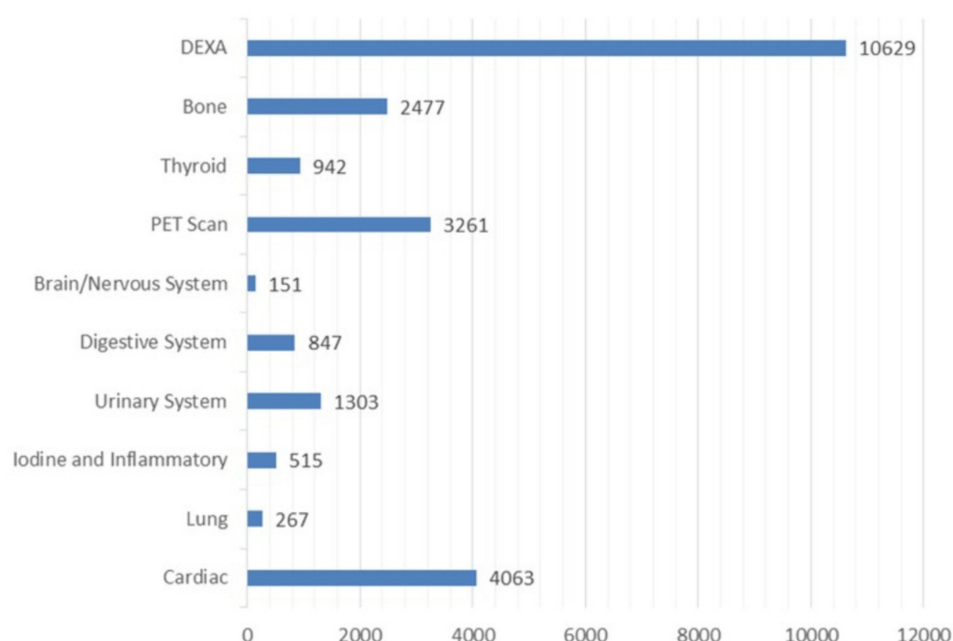


Figure 1 No. of Patients Depending on Procedure in all Periods.

was the second most common procedure, accounting for 4,063 cases, emphasizing the significant role of nuclear medicine in cardiovascular diagnostics. PET scans, crucial for oncological and metabolic assessments, were also widely performed, with 3,261 cases recorded. Other procedures, such as bone imaging (2,477 cases), urinary system imaging (1,303 cases), and thyroid scans (942 cases), exhibited lower but notable frequencies. The least commonly performed procedures included brain/nervous system imaging (151 cases) and lung imaging (267 cases), indicating their more specialized applications. This distribution reflects the varying demand for nuclear medicine services, with certain procedures, particularly DEXA and cardiac imaging, remaining essential components of routine patient care. The results also suggest potential changes in procedural demand over time, possibly influenced by the COVID-19 pandemic and healthcare accessibility factors.

Table 2 shows a comparative analysis of categorical variables across distinct periods: pre-corona, during corona, and post-corona. This analysis aims to elucidate any discernible patterns or shifts in patient demographics, admission types, and procedural frequencies throughout these temporal phases.

Table 2 Comparison of Patient Demographics, Admission Types, and Procedure Frequencies Across Pre-, During-, and Post-COVID-19 Periods

Category		Pre Corona	During Corona	Post Corona	Sig. Chi-Square	Cramer's V	Sig.
Patient sex	Male	2999 (31.7%)	522 (34.8%)	5953 (29.3%)	0.000	0.035	0.000
	Female	6450 (68.3%)	977 (65.2%)	9554 (70.7%)			
Admission type	Business centre outpatients	1 (0.01%)	0 (0.0%)	1 (0.007%)	0.000	0.057	0.000
	Pre-admission	18 (0.2%)	4 (0.3%)	121 (0.9%)			
	Outpatient	8376 (88.6%)	1222 (81.5%)	11,682 (86.5%)			
	Inpatient	1009 (10.7%)	269 (17.9%)	1541 (11.4%)			
	Emergency	45 (0.5%)	4 (0.3%)	162 (1.2%)			

(Continued)

Table 2 (Continued).

Category		Pre Corona	During Corona	Post Corona	Sig. Chi-Square	Cramer's V	Sig.
Procedure Name	Cardiac	1548 (16.4%)	239 (15.9%)	2276 (16.9%)	0.000	0.145	0.000
	Lung	90 (1.0%)	27 (1.8%)	150 (1.1%)			
	Iodine and Inflammatory	162 (1.7%)	45 (3.0%)	308 (2.3%)			
	Urinary System	465 (4.9%)	129 (8.6%)	709 (5.2%)			
	Digestive System	219 (2.3%)	43 (2.9%)	585 (4.3%)			
	Brain/Nervous System	33 (0.3%)	10 (0.7%)	108 (0.8%)			
	PET Scan	1925 (20.4%)	250 (16.7%)	1086 (8.0%)			
	Thyroid	348 (3.7%)	83 (5.5%)	511 (3.8%)			
	Bone	747 (7.9%)	241 (16.1%)	1489 (11.0%)			
	DEXA	3912 (41.4%)	432 (28.8%)	6285 (46.5%)			

In the analysis of patient demographics, notable fluctuations were observed in the representation of male patients across distinct phases of the pandemic. Specifically, the proportion of male patients slightly increased from 31.7% in the pre-corona period to 34.8% during the corona period, followed by a subsequent decrease to 29.3% in the post-corona phase. In contrast, the percentage of female patients remained relatively stable, ranging from 68.3% to 70.7% throughout the pre-corona, during corona, and post-corona periods, indicating a consistent demographic distribution within the dataset.

Examining patient sex in relation to the periods reveals a statistically significant association ($\chi^2 = 29.677$, $p < 0.001$), indicating variations in the distribution of male and female patients over time. Despite statistical significance, Cramér's V suggests a weak effect size ($V = 0.035$), implying a relatively minor impact of the period on the distribution of patient sex.

Examining admission types revealed consistent trends in outpatient admissions, which constituted the majority across all periods, with percentages ranging from 81.5% to 86.5%. However, inpatient admissions demonstrated significant fluctuations, increasing from 10.7% in the pre-corona phase to 17.9% during the corona phase before declining to 11.4% in the post-corona phase, suggesting dynamic shifts in inpatient care demands during the pandemic. Notably, business centre outpatients remained negligible ($<0.01\%$) throughout all periods, while emergency admissions maintained a relatively low prevalence, comprising percentages ranging from 0.3% to 1.5%.

A pronounced association with period is observed ($\chi^2 = 158.678$, $p < 0.001$), accompanied by a moderate effect size ($V = 0.057$). This finding underscores notable fluctuations in admission patterns across the pre-corona, during-corona, and post-corona phases, signifying the dynamic nature of healthcare utilization during the pandemic.

Regarding procedural frequencies, DEXA procedures emerged as the most prominent, with percentages rising substantially from 28.8% during the corona phase to 46.5% in the post-corona phase, indicating an increased demand for DEXA scanning services post-pandemic. Conversely, PET scan procedures witnessed a significant decline in percentage representation, decreasing from 20.4% in the pre-corona phase to 8.0% in the post-corona phase, suggesting a notable shift in demand for PET imaging services. Other procedures, such as Cardiac and Bone interventions, exhibited relatively stable representation across periods. In contrast, certain procedures, including Lung and Brain/Nervous System-related interventions, demonstrated minor fluctuations in percentage distribution.

Similarly, procedural frequencies exhibit substantial variation across periods, as indicated by a significant association ($\chi^2 = 1023.694$, $p < 0.001$) and a relatively strong effect size ($V = 0.145$). This suggests significant shifts in procedural demand and utilization in response to evolving circumstances during different stages of the pandemic.

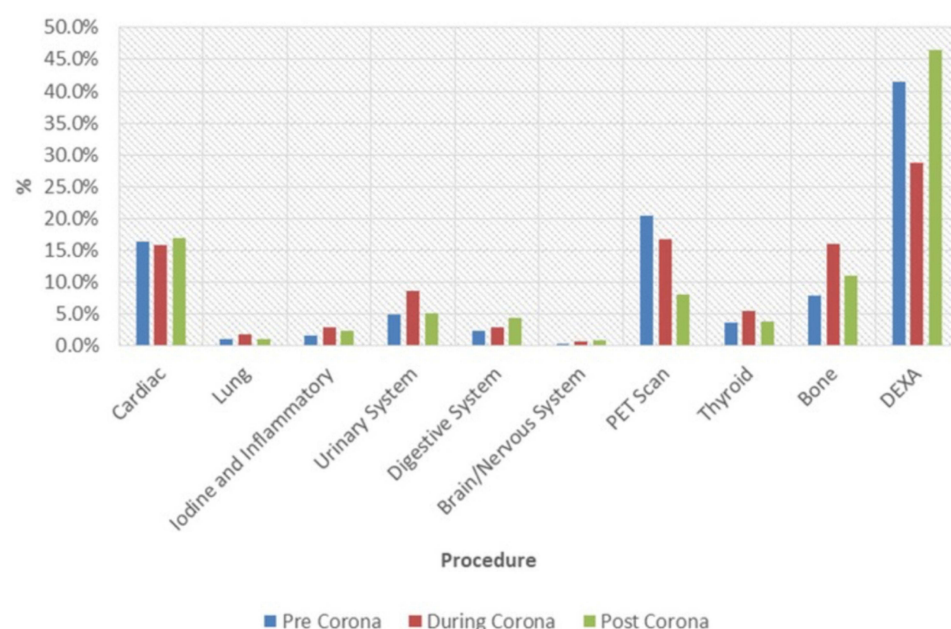


Figure 2 Association between Procedure and Time of Procedure.

Figure 2 illustrates the association between different nuclear medicine procedures and the time period in which they were performed, categorized into Pre-Corona, During-Corona, and Post-Corona phases. The DEXA scan was the most frequently performed procedure, with a significant increase post-pandemic. Cardiac imaging and PET scans, essential for cardiovascular and oncological evaluations, showed a decline during the COVID-19 period but rebounded post-pandemic. Conversely, procedures such as brain/nervous system imaging, digestive system scans, and urinary system imaging exhibited minimal fluctuation, indicating their relatively stable demand regardless of pandemic-related disruptions. Notably, all procedures experienced a sharp decline during the pandemic period, likely due to restricted hospital access, non-urgent care, and resource reallocation toward COVID-19 management. However, post-pandemic trends indicate a recovery, with most procedures returning to pre-pandemic levels or even surpassing them, particularly in the case of DEXA and cardiac imaging. This trend underscores the delayed but eventual return to normal in nuclear medicine services as healthcare systems adapted to post-COVID conditions.

Figure 3 presents the number of patients undergoing different nuclear medicine procedures during three distinct periods: Pre-Corona, During-Corona, and Post-Corona. The trend clearly illustrates a sharp decline in procedures during the COVID-19 pandemic, represented by the red line, which remains consistently low across all procedures. However, post-pandemic recovery is evident, as seen in the green line, with most procedures showing an increase, often surpassing pre-pandemic levels.

Table 3 presents a comparative analysis of categorical variables within 7-month intervals across the pre-corona, during corona, and post-corona phases. This analysis aims to elucidate any temporal shifts in patient demographics, admission types, and procedural frequencies during distinct time segments.

In the comprehensive analysis of Table 3, we continue to explore the categorical variables within 7-month intervals across the pre-corona, during corona, and post-corona phases. Starting with patient demographics, we observe notable fluctuations in the representation of male patients across these time segments. The proportion of male patients begins at 31.4% during the pre-corona 7-month period, rises to 34.8% during the corona 7-month phase, and subsequently decreases to 28.2% in the post-corona 7-month period. In contrast, female patients consistently constitute the majority, ranging from 65.2% to 71.8% throughout these intervals, indicating a stable demographic distribution.

Examining patient sex in relation to 7-month intervals reveals a significant association with time segments ($\chi^2 = 48.310$, $p < 0.001$), indicating variations in the distribution of male and female patients over time. The association is

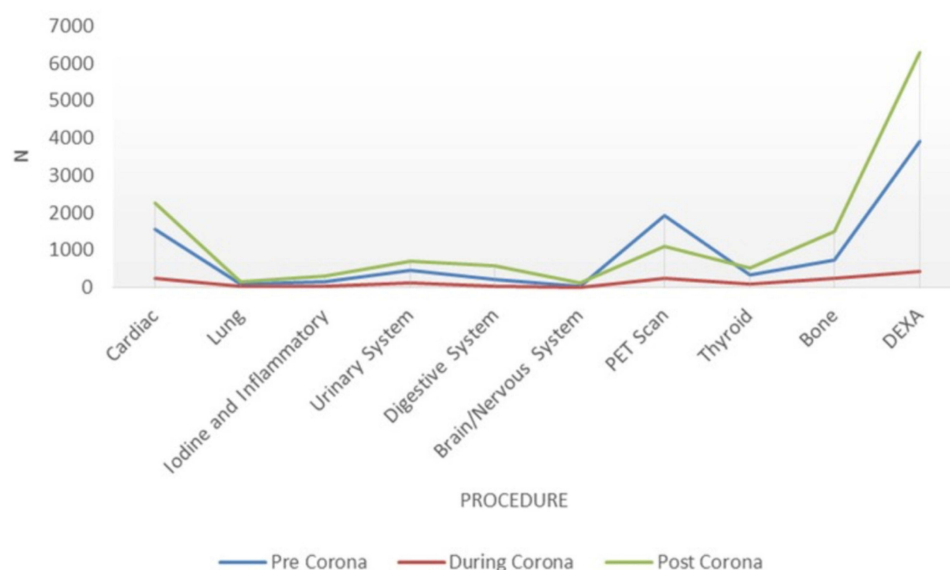


Figure 3 Patients Number During each Period According to Procedure.

further supported by a moderate effect size ($V = 0.049$), suggesting a notable impact of time segments on the distribution of patient sex within the dataset.

Moving on to admission types, elective admissions remain negligible, with percentages remaining close to 0% across all time intervals. Pre-admission cases show a slight increase from 0.2% in the pre-corona 7-month period to 1.1% in the post-corona 7-month phase, suggesting potential shifts in pre-admission healthcare utilization patterns. Outpatient admissions maintain dominance, comprising percentages ranging from 81.5% to 86.4% across all intervals. In contrast, inpatient admissions demonstrate variability, peaking at 17.9% during the corona 7-month period, reflecting fluctuations in the need for inpatient care throughout the pandemic. Emergency admissions remain relatively low, ranging from 0.3% to 1.5%, indicating their minor contribution to overall admission patterns.

Regarding admission types, a pronounced association with time segments is observed ($\chi^2 = 121.861$, $p < 0.001$), accompanied by a relatively strong effect size ($V = 0.077$). This finding underscores substantial fluctuations in admission

Table 3 Comparison of Patient Demographics, Admission Types, and Procedure Frequencies Over a 7-Month Period Pre-, During-, and Post-COVID-19 Pandemic

Category		Pre Corona 7 Months	During Corona 7 Months	Post Corona 7 Months	Sig. Chi-Square	Cramer's V	Sig.
Patient sex	Male	1507 (31.4%)	522 (34.8%)	1120 (28.2%)	0.000	0.049	0.000
	Female	3292 (68.6%)	977 (65.2%)	2845 (71.8%)			
Admission type	Business centre outpatients	1 (0.02%)	0 (0.0%)	0 (0.0%)	0.000	0.077	0.000
	Pre-admission	11 (0.2%)	4 (0.3%)	44 (1.1%)			
	Outpatient	4242 (88.4%)	1222 (81.5%)	3424 (86.4%)			
	Inpatient	520 (10.8%)	269 (17.9%)	439 (11.1%)			
	Emergency	25 (0.5%)	4 (0.3%)	58 (1.5%)			

(Continued)

Table 3 (Continued).

Category		Pre Corona 7 Months	During Corona 7 Months	Post Corona 7 Months	Sig. Chi- Square	Cramer's V	Sig.
Procedure Name	Cardiac	770 (16.0%)	239 (15.9%)	773 (19.5%)	0.000	0.206	0.000
	Lung	38 (0.8%)	27 (1.8%)	40 (1.0%)			
	Iodine and Inflammatory	82 (1.7%)	45 (3.0%)	75 (1.9%)			
	Urinary System	263 (5.5%)	129 (8.6%)	201 (5.1%)			
	Digestive System	110 (2.3%)	43 (2.9%)	155 (3.9%)			
	Brain/Nervous System	15 (0.3%)	10 (0.7%)	26 (0.7%)			
	PET Scan	986 (20.5%)	250 (16.7%)	100 (2.5%)			
	Thyroid	171 (3.6%)	83 (5.5%)	171 (4.3%)			
	Bone	355 (7.4%)	241 (16.1%)	419 (10.6%)			
	DEXA	2009 (41.9%)	432 (28.8%)	2005 (50.6%)			

patterns across different time segments, reflecting the evolving healthcare landscape during the pre-corona, during corona, and post-corona periods.

Regarding procedural frequencies, cardiac procedures exhibit slight fluctuations, with percentages ranging from 15.9% to 19.5% across time intervals. Similarly, procedures such as lung, iodine and inflammatory, urinary system, digestive system, and brain/nervous system demonstrate minor variations in percentage distribution across the three intervals. PET scan procedures experience a significant decline in percentage representation, decreasing from 20.5% in the pre-corona 7-month phase to 2.5% in the post-corona 7-month phase. Similarly, bone procedures show a decrease from 16.1% during the corona 7-month phase to 10.6% in the post-corona 7-month phase. Conversely, DEXA procedures witness a notable increase in percentage representation, rising from 28.8% during the corona 7-month phase to 50.6% in the post-corona 7-month phase.

Similarly, procedural frequencies exhibit significant variation across time segments ($\chi^2 = 872.621$, $p < 0.001$), with a relatively strong effect size ($V = 0.206$). This suggests notable shifts in procedural demand and utilization within 7-month intervals, indicative of dynamic healthcare needs and resource allocation strategies throughout the pandemic phases.

Figure 4 illustrates the association between different nuclear medicine procedures and the time period in which they were performed over a 7-month duration in the Pre-Corona, During-Corona, and Post-Corona periods. The trend indicates a significant drop in all procedures during the COVID-19 pandemic, represented by the red bars, highlighting the severe impact of lockdowns. DEXA scans, PET scans, cardiac imaging, and bone scans were among the most affected but demonstrated strong post-pandemic recovery, as shown by the green bars. The DEXA scan exhibited the highest increase post-pandemic, emphasizing the growing demand for osteoporosis screening and bone health assessments. Similarly, cardiac imaging and PET scans rebounded significantly, reflecting a return to routine diagnostic procedures. In contrast, procedures such as brain/nervous system imaging and lung scans showed minimal fluctuations across all periods, indicating their lower demand or specialized nature. The overall trend confirms a sharp decline during the pandemic followed by a recovery phase.

Figure 5 illustrates the number of patients undergoing different nuclear medicine procedures within a 7-month period across three phases: Pre-Corona, During-Corona, and Post-Corona. The Pre-Corona period (blue line) shows relatively high patient numbers for most procedures, particularly DEXA scans, PET scans, and cardiac imaging, indicating their essential role in routine diagnostics. However, the During-Corona period (red line) reflects a sharp decline in all

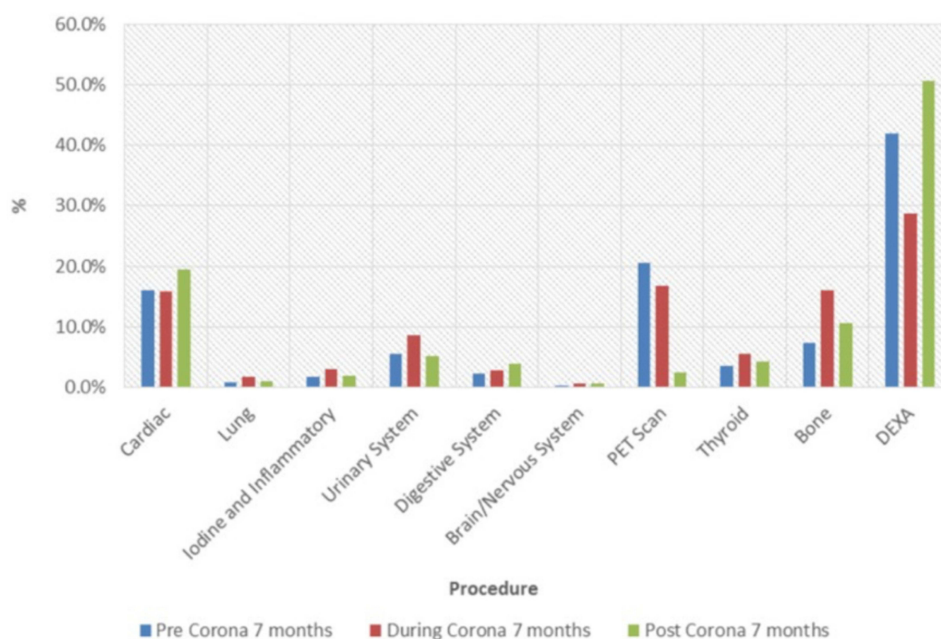


Figure 4 Association between Procedure and Time of Procedure During 7 Months.

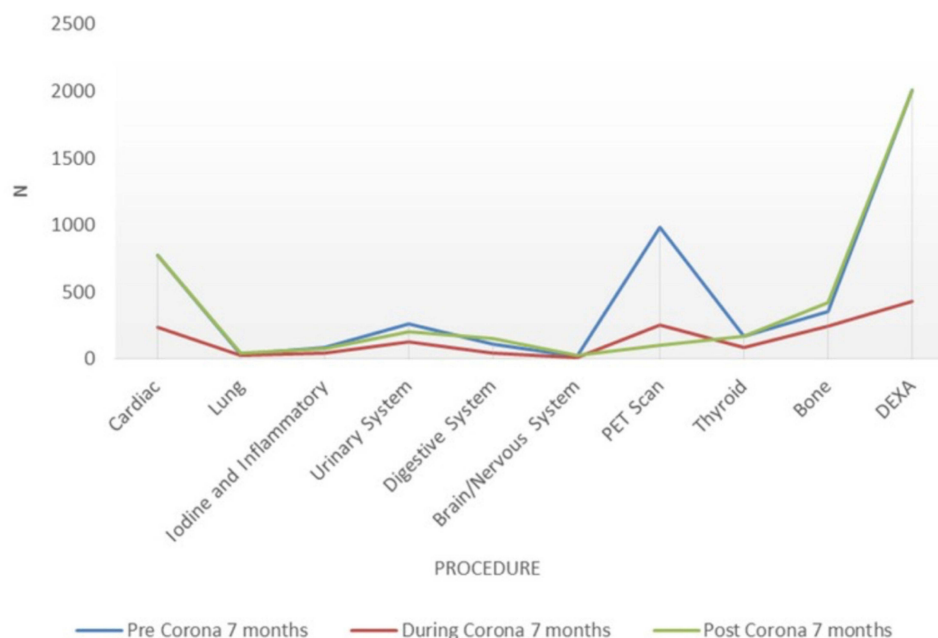


Figure 5 Patient Number During each Period within 7 Months According to Procedure.

procedures, likely due to COVID-19 restrictions, hospital access limitations. PET scans and DEXA scans were significantly impacted, showing a major drop during this phase. The Post-Corona period (green line) indicates a strong recovery, with most procedures returning to or even exceeding pre-pandemic levels. The DEXA scan, in particular, experienced the highest post-pandemic increase. Cardiac imaging, PET scans, and bone scans also rebounded significantly, reflecting the resumption of routine and specialized diagnostic services. The overall trend highlights the pandemic's impact on nuclear medicine services and the healthcare system's gradual adaptation and recovery post-COVID-19.

Regarding procedural frequencies, a clear divergence in trends was observed between PET scans and DEXA procedures. PET imaging utilization declined markedly, from 20.4% in the pre-pandemic phase to 8.0% post-pandemic. This decline can be attributed to multiple factors. First, oncology patients experienced interruptions in diagnostic and staging services as elective or non-urgent imaging was deprioritized in favor of urgent COVID-19 care, consistent with international reports of reduced PET volumes during the pandemic.^{6,12,14} Second, radiopharmaceutical supply chain disruptions—particularly shortages of 18F-FDG and delays in importing generator-based isotopes—restricted the capacity to perform PET scans during and immediately after the pandemic.⁸ Third, patient hesitancy to visit hospitals for cancer-related diagnostics further suppressed demand in the short term.

In contrast, DEXA scans demonstrated a substantial rebound and increase post-pandemic, rising from 28.8% during the pandemic to 46.5% afterward. This increase likely reflects the resumption of routine osteoporosis screening programs that had been deferred during the lockdown period. Furthermore, DEXA is a relatively low-cost, low-risk, and high-volume procedure, making it easier to resume once restrictions were lifted. Given the high prevalence of osteoporosis in women and the demographic predominance of female patients in our study (69.4%), the surge in DEXA procedures may also be explained by pent-up demand for bone mineral density testing, a trend consistent with recovery patterns in other countries where bone health evaluations were temporarily suspended but prioritized upon service restoration.^{15,16}

Other procedures, such as cardiac imaging and bone scintigraphy, exhibited more stable demand across all phases, reflecting their role as essential diagnostic tools for acute and chronic conditions. In contrast, more specialized procedures (eg, brain and lung scans) showed only minor fluctuations, indicating that their utilization was less directly impacted by pandemic-related service reorganization.

Discussion

The COVID-19 pandemic had a significant impact on the Nuclear Medicine Department at King Saud University Medical City (KSUMC), causing marked changes in patient demographics, admission types, and procedural trends. The results of this study indicate a sharp decline in nuclear medicine procedures during the pandemic, with a gradual recovery afterward. This finding aligns with the global experience of nuclear medicine services, where similar disruptions were observed in multiple regions. Albano et al² reported a substantial reduction in nuclear medicine activity across Europe, and Freudenberg et al¹² documented comparable declines in a global survey conducted in April 2020. These observations confirm that the trends at KSUMC were not unique, but part of a broader international phenomenon.

One of the most important findings of this study is the decrease in the number of patients undergoing nuclear medicine procedures during the pandemic, dropping to 6.1% of all cases compared to 38.6% before the pandemic. This decline can be attributed to lockdown measures, patient reluctance to visit hospitals, and the prioritization of COVID-19-related medical services over routine diagnostic imaging. Similar decreases were observed worldwide, with Currie⁹ reporting a significant reduction in Australia, and Kirienko et al¹⁴ highlighting comparable declines across European centers. Annunziata et al⁶ further emphasized that oncology-related PET procedures were disproportionately affected during the peak of the pandemic, reflecting the global postponement of non-urgent diagnostic services.

The gender distribution analysis in our study revealed a consistently high proportion of female patients (69.4%), consistent across all time periods. This may be explained by the increased demand for osteoporosis screening in women, corresponding to the high frequency of DEXA (dual-energy X-ray absorptiometry) scans (43.5%) observed in this cohort. Similar findings have been reported in the literature, where osteoporosis imaging remains more common in female populations due to higher prevalence of bone mineral density loss among women after menopause.¹⁶

Hospitalization trends revealed that outpatient visits remained the most common throughout the study period (87.0% of cases), but there was a decline during the pandemic (81.5%) compared to the pre-pandemic phase (88.6%). This pattern reflects an overall decrease in non-urgent hospital visits during COVID-19, consistent with trends observed internationally.^{7,17}

The increase in inpatient cases during the pandemic (17.9%) may be related to admissions for COVID-19 itself and stricter admission criteria for non-COVID patients.

Analysis of procedural types highlighted DEXA as the most frequently performed examination, followed by cardiac imaging and PET scans. However, PET utilization declined after the pandemic (from 20.4% to 8.0% before the

pandemic), which can be attributed to disruptions in the radiopharmaceutical supply chain and decreased demand for tumor diagnostic procedures. Buck et al⁸ reported that international shipping restrictions and reduced molybdenum-99/technetium-99m availability significantly constrained nuclear medicine practices worldwide. Conversely, DEXA utilization increased after the pandemic (46.5%), likely reflecting the resumption of delayed osteoporosis screening. These findings emphasize the vulnerability of nuclear medicine services to supply chain interruptions and underscore the need for contingency planning to ensure stable access to radiopharmaceuticals during future global crises.

From a policy and practice perspective, healthcare system adaptations—such as prioritizing urgent procedures, streamlining infection control protocols, and, in some countries, incorporating telemedicine consultations—helped mitigate the decline in services. At KSUMC, however, telemedicine integration for nuclear medicine referrals was limited, which may partly explain the sharp decline observed in procedure volumes compared to institutions where such strategies were more widely adopted.^{7,17}

This study has several limitations. First, it is a retrospective analysis, relying on departmental records rather than prospectively collected clinical data. Second, the inclusion of a heterogeneous range of nuclear medicine procedures makes subgroup comparisons less precise, although it reflects the real-world scope of nuclear medicine practice. Third, patient-specific clinical metrics such as performance scores and vital signs were not available in the dataset, limiting the ability to correlate utilization trends with individual patient health status. Finally, as this was a single-center study, the results may not be fully generalizable to other institutions in Saudi Arabia or beyond.

An important area for future research is the potential long-term impact of the pandemic on nuclear medicine services. While volumes at KSUMC gradually recovered, it remains uncertain whether utilization has fully returned to pre-pandemic levels, or if structural changes in healthcare delivery (such as greater reliance on telemedicine, altered patient behavior, or policy-driven prioritization of procedures) will persist. Lessons from the COVID-19 crisis—particularly in supply chain management, infection control, and contingency planning—should inform preparedness strategies to safeguard nuclear medicine services against future global health emergencies.

Conclusion

This study highlights the profound impact of the COVID-19 pandemic on nuclear medicine services at KSUMC, with patient numbers declining by 84.1% during the pandemic period and only gradually recovering thereafter. While the observed fluctuations largely reflect the consequences of COVID-19 restrictions, additional factors such as equipment maintenance and supply chain disruptions for critical tracers (eg, ^{99m}Tc/^{99m}Mo and ¹³¹I) likely contributed to the reduced procedural volume.

Importantly, these findings underscore the need to enhance resilience and preparedness of nuclear medicine services during health crises. Policy measures could include establishing redundant and diversified supply chains for radiopharmaceuticals, developing national stockpiling strategies, and ensuring the continuity of essential diagnostic procedures through streamlined infection-control pathways. Operational adjustments, such as expanding the use of telemedicine for referrals and follow-up, prioritizing urgent over elective imaging during crises, and incorporating alternative imaging modalities when tracer shortages occur, may further safeguard continuity of care.

This single-center study is limited in its generalizability, and future research should focus on multi-center and multi-regional cohorts to provide broader perspectives on service disruptions and recovery. Additionally, longitudinal studies are warranted to examine the long-term implications of pandemic-related service reductions on patient outcomes and to evaluate the extent to which nuclear medicine utilization has returned to, or evolved beyond, pre-pandemic patterns.

By documenting both the vulnerabilities and recovery trends in nuclear medicine practice, this study provides evidence to guide policy development, operational planning, and future research that can better prepare nuclear medicine departments to withstand future global health emergencies.

Institutional Review Board Statement

This study was approved by the Institutional Review Board of King Saud University (Ref No. E-22-7251; Date of approval 1 Nov 2022).

Ethical/Copyright

The data accessed complied with relevant data protection and privacy regulations.

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Disclosure

The authors report no conflicts of interest in this work.

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