The Use of Dyes in CT Scans

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Abstract: Background and objective: Effective management of MRI and CT scan scheduling workflows is crucial in healthcare settings to ensure timely diagnosis and treatment. This study aims to analyze the scheduling workflows for MRI and CT scans in two major government hospitals in Saudi Arabia by assessing the time intervals from physician request to exam execution.

Methods: A retrospective study was conducted using data from January 1, 2017 to December 31, 2022. The study included all patients who underwent MRI or CT scans at the selected hospitals. The following three main intervals were analyzed: Days from Request to Appointment (DRA), Days from Appointment to Scheduled (DAS), and Days from Scheduled to Performed (DSP).

Results:The CT scans had a mean DRA of 2.67 days (SD = 18.13) and a mean DAS of 5.25 days (SD = 20.19). The DSP for both scans was less than one day, indicating that scans are typically performed on the same day they are scheduled. The MRI scans showed a mean DRA of 11.10 days and a DAS of 20.25 days, with a similarly quick DSP. Overall, CT scans had shorter and less variable waiting times than MRI scans. The study also noted a significant drop in scans during the COVID-19 pandemic, followed by a gradual return to normal volumes.

Conclusion:The MRI scans typically experience longer and more variable durations compared to CT scans. Employing timestamps has proven effective in breaking down these waiting periods into distinct stages to provide a clear view of delays. This detailed analysis provides actionable insights for targeting key issues, guiding decisions to improve scheduling efficiency and ultimately reduce patient waiting times.

Keywords: Dyes -CT –Scans.

Introduction:

Dyes in CT scans enhancement is a routine strategy for daily CT imaging in clinical practice. It is generally classified into five phases, including non-contrast (without injecting contrast agent), arterial, portal venous, nephrographic, and delayed based on the post-injection timing .

The passage of contrast agents through the bloodstream not only exaggerates the visual difference (Fig. 1B-E) but also highlights lesions (Radetic et al., 2020, Rawson and Pelletier, 2013, Legesse et al., 2023) and visualizes blood vessels in different contrast phases (Radetic et al., 2020). For instance, the arterial phase helps to identify hypervascular liver lesions (Rawson and Pelletier, 2013). Hypovascular liver metastases are better detected in the portal venous phase. Certain type of hypervascular tumors are assessed in the delayed phase to detect the contrast washout phenomenon (Kulkarni et al., 2021). Therefore, multiple Dyes in CT scans phases of CT scans are important to facilitate the diagnosis of lesions and tumors.

I. The Dyes in CT scans phase is also important for training data curation in many medical AI applications. Contrast-enhanced CT scans were used in classifying intra-adrenal pheochromocytomas and extra-adrenal paragangliomas (Santra et al., 2023), detecting liver lesions (Kaga et al., 2021), lymphoma (Liu et al., 2023), ascites (Nag et al., 2023), and segmenting adrenal glands (Robinson-Weiss et al., 2022). Non-contrast CT scans were also useful for the evaluation of renal masses (Bucolo et al., 2023) and pancreatic lesions (Liang et al., 2023, Cao et al., 2023).
II. Classifying the Dyes in CT scans phase of CT scans is thus of high interest in medical imaging research (Dao et al., 2022, Esquinas et al., 2022). Contrast and non-contrast CT scans were accurately classified using ResNet (He et al., 2016), InceptionV3 (Szegedy et al., 2016), and EfficientNetB4 (Ye et al., 2021, Tan and Le, 2019). Previous research on multiple Dyes in CT scans phase classification often determined the phase of CT slices first, followed by combining all per-slice results to decide the final phase of the entire CT scan. The classification models on CT slices could be ResNet-34, VGG19, and DenseNet-121 (Anand et al., 2023) . A multi-domain disentangled representation model was also developed to extract robust image features to classify the Dyes in CT scans phase on CT slices (Tang et al., 2020). Recently, a 3D classification model was proposed to directly determine the contrast phase on CT scans (Muhamedrahimov et al., 2021). Instead of treating each Dyes in CT scans phase (Fig. 1) independently, their inter-phase relation was modeled as a categorical label representation. Contrast phase classification was thus converted into an ordinal regression problem.

Our goal is to develop a 3D classification model to directly determine the Dyes in CT scans phase of a CT scan. the proposed method is robust to the wide body range coverage of CT acquisitions (e.g., chest, abdomen, or pelvic CT). To improve the robustness of the classification model, a set of key organs that are affected by contrast enhancement are identified and segmented.

Intensity features from these segmented organ regions are used for a lightweight classification model, such as a random forest model (Qi, 2012), to classify Dyes in CT scans phases. Since intensity features of key organs are highly impacted by contrast agents, they are robust to differences in body parts, scanners, and imaging protocols. Over the past decade, healthcare services such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scans have experienced a significant increase in demand (Barua, 2017). Alongside this high demand, the cost of CT and MRI scans presents an additional challenge. These imaging modalities are costly to operate and maintain, necessitating the optimization of scheduling processes in healthcare facilities to minimize expenses while effectively meeting patient needs (Lu, Li, & Gisler, 2011). The high demand for these modalities, coupled with the high cost and limited availability of equipment and resources, often leads to prolonged waiting times for appointments (Sutherland, Russell, Gibbard, & Dobrescu, 2019). This delay in appointments can have significant implications for patient care and outcomes. Appointment waiting time is defined as the time between the clinician's determination that a test is required and the time when the patient actually has the test performed without needing to go to a private clinic (Björnberg & Phang, 2019). The issue of extended waiting times for CT and MRI appointments poses a significant obstacle in healthcare operations. Timely scheduling is essential for these imaging modalities, as it directly influences patient outcomes and the overall efficiency of healthcare services. The COVID-19 pandemic further complicated the demand and scheduling of CT and MRI services. Examining the pandemic's impact on CT and MRI waiting times is critical for understanding how sudden demand shifts and operational restrictions affect access to diagnostic care.

Waiting time can be used to assess the performance of a healthcare system (Siciliani & Verzulli, 2009). For example, from 2010 to 2016, the waiting time for an MRI exam in the Netherlands had not exceeded three weeks (Michas, 2020b). In 2021, the Netherlands ranked ninth in the health and health systems ranking of countries worldwide (Statista Research Department, 2022). On the other hand, in 2018, the average waiting time for an MRI exam was approximately 9 months in Croatia (Biloglav et al., 2020). In comparison to the Netherlands, in 2021, Croatia was ranked 52nd in the health and health systems ranking of countries worldwide (Statista Research Department, 2022).

There are no established recommended waiting times for CT and MRI appointments for non-urgent patients, and this area requires further study. However, recommended waiting times for semi-urgent, urgent, and emergent patients have been established. The waiting times for CT and MRI appointments are recommended to be no longer than 30 days for semi-urgent patients and within 7 days and 24 h for urgent and emergent patients, respectively ("CADTH Health Technology Review: Wait List Strategies for CT and MRI Scans," 2023).

The extended waiting times for CT and MRI scans have a substantial impact on patient outcomes. Delays in obtaining crucial diagnostic imaging can lead to prolonged suffering for patients and potentially exacerbate their conditions.

Moreover, long waiting times may also result in increased anxiety and distress for the individuals waiting for these essential tests. Additionally, delayed access to diagnostic imaging can impede the timely initiation of appropriate treatment, which in turn can negatively affect a patient's prognosis and recovery. Therefore, addressing and mitigating these extended waiting times for CT and MRI appointments is critical for ensuring better patient outcomes and overall satisfaction with healthcare services ("CADTH Health Technology Review: Wait List Strategies for CT and MRI Scans," 2023).

Governments around the world are seeking ways to minimize waiting times for healthcare services to improve their healthcare quality. For instance, to reduce strain in the public sector, agreements with private healthcare providers were established in Portugal, allowing patients to receive exams without losing the benefits of the National Health Service (Granja, Almada-Lobo, Janela, Seabra, & Mendes, 2014).

However, the demand for healthcare services is continuously growing, which will inevitably lengthen the waiting time.

Reducing the waiting time for healthcare services may improve patient satisfaction, save patients time, and enhance healthcare quality. Understanding the key steps contributing to longer waiting times is essential to develop effective solutions. Major key issues that affect waiting times include appointment scheduling practices and issues around equipment and human resources (Graban, 2016; MacDonald, MacPherson, & Gallaghan, 2011). An example of equipment and human resource issues would be limited hours of operation and access for CT and MRI exams, resulting in underutilization of these expensive devices (MacDonald et al., 2011).

In Saudi Arabia, the Ministry of Health plays a pivotal role in overseeing healthcare and hospital services across both the public and private sectors. However, the efficiency of appointment scheduling, particularly for advanced imaging modalities such as CT and MRI, has not been comprehensively studied in the region. Timely access to these diagnostic services is critical for effective patient care, impacting clinical outcomes and overall healthcare system performance. Understanding the current state of scheduling timeliness for CT and MRI appointments in Saudi Arabia is essential to identify potential areas for improvement and to develop strategies that could enhance healthcare delivery.

This study seeks to fill the knowledge gap by providing a detailed analysis of appointment scheduling practices for CT and MRI services in Saudi Arabia. By benchmarking against international standards and practices observed in other advanced healthcare systems, we aim to identify both the strengths and weaknesses inherent in the Saudi Arabian healthcare framework.

2. Literature survey

Several previous investigations have delved into the issue of scheduling delays in medical imaging. These studies have highlighted the average waiting times for CT and MRI appointments as well as the negative impact of long waiting times on patient outcomes and the importance of timely scheduling in healthcare delivery. Table 1 shows some of these studies.

Table 1. Studies that have been conducted to examine the average waiting time for CT and MRI scans internationally.

Country	**Year**	**Average waiting time for CT scan**	**Average waiting time for MRI scan**	**Citations**
Netherlands	2016	14 Days	18 Days	Michas (2020a) Michas (2020b)
Croatia	2018	78 Days	268 Days	Biloglav et al. (2020)
Poland	2022	28 Days	51 Days	Sas (2023)
Canada	2015 to 2021	32 Days	74 Days	Stewart (2022a) Stewart (2022b)

There are several factors that can contribute to long waiting times for various services. Some of the reasons for extended waiting periods include high demand for the service, understaffing, inefficient processes, and technical issues (Nuti & Vainieri, 2012; Roifman et al., 2018; Sutherland et al., 2019; Wylie, 2021). High demand can lead to a backlog of requests, while understaffing and inefficient processes can slow down the delivery of services. Additionally, technical issues such as system crashes or malfunctions can disrupt the normal flow of operations and cause delays not only on the day of the issue itself, but also on subsequent days. Addressing these factors can help reduce waiting times and improve overall service delivery.

A crucial aspect of understanding and reducing waiting times involves decomposing the steps within the appointment waiting time. By analyzing each stage of the process—from the initial request to exam—healthcare providers can identify specific bottlenecks and inefficiencies. This detailed analysis allows for targeted interventions to address these delays, ultimately improving the patient experience. Informatics studies have demonstrated the value of analyzing process components using timestamps and other data quality metrics highlighting the importance of comprehensive data tracking and analysis in healthcare settings to enhance service delivery (Jabour, Varghese, Damad, Ghailan, & Mehmood, 2021; Rule, Chiang, & Hribar, 2020). For example, in the Indiana State Cancer Registry, timeliness was assessed by examining the duration between key steps in data reporting, leading to improvements in data management practices (Jabour & Dixon, 2018; Jabour, Dixon, Jones, & Haggstrom, 2016).

By applying similar methods to healthcare appointment processes, providers can gain valuable insights into where time is being lost. Deconstructing the waiting time for appointments can reveal extended periods between patient check-in and examination start times or delays in processing and delivering results. Identifying these bottlenecks allows healthcare facilities to implement targeted solutions such as automated scheduling systems, enhanced staff training, or optimized resource allocation to streamline operations.

3. Methods

We conducted a retrospective study to evaluate the scheduling workflow for MRI and CT scan procedures. This study aimed to perform a temporal analysis of the distinct phases within this workflow, which are critical for patient access to diagnostic services. The study assessed the time intervals from the initial physician's request for imaging to the execution of an exam for both MRI and CT scans.

The study was approved by the Institutional Review Board (IRB) at the Ministry of Health (MOH) with approval number 23-9M dated 3/10/2023. All patient data were anonymized prior to analysis to ensure privacy and comply with ethical standards. Data for this study were extracted from a shared radiology information system, which compiles information from two major government hospitals operating under the MOH, with capacities of 300 and 450 beds. This system's database provided a comprehensive set of patient scheduling timestamps, which allowed us to analyze the imaging service workflow in detail. The dataset encompassed six years, from January 1, 2017 to December 31, 2022. We selected MOH hospitals instead of private or semi-private institutions because MOH hospitals represent the government health services that cover the majority of Saudi citizens. The study population included all patients who underwent MRI or CT scans during the specified study period, with an emphasis on cases that had complete data records for the relevant time intervals.

According to the Euro Health Consumer Index (EHCI) 2018, waiting time is defined as the period between the physician's decision that the scan is needed and the time when the patient undergoes the examination without needing to visit a private clinic. This waiting time is categorized as less than 7 days (good = up to 1), 7–21 days (intermediate = up to 2), and more than 21 days (bad = 3) (Björnberg & Phang, 2019). Due to the variation in practice of how radiology procedures are requested, scheduled, and performed, different studies defined waiting times differently. In this study, we followed the Western Canada Waiting List Project (WCWL) definition of waiting (Sanmartin and Steering Committee of the Western Canada Waiting List Project, 2003). The WCWL defines radiology procedures waiting time as "the time between the date of the request for an examination and the date of the examination." (Sanmartin and Steering Committee of the Western Canada Waiting List Project, 2003).

The date of request refers to the time when patients and their physician decide that the procedure is necessary. The period between those two data points (the date of request and the date of the examination) reflects the waiting time (Sanmartin & Steering Committee of the Western Canada Waiting List Project, 2003).

The following three main time intervals were examined in this study:

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) software v23. We employed descriptive statistics to calculate the mean and standard deviation for each time interval. Additionally, trend analyses were performed to assess the temporal changes in the duration of each phase over the study period. These statistical analyses were critical to identify any patterns or significant variations in scheduling timelines.

4. Results

This study analyzed the scheduling and performance of MRI and CT scans over a six-year period from 2017 to 2022. We examined trends in the monthly number of scans, the impact of the COVID-19 pandemic on these trends, and the variability in waiting times for different phases of the scheduling process. The study provides a comprehensive temporal analysis of the workflow, highlighting differences between CT and MRI scan processes and identifying areas for potential improvement in patient access to diagnostic services.

4.1. CT Scan trends and waiting times

During the initial three-year period from 2017 to 2019, the monthly number of CT scan cases ranged between approximately 700 and 900 (Fig. 1). However, in 2020, a notable decline was observed, with the lowest monthly incidence recorded in April at around 400 cases. This decrease coincided with the onset of the COVID-19 pandemic, which likely affected the number of CT scans performed. Subsequently, a pronounced upward trend was detected over the next two years, with the incidence peaking at just under 1800 cases in October 2022. This increase may reflect a backlog of cases and a return to normal healthcare operations.

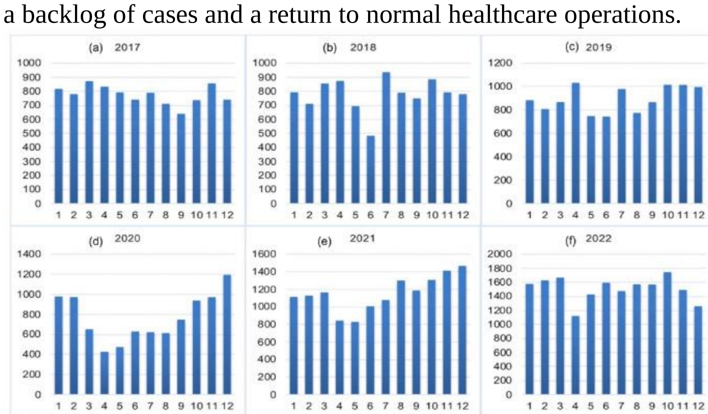

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Fig. 1. The monthly number of CT scan cases from 2017 to 2022.

4.2. MRI Scan Trends and Waiting Times:

The monthly incidence of MRI cases displayed greater variability compared to CT scans (Fig. 2). Similar to CT scans, there was a marked reduction in the number of MRI cases in 2020, reaching a minimum of around 100 cases in April 2020, likely due to the impact of the COVID-19 pandemic on healthcare services. Following this decline, an increase in the monthly number of MRI cases was observed in 2021 and 2022, but the growth was less pronounced than that observed for CT scans. This finding suggests that while both modalities were affected by the pandemic, the recovery in MRI usage was more gradual.

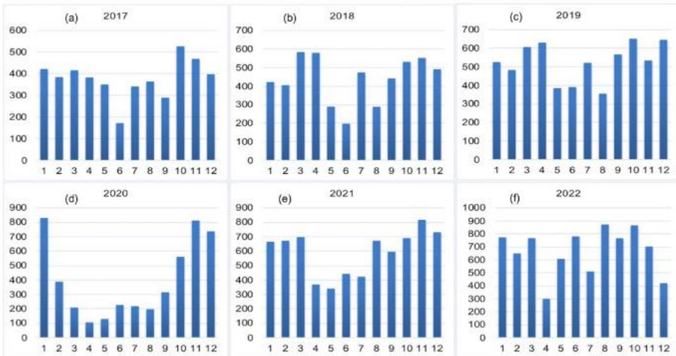

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Fig. 2. The monthly number of MRI cases from 2017 to 2022.

4.3. Detailed interval analysis for CT scans

Table 2 provides a detailed analysis of the time intervals between different steps in the scheduling and performance of CT scans. For DRA, which measures the time from the physician's imaging request to the patient's booking of the appointment, the mean duration is 2.67 days. The mode is 0 days, indicating that requests and scheduling are made on the same day. However, the maximum waiting time can extend to 1008 days, reflecting significant variability. The standard deviation of 18.13 further highlights this variability.

Table 2. CT number of days per step.

Interval	Mean	EHCI Waiting Time	Mode	Min	Max	SD
DRA	2.67	1	0	0	1008	18.13
DAS	5.25	1	0	0	358	20.19
DSP	0.000073	1	0	0	2	0.0101

For the DAS, which spans from the patient's booking of the appointment to its scheduling date in the hospital's system, the mean duration is 5.25 days, with a mode of 0 days, and a maximum of 358 days. This phase shows a slightly higher standard deviation of 20.19, indicating even greater variability in scheduling times.
The DSP, which measures the time from the appointment's scheduling to the actual performance of the imaging procedure, was nearly zero, indicating that most CT scans are conducted on the same day they are scheduled.

4.4. Detailed interval analysis for MRI scans:

Table 3 provides a detailed analysis of the time intervals between different steps in the scheduling and performance of MRI scans. For the DRA, which measures the time from the physician's imaging request to the patient's booking of the appointment, the mean duration is 11.10 days and the mode is 0 days, indicating that the request and scheduling occur on the same day. However, the maximum waiting time can extend up to 974 days, reflecting substantial variability. The standard deviation of 36.07 further highlights this variability.

Table 3. Number of days per step in the MRI process.

Interval	Mean	Mode	Min	Max	SD
DRA	11.10	0	0	974	36.07
DAS	20.25	0	0	378	34.57
DSP	0.000809	0	0	12	0.0793

For the DAS, which spans from the patient's booking of the appointment to its scheduling date in the hospital's system, the mean duration is 20.25 days, with a mode of 0 days and a maximum of 378 days. This phase shows a standard deviation of 34.57, indicating significant variability in scheduling times.
The interval DSP, measuring the time from the appointment's scheduling to the actual performance of the imaging procedure, has a mean duration of 0.000809 days and a standard deviation of 0.0793. This indicates that once scheduled, MRI scans are performed almost immediately.

4.5. Comparison of CT and MRI waiting times

When comparing the MRI waiting durations to those for CT scans (Table 2), we found that MRI appointments generally involve longer waiting times. The mean DRA for MRIs is 11.10 days compared to 2.67 days for CT scans, and the DAS for MRIs is 20.25 days compared to 5.25 days for CT scans (Table 4). Both intervals show greater variability for MRI, as reflected in the higher standard deviations.

Table 4. Days from making an appointment to performance of CT and MRI.

Year	CT					MRI				
	Mean	Min	Max	SD	N	Mean	Min	Max	SD	N
2017	6.58	0	888	25.14	9299	17.66	0	1223	32.35	4515
2018	6.35	0	920	28.41	9333	16.87	0	367	28.52	5249
2019	4.83	0	325	18.43	10727	19.69	0	772	35.12	6297
2020	2.83	0	323	14.72	9213	15.45	0	597	34.45	4735
2021	6.51	0	505	22.09	13831	30.48	0	378	46.06	7107
2022	5.42	0	329	20.38	17670	20.66	0	392	35.12	7562

We also calculated the total waiting times (from the date of request to the day the procedure was performed) for CT and MRI cases for each year (2017–2022). The percentage distribution across different waiting time ranges (2 days or less, 3–7 days, 7–14 days, 15–30 days, 31–90 days, and 91 days or over).

For CT scans (Fig. 3), the majority (over 70% each year) were completed within 2 days. The highest percentage was observed in 2020, where 83.64% of cases fell within this range. There was a notable reduction in cases requiring longer waiting times (over 91 days), with percentages consistently decreasing from 3.47% in 2017 to 1% in 2020, then slightly increasing again to 2.29% in 2022. This suggests an improvement in the rapid processing of CT cases over the years, although there was a slight increase in cases waiting 15–30 days and 31–90 days in 2021 and 2022.

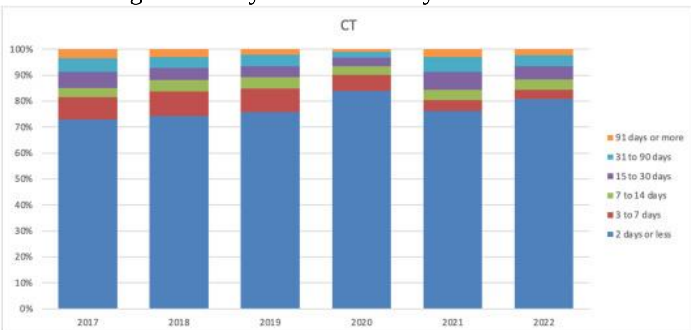

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Fig. 3. The distribution of CT Cases by Days from Request to Scan Over the Years (2017–2022). Each bar represents the percentage of cases within specific time ranges for each year.

The MRI scans, in contrast (Fig. 4), show a longer and more distributed waiting time pattern. The percentage of cases completed within 2 days was greater and showed an increase from 24.53% in 2017 to 40.83% in 2020, before settling around 29% in 2022. Longer waiting times (31–90 days) also show a significant presence, with a peak in 2021 where 28.09% of cases fell within this range. There is a marked decrease in the longest waiting times (over 91 days), reducing from 8.08% in 2017 to 5.91% in 2020, followed by an increase to 16.48% in 2021, and then a decrease to 9.41% in 2022.

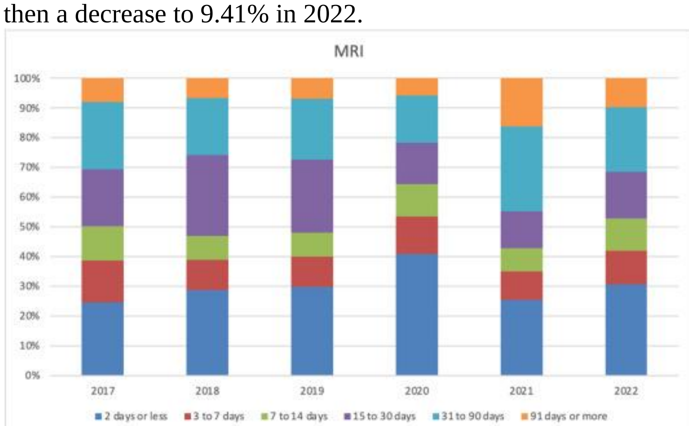

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Fig. 4. The Distribution of MRI Cases by Days from Request to Scan Over the Years (2017–2022). Each bar represents the percentage of cases within specific time ranges for each year.

5. Discussion

Our study provides a comprehensive temporal analysis of MRI and CT scan scheduling workflows over a six-year period in two major government hospitals in Saudi Arabia. The following key time intervals were examined: from request to appointment, scheduling, and exam completion. Using these intervals, we identified the critical points in patient waiting time. Our findings offer a valuable insight into potential inefficiencies and support policy recommendations for resource allocation, process redesign, and advanced technology adoption to streamline scheduling and ultimately improve patient care and service delivery.

The data reveals significant variability in the scheduling workflows for both CT and MRI scans in Saudi Arabia. The CT scans have a mean duration of 2.67 days from request to appointment, while MRI scans show an average of 11.10 days. This discrepancy highlights either a higher demand or a more complex scheduling process for MRI scans. In addition, the mode of 0 days for both imaging modalities indicates that some requests are addressed immediately, likely due to prioritization based on clinical urgency. The standard deviations (18.13 for CT and 36.07 for MRI) highlight the variability in scheduling times, suggesting that while some patients have timely appointments, others experience significant delays. This variability can be attributed to several factors, including fluctuating demand, availability of imaging equipment, and administrative efficiency (Kilgour, McLean, Paul, & Knight, 2024; Nickel & Schmidt, 2009; Omar, Al-Shahrani, Almushafi, & Boraie, 2022; White, Froehle, & Klassen, 2011).

The observed scheduling delays are consistent with findings from other international studies. For example, research conducted in the Netherlands, Croatia, Poland, and Canada indicates that average waiting times range from 14 to 78 days for CT scans and 18–268 days for MRI scans. These extended waiting times are often due to high demand, inadequate staffing, and technical issues or incompetence. The Ministry of Health in Saudi Arabia has policies aimed at improving access to healthcare, which includes guidelines to reduce waiting times for diagnostic procedures. Strategies such as increasing operating hours, enhancing equipment capacity, and incorporating private sector resources are recommended to address scheduling deficiencies. However, the effectiveness of these policies varies, and implementing them may not be sufficient to reduce waiting times.

When compared to other countries, the time periods for MRI and CT scans in Saudi Arabia are relatively shorter. For example, Canada reported average waiting times of 32 days for CT scans and 74 days for MRI scans from 2015 to 2021. Croatia saw the longest delays, with MRI waiting times extending to 268 days. These comparisons indicate that although Saudi Arabia faces challenges in imaging workflow efficiency, the situation is relatively good compared to other regions.

According to international guidelines, ideal waiting times for non-urgent MRI and CT scans should not exceed 30 days ("CADTH Health Technology Review: Wait List Strategies for CT and MRI Scans," 2023). Both the National Institute for Health and Care Excellence (NICE) (Noble et al., 2020) and the American College of Radiology (ACR) (Sistrom & Honeyman, 2002) emphasize timely access to imaging services to avoid negative impacts on patient outcomes. The data from Saudi Arabia, particularly for MRI scans, often exceed these recommended standards, indicating a need for policy adjustments and resource allocation to meet these benchmarks.

The variability in scheduling times significantly impacts hospital administration and policy. Long waiting times can lead to patient dissatisfaction, delayed diagnosis, and potentially worse health outcomes. For hospital administration, these inefficiencies result in increased operational costs and resource utilization.

The value of timestamp data for quality monitoring and understanding the process lies in its ability to highlight inefficiencies and bottlenecks in the scheduling and performance of medical imaging procedures. By analyzing the time intervals between request, appointment, and performance, healthcare providers can identify areas requiring improvement. Attention should be given to the stages with the most significant delays and variability, such as the "Days from Appointment to Scheduled" for both CT and MRI scans, as these stages demonstrate the greatest inconsistency and longest waiting times. Optimizing these stages can lead to more efficient workflows, reduced waiting times, and improved patient satisfaction.

Our research has important practical implications for enhancing healthcare efficiency. To effectively reduce patients' waiting times and improve service delivery, policymakers can utilize date stamp analysis to closely monitor and address the waiting time challenges and aid in the decisions related to investing in additional imaging equipment, hiring more staff, and redesigning administrative processes. On the other hand, utilizing advanced technologies, such as artificial intelligence (AI) for scheduling optimization and teleradiology, can mitigate some of these challenges (Li et al., 2021; Ranschaert, Topff, & Pianykh, 2021). While algorithm-based scheduling has previously addressed elements like resource allocation and case prioritization, AI adds new dimensions of power and adaptability (Cappanera, Visintin, Banditori, & Di Feo, 2019; Huang & Marcak, 2013). Artificial intelligence's ability to analyze larger, more complex datasets, including patient flow, appointment histories, and health conditions allows it to dynamically optimize scheduling and accurately forecast peak times. In this way, AI can help prioritize cases based on urgency, and, ideally, reduce waiting times for critical patients. Technologies such as Teleradiology can also distribute the workload more evenly across radiologists, ensuring timely reporting and fewer backlogs.

CT Angiogram - Contrast Enhanced

While this study provides valuable insights into the scheduling and performance of MRI and CT scans over six years at two major hospitals, several limitations should be acknowledged. Our results were limited to two specific hospitals, which may not be fully representative of the broader healthcare system. Including more sites would provide a more generalized and comprehensive overview of the scheduling and performance trends across different regions and healthcare settings.

Future research can expand on this study by incorporating data from more hospitals to achieve a more generalized understanding of MRI and CT scan scheduling and performance trends. Moreover, the integration of AI and advanced dashboard systems could significantly enhance the monitoring and management of radiology workflows. The AI-driven analytics could provide real-time monitoring of waiting times and identify potential bottlenecks, enabling hospitals and decision-makers to implement timely interventions and optimize resource allocation. Such systems could improve the quality of patient care by ensuring more efficient and effective scheduling processes, ultimately reducing waiting times and enhancing overall patient satisfaction.

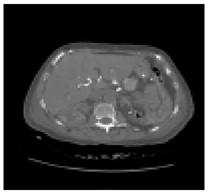

Figure:

Contrasted Computed Tomography of the Abdomen, Aortic Thrombosis Contributed by S Dulebohn, MD

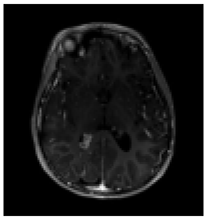

Figure:

Axial T1 Postcontrast Brain MRI. MRI demonstrates leptomeningeal enhancement and enlarged choroid plexus. Contributed by S Dulebohn, MD

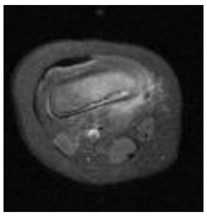

Figure:

MRI T1-Weighted Postcontrast, Knee Osteomyelitis Contributed by S Dulebohn, MD

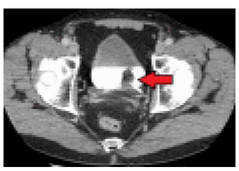

Figure:

Transitional Cell Carcinoma of the Bladder. The white area in the bladder is contrast. James Heilman, MD, Public Domain, via Wikimedia Commons

Figure:

Computed Tomography With Contrast. Computed tomography with contrast axial image showing cancer of the esophagus. Tdvorak, Public Domain, via Wikimedia Commons.

6. Conclusion:

This study reveals significant variation in the workflow of scheduling MRI and CT scans in two major hospitals in Saudi Arabia. The MRI scans showed longer and more variable waiting times than CT scans, suggesting higher demand or more complex scheduling processes. We observed a large decline in volume during the peak of the COVID-19 pandemic in 2020, followed by a gradual increase.

Despite improvements, waiting times for MRI scans often exceed international standards, necessitating policy changes and better resource allocation. The implementation of advanced technologies, such as artificial intelligence and teleradiology , has the potential to reduce delays and enhance scheduling efficiency. Addressing these shortcomings is essential for improving patient access to timely diagnostic services and overall patient satisfaction.

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