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Characterization of Pediatric Imaging Trends and Likelihood of Exam Cancellation in the COVID-19 Pandemic

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Rationale and Objective: The COVID-19 pandemic has caused unprecedented changes in radiology practice worldwide. There is a need for a framework of pediatric radiology resource allocation for future acute resource-limited settings. The aim of this study is to quantify and analyze changes in pediatric radiology practice during the COVID-19 pandemic considering demographic and clinical characteristics.

Materials and Methods: We retrospectively searched our institution's electronic health record for pediatric imaging exams from 09/15/19 to 05/01/20, with 03/15/20 as the dividing date between baseline and pandemic periods. Age, modality, exam indication, need for anesthesia/sedation, and exam completion or cancellation were recorded. All exams were compared between baseline and pandemic periods using a chi-square test and a logistic regression multivariate analysis.

Results: 15,424 exams were included for analysis [13,715 baseline period (mean age 10±5 years; 7440 males); 1047 COVID-19 period (mean age 9±5 years; 565 males)]. A statistically significantly lower proportion of adolescent exams (45.5% vs 53.3%), radiography modality (62.4% vs 70.4%) and non-traumatic pain indication (39.1% vs 46.3%) was observed during the COVID-19 period. Conversely, we found a higher proportion of neonatal (5.8% vs 3.8%), infant (5.6% vs 4.1%) and early childhood patients (12.9% vs 9.8%), CT (7.4% vs 5.9%) and ultrasound modalities (18.3% vs 13.5%), oncologic (8.8% vs 6.5%) and congenital/development disorder indications (6% vs 3.9%), and studies performed under anesthesia (2.7% vs 1.3%). Regarding exam completion rates, the neonatal age group (OR 1.960 [95% CI 0.353 – 0.591]; $p < 0.020$) and MRI modality (OR 1.502 [95% CI: 0.214 – 0.318]; $p < 0.049$) had higher odds of completion during the COVID-19 pandemic, while fluoroscopy modality was associated with lower odds of completion (OR 0.524 [95% CI: 0.328 – 0.839]; $p = 0.011$).

Conclusion: The composition and completion of pediatric radiology exams changed substantially during the COVID-19 pandemic. A sub-set of exams resilient to cancellation was identified.

Key Words: Pediatric radiology; Orders; Cancellation; Anesthesia; Imaging; Children.

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Abbreviations: Coronavirus 2019 (COVID-19), Magnetic resonance imaging (MRI), Computed tomography (CT), Odds ratio (OR)

INTRODUCTION

The coronavirus disease 2019 (COVID-19) global pandemic has caused unprecedented worldwide changes in healthcare delivery (1). While containment and mitigation approaches have been intensified, the exponential

and progressive increase in the number of cases has overwhelmed health systems globally (2,3). In an effort to mitigate the spread of COVID-19 and diminish its impact on healthcare systems during the initial pandemic phase in early 2020, many institutions underwent drastic changes in their operations to prioritize COVID-19 patient care, decreasing the volume of elective and nonurgent procedures in order to conserve vital resources and reduce the risk of infection to patients and medical staff (4,5). As a result, radiology departments' practice patterns worldwide significantly changed, with a drastic decline in volume particularly among outpatient exams (5–8).

Multiple factors account for the observed decrease in volume of imaging studies (7,9–11). Pediatrician daily clinical practices changed, including increased virtual care and

Acad Radiol 2022; 29:508–513

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<https://doi.org/10.1016/j.acra.2021.12.011>

accompanying alterations in threshold for ordering imaging (12). Additionally, deferrals and cancellations of nonurgent surgeries and other procedures had an indirect effect on requests for procedure-related imaging (13,14). Characterizing the impact of COVID on pediatric radiology practice is of particular interest because, even though the number of cases of severe COVID-19 in this population has been relatively low compared with adults, the disruptions caused by the pandemic have substantially changed the daily practices of pediatricians and pediatric patients (8,15). There is a close relationship between COVID-related school restrictions and the incidence of pediatric non-COVID infections and traumatic injuries (15). Additionally, parents and caregivers make decisions on whether to appear for radiology appointments, independent of provider decisions to order exams, which are often related to perceived COVID risk in hospital environments and can affect radiology volume (13,14,16).

Several studies have assessed the impact of COVID-19 on radiology practice in terms of overall changes in exam volume; however, there is limited information regarding the pandemic's specific impact on pediatric radiology (13,14). The purpose of this study is to characterize the changes in pediatric imaging exams during the COVID-19 pandemic and identify those factors most affecting the likelihood of exams taking place during the pandemic.

MATERIALS AND METHODS

The Institutional Review Board approved this single-institution retrospective study of a large academic pediatric tertiary care center embedded within a general hospital providing care for children and adults, and all procedures were compliant with the Health Insurance Portability and Accountability Act. The requirement for informed consent was waived. We searched our institution's electronic health record for inpatient and outpatient pediatric imaging exam orders and completed exams scheduled from 09/15/2019 to 05/01/2020, a time frame that included a baseline period and the first wave of the COVID-19 pandemic in our institution's local region (17). We set the cut-off date between the baseline at pandemic periods on 03/15/2020, corresponding to the date of local government enacted school closure. Inclusion criteria for our search were: (a) age < 18 years; (b) exam modality was fluoroscopy, Magnetic Resonance Imaging (MRI), radiography, nuclear medicine, ultrasound, or computed tomography (CT); and (c) exam indication corresponded to: (i) fever/infectious, (ii) trauma, (iii) non-trauma pain, (iv) oncologic, or (v) congenital/developmental (previously identified most common pediatric exam indications). We recorded the patient's age, sex, need for anesthesia or deep sedation, and if the exam was completed or canceled. Age was classified in neonatal (0 – 27 days), infant (28 days – 1 year), early childhood (>1 – 5 years), late childhood (>5 – 12 years), or adolescent (>12 v 18 years) groups.

We compared the differences in the proportion of exams completed between the baseline and pandemic period for age, indication, modality, and need for anesthesia/sedation groups. Each category was compared using a Pearson chi-square test. A multivariate logistic regression model was used to evaluate age groups, indications, modalities, and need for anesthesia/sedation as predictors of exam completion for each period (considering all exam orders). Coefficients for each analysis were compared using a seemingly unrelated estimation-based Wald test. Confidence intervals were calculated with seemingly unrelated estimation robust standard error estimates adjusted for patient clusters. All tests had an alpha threshold of 0.05. Tests and graphs were created in Stata v16 (StataCorp, College Station, Texas) and R v3.6 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Study Population

A total of 15,424 pediatric imaging exams were included for analysis [13,715 baseline period (mean age 10 ± 5 years; 7,440 males); 1,047 COVID-19 period (mean age 9 ± 5 years; 565 males)] (Fig 1).

Completed Exams

Several statistically significant differences between the baseline and pandemic periods in both clinical and sociodemographic characteristics were identified (Table 1; Fig 2). Exams during the pandemic period tended to belong to younger patients, with a significant increase in neonatal (5.8% vs 3.8%; $p = 0.0016$), infant (5.6% vs 4.1%; $p = 0.0232$), and early childhood patients (12.9% vs 9.8%; $p = 0.0016$), and a lower proportion of adolescents (45.5% vs 53.3%; $p < 0.001$). An increase in the proportion of CT (7.4% vs 5.9%; $p = 0.047$) and ultrasound exams (18.3% vs 13.5%; $p < 0.001$), and decreased radiography orders (62.4% vs 70.4%; $p < 0.001$) was also noted. Furthermore, indication for exams due to oncologic (8.8% vs 6.5%; $p = 0.0046$) and congenital or developmental disorders (6% vs 3.9%; $p = 0.001$) had a proportional increase, while a lower proportion of exams ordered for non-traumatic pain evaluation (39.1% vs 46.3%; $p < 0.001$) was seen. Finally, the proportion of orders for studies with anesthesia significantly increased (2.7% vs 1.3%; $p < 0.001$) when compared to the baseline period.

Multivariate Model Analysis

Adjusting for all demographic and clinical variables (age group, need for anesthesia/sedation, modality, and indication group), the baseline and pandemic periods had different predictors of exam completion (Table 2). Neonatal patients were less likely to have imaging orders in the baseline period (OR 0.457) as well as lower rate of exam completion ($p = 0.020$) compared with the pandemic period (OR 1.960)

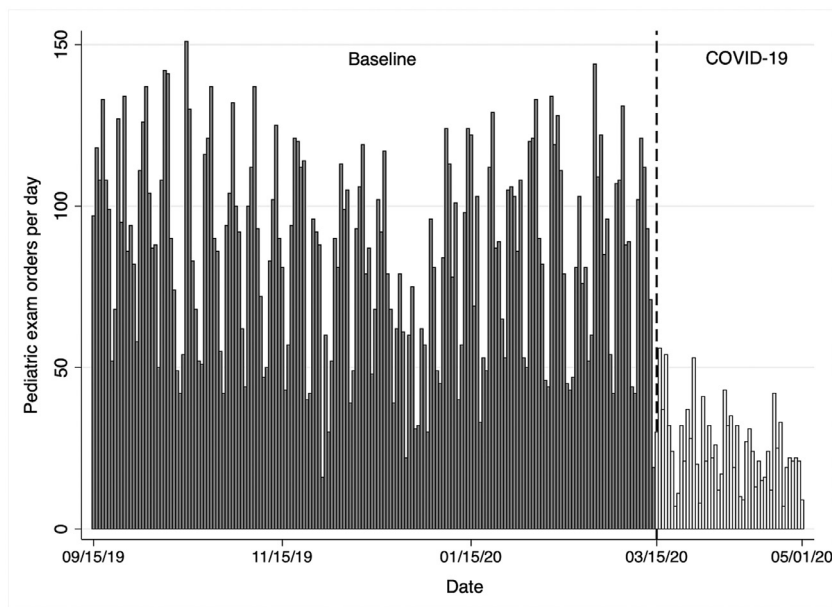


Figure 1. Pediatric exam orders per day in baseline and pandemic periods.

Legend: histogram of pediatric imaging exam orders per day in the baseline and pandemic periods. Cut-off date set at March 15th, 2020 (Massachusetts elementary and secondary school closure).

when compared to the adolescent age group (reference group). Similarly, MRI exam orders were less likely to be ordered in the baseline period (OR 0.261) and also less likelihood of being completed; $p = 0.049$) relative to the pandemic period (OR 0.502) compared to radiography exams (reference group). In contrast, fluoroscopy exams had a higher likelihood of being ordered (OR 0.524) as well as completed ($p = 0.011$) in the baseline period relative to the pandemic (OR 0.095) when compared to radiography exams (reference group). There were no significant differences between the baseline and pandemic models for exam order likelihood based on study indication (all $p > 0.639$) or the need for anesthesia/ sedation ($p = 0.555$).

DISCUSSION

In this single-institution retrospective study, we characterized changes in pediatric imaging exams during the COVID-19 pandemic related to demographic and study variables. A dramatic decrease in imaging volume for all imaging modalities across all age groups and study indications was found, plus several changes in the exams' compositional mix. These findings are concordant with previously reported studies on changes in general radiology practice (5–7, 18) and align with previous predictive models that suggest a significant negative impact on the likelihood of exam completion (5,9).

TABLE 1. Imaging Studies During The Baseline vs Pandemic Period

Variable	Baseline Period		Pandemic Period		p-Value	
		13715		1047		
Age Category	Neonatal	520	3.8%	61	5.8%	0.0016
	Infant	569	4.1%	59	5.6%	0.0232
	Early childhood	1342	9.8%	135	12.9%	0.0016
	Late childhood	3979	29.0%	316	30.2%	0.4176
	Adolescent	7305	53.3%	476	45.5%	0.0000
Gender Female		6275	45.8%	482	46.0%	0.8725
Anesthesia		179	1.3%	28	2.7%	0.0009
Modality	Fluoroscopy	112	0.8%	6	0.6%	0.4747
	Magnetic Resonance	1246	9.1%	113	10.8%	0.0651
	X-Ray	9655	70.4%	653	62.4%	0.0000
	Nuclear Medicine	46	0.3%	5	0.5%	0.4082
	Ultrasound	1846	13.5%	192	18.3%	0.0000
	Computed Tomography	810	5.9%	78	7.4%	0.0475
Indication	Fever/Infectious	1707	12.4%	120	11.5%	0.4075
	Trauma	4240	30.9%	363	34.7%	0.0123
	Non-Trauma Pain	6349	46.3%	409	39.1%	0.0000
	Oncologic	887	6.5%	92	8.8%	0.0046
	Congenital/ developmental	532	3.9%	63	6.0%	0.0010

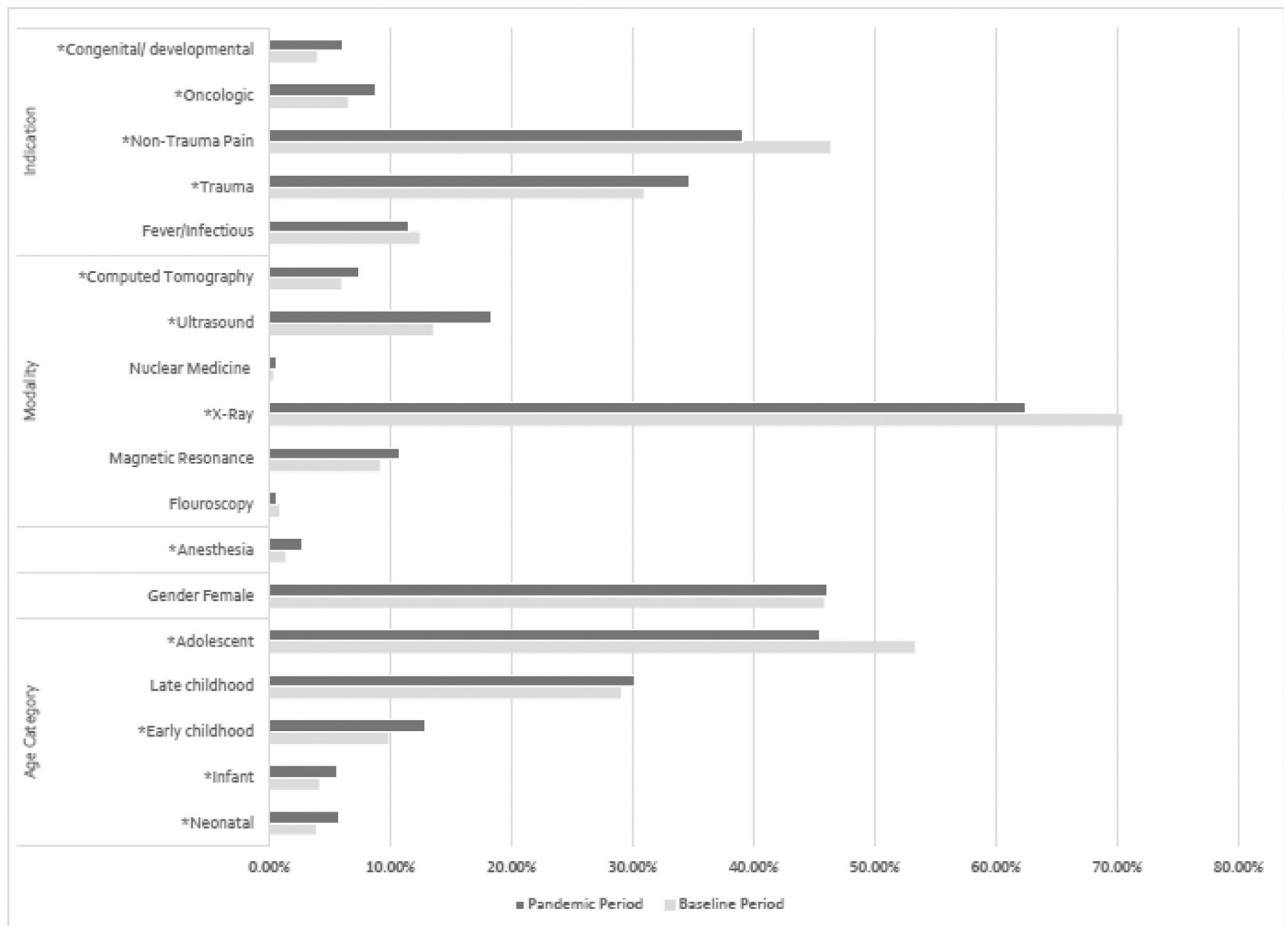


Figure 2. Imaging studies during the baseline vs pandemic period.

Legend: Percent exams completed during the baseline versus pandemic period.

The pandemic led to drastic changes in the daily practice of healthcare providers that significantly reduced in-person visits, with radiology orders decreased as a result (8). Many radiology departments also substantially reduced image services, especially outpatient and nonurgent exams, often in response to government policies to delay nonessential medical care as part of widespread efforts to slow the rate of new infections (5,18). Access to medical care was reduced for many patients because of these issues, combined with the fact that many patients and families did not feel comfortable coming to medical centers located in urban areas or participating in the care of COVID-19 patients (19,20). The confluence of all these factors led to distinctive trends in pediatric exam orders and exam completion rates in the pandemic period compared with baseline.

We observed a relative decrease of completed exams associated with adolescent age group, radiography modality, and non-trauma pain indication. These were all the largest groups of their respective categories at baseline, and, although this trend continued in the pandemic period, we observed more heterogeneity in terms of age, modality, and indications. This phenomenon was associated with a corresponding relative increase in exams for younger age groups (neonates, infants,

and early childhood groups) in the pandemic period, along with a shift towards a more significant demand for pediatric CT and ultrasound. Similarly, there was a relative increase in exams for oncologic and congenital/developmental indications. We hypothesize that the observed changes in the exams' compositional mix are a product of changes in the clinical practice of healthcare providers that deferred nonurgent and routine care, and prioritized diagnosis or follow-up of conditions such as cancer or congenital syndromes with critical implications on patient management and prognosis (8,21).

Additionally, our results suggest that exams performed in older patients, performed for non-traumatic pain indication, and plain radiographs, were more likely to be deferred during the COVID-19 pandemic. One explanation for this observation is that the clinical questions that these exams would address could be answered more easily without imaging (eg, with a phone call or virtual visit over time to assess for symptom resolution). Alternatively, these exams may be more likely to have been generated by outpatient clinic visits that were canceled during the COVID-19 pandemic.

The absolute change in the distribution of completed radiology exams was only one side of the observed trends. We

TABLE 2. Comparison of Multivariate Logistic Regression Models between Baseline and COVID-19 Emergency Periods

	Baseline			COVID-19			Comparison of estimated coefficients**
	OR of exam completion	ρ	[95% Conf. Interval]*	OR of exam completion	ρ	[95% Conf. Interval]*	
Age							
Neonatal	0.457	<0.001	0.353	0.591	1.960	0.270 0.592	6.487 0.020
Infant	0.700	0.023	0.514	0.953	0.614	0.236 0.274	1.375 0.764
Early Childhood	0.713	0.003	0.569	0.894	0.803	0.518 0.413	1.561 0.742
Late Childhood	0.886	0.148	0.752	1.044	0.802	0.371 0.494	1.301 0.702
Adolescent (Reference)	1.000				1.000		
Anesthesia/ sedation	0.554	0.001	0.389	0.789	0.413	0.057 0.166	1.026 0.555
Modality							
Magnetic resonance	0.261	<0.001	0.214	0.318	0.502	0.031 0.269	0.939 0.049
Fluoroscopy	0.524	0.007	0.328	0.839	0.095	<0.001 0.028	0.324 0.011
Nuclear Medicine	0.594	0.404	0.175	2.020	0.303	0.343 0.026	3.582 0.612
Ultrasound	0.402	<0.001	0.338	0.478	0.483	0.005 0.291	0.802 0.501
Computed tomography	0.327	<0.001	0.267	0.399	0.324	0.001 0.171	0.615 0.985
Radiography (Reference)	1.000				1.000		
Indication							
Fever/ infectious	0.714	0.001	0.589	0.867	0.454	0.012 0.245	0.841 0.173
Trauma	0.660	<0.001	0.554	0.785	0.989	0.969 0.567	1.726 0.174
Oncologic	0.915	0.484	0.713	1.174	0.785	0.434 0.429	1.437 0.639
Congenital/ developmental	1.024	0.867	0.778	1.346	0.589	0.254 0.238	1.462 0.252
Non-Trauma Pain (Reference)	1.000				1.000		

* 95% confidence intervals calculated with seemingly unrelated estimation robust standard error estimates adjusted for patient clusters.

** Estimated coefficients for each model (baseline and pandemic) were compared using seemingly unrelated estimation-based Wald tests.

also analyzed differences in the proportion of pediatric radiology exam orders that were completed. The pandemic was associated with an overall significant decrease in rate of radiology exam completion, which would include exams that were cancelled by the provider or the radiology department, as well as exams in which the patient did not show. Fluoroscopy exams followed this trend, with significantly lower odds of exam completion during the pandemic. These procedures typically involve close patient contact with the technologist and radiologist, and can be aerosol generating (eg, upper gastrointestinal series), and thus would be targeted for cancellation or deferral if not ordered for urgent indications (eg, rule out midgut volvulus in a neonate). We believe that fluoroscopy exams were preferentially cancelled in older patients because the clinical questions that they addressed were more likely to be addressed empirically (eg, prescription of anti-reflux medication).

Notably, our results demonstrate that imaging exams requiring anesthesia or sedation were generally resistant to cancellation and more likely to be completed. Despite the increased concern for aerosol generation related to airway protection during anesthesia and the need in many hospitals to conserve ventilators for the care of COVID-19 patients, pediatric anesthesia exams were not more likely to be canceled in the pandemic period when compared to baseline. This is especially noteworthy because the proportion of anesthesia/sedation exams more than doubled in the pandemic

period, reflecting a younger population shift and a relative increase in demand for more complex exam modalities like MRI. Furthermore, when adjusted for all relevant covariates, our analysis identified that neonatal and MRI exams had higher odds of exam completion in the pandemic period when compared to baseline. We hypothesize this could be due to: (a) the overall decrease in ordered exam volume enriching for cases with important clinical questions requiring advanced imaging like MRI, and (b) there is a high baseline clinical threshold for referring providers to order imaging exams under anesthesia, such that the clinical question cannot be answered by other means. Consequently, we consider anesthesia/sedation imaging exams to be highly prioritized studies even during the COVID-19 pandemic.

Our study is limited by its retrospective and single-center nature; as a result, the exact reasons for radiology exam orders and exam noncompletion were limited. A potential confounding variable in our analysis is seasonality, as the months of the baseline period do not exactly match those of the pandemic period. We chose to define our time periods as a continuous timeframe in order to minimize any annual variations in patient or exam volume and distribution that might occur if the two periods were separated in time. Additionally, it is an initial analysis to the complex and still emerging changes in health-care delivery during the ongoing COVID-19 pandemic. Nonetheless, the population size we analyzed permitted a multivariable analysis that allowed our study to consider both

clinical and demographic characteristics. Furthermore, it builds upon previous literature by examining the changes in exam orders and completion/cancellation rates to better understand the reasons behind changes in overall exam volume.

CONCLUSION

Our study proposes an assessment framework of pediatric radiology exam order volume that can be applied to future acute resource-limited settings. This analysis characterized a complex shift in exam order pattern, identifying a set of imaging modalities, patient age groups, and order indications that are prone and resilient to cancellation during COVID-19. For example, our data suggest that technologists and radiologists assigned to fluoroscopy and radiography services may be more easily reassigned to other services in future pandemics, while it is important to preserve anesthesia/sedation radiology appointment times. This strengthens the need to apply clinical decision support tools for appropriateness of exam ordering and selection during a future resource-limited setting or even during non-emergent situations as a resource-conservation strategy. Although our study was focused on changes in pediatric radiology practice during the COVID-19 pandemic, our approach and findings may be extrapolatable to the daily radiology practice. Similarly, this study shows the multifaceted nature of radiology exam volume variation that includes factors contributing to changes in exam orders as well as those impacting likelihood of exam completion. This topic merits further exploration. This type of analysis is likely to aid pediatric radiology departments to more effectively preserve critical radiology services while minimizing health risk to patients and staff during a future emergency setting.

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