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Impact of COVID-19 Workflow Changes on Patient Throughput at Outpatient Imaging Centers

Gregory Chang, MD, MBA, Ankur Doshi, MD, Hersh Chandarana, MD, MBA, Michael Recht, MD

Rationale and Objectives: To determine the impact of COVID-19 workflow changes on patient throughput at the outpatient imaging facilities of a large healthcare system in New York City.

Materials and Methods: COVID-19 workflow changes to permit social distancing and patient and staff safety included screening at the time of scheduling, encouraging patients to use our digital platform to complete registration/safety forms prior to appointments, stationing screeners at all entrances, limiting waiting room capacity, implementing a texting system to notify patients of delays, limiting dressing room use by encouraging patients to wear exam-appropriate clothing, and accelerating MRI protocols without reducing image quality. We assessed patients' pre-exam wait times, MR exam times, overall time spent on site, and registration for and use of the digital portal before (February 2020) and after (June 2020) implementation of these measures.

Results: Across 17 outpatient imaging centers, workflow changes resulted in a 23.1% reduction (-6.8 minutes) in all patients' pre-exam wait times ($p < 0.00001$). Pre-exam wait times for MRI, CT, ultrasound, x-ray, and mammography decreased 28.4% (-10.3 minutes), 16.5% (-6.7 minutes), 25.3% (-7.7 minutes), 22.8% (-3.7 minutes), and 23.9% (-5.0 minutes), respectively ($p < 0.00001$ for all). MR exam times decreased 9.7% (-3.5 minutes) and patients' overall time on site decreased 15.2% (-8.0 minutes). The proportions of patients actively using the digital patient portal (56.1%–70.1%) and completing forms electronically prior to arrival (24.9%–47.1%) increased ($p < 0.0001$ for both).

Conclusion: Workflow changes necessitated by the COVID-19 pandemic to ensure safety of patients and staff have permitted higher outpatient throughput.

Key Words: COVID-19; Administration; Operations; Radiology; Outpatient.

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INTRODUCTION

The COVID-19 pandemic has threatened the lives of tens of millions of people worldwide and has caused a major shift in how healthcare is delivered. During the first three months of the pandemic in the United States, the epicenter was New York State, whose tally at the end of June 2020 (390,000) surpassed that of all nations outside the United States, except Brazil, Russia, and India (1). Within New York State, New York City was the hardest hit, reporting nearly 6400 new daily cases at the peak of the pandemic in April 2020 and 212,000 total cases and 18,500 deaths by the end of June 2020 (2).

In response to the pandemic, governments implemented stay-at-home and social distancing measures, aiming to limit human movement, prevent overcrowding, and reduce

person-to-person spread of the virus. By May 2020, states that began to see a decline in new COVID-19 cases (Massachusetts, New York, Connecticut, New Jersey) began relaxing stay-at-home orders and allowing business activity, including elective healthcare procedures, to resume. When elective procedures resumed, social distancing measures remained in place. In addition, although stay at home orders were relaxed, there remained significant safety concerns among patients about having imaging procedures.

To ensure patients' and staff's safety, multiple workflow changes were introduced. Although similar changes have been described in prior articles (3–5), their effect on patient throughput has not yet been studied. A negative effect on patient throughput would lead to a corresponding decrease in departmental revenue. Although operating hours could potentially be increased to offset this decrease in throughput and revenue, this would lead to increases in costs and potential negative effects on faculty and staff morale and work-life balance. The goal of this study was to assess the overall impact of COVID-19 workflow changes on patient throughput at outpatient imaging centers at a tertiary care academic center at the epicenter of the COVID-19 pandemic.

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From the Department of Radiology, NYU Langone Health, New York, New York 10016 (G.C., A.D., H.C., M.R.). Received November 22, 2020; revised December 20, 2020; accepted December 22, 2020. **Address correspondence to:** G.C. e-mail: gregory.chang@nyulangone.org

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METHODS

Data Collection

All data was captured via electronic medical record (EPIC, Verona, Wisconsin) and our analytics software (Primordial Design, Nuance, Burlington, Massachusetts). For the months of February 2020 (old workflow) and June 2020 (new workflow), we retrospectively collected data from 17 of our highest volume outpatient imaging centers located in Manhattan, Brooklyn, Queens, Staten Island, and Long Island, which offered more than one modality and for which we are directly responsible for all operations. Magnetic resonance imaging (MRI), computed tomography (CT), ultrasound (US), radiography, and mammography were performed across all the sites, though not all imaging modalities were offered at every site. Specifically, one site offered two modalities (MRI, US), three sites offered three modalities (two sites: MR, CT, US and one site: MR, CT, XR), five sites offered four modalities (four sites: MR, CT, US, XR and one site: MR, US, XR, MG), eight sites offered five modalities (MR, CT, US, XR, MG).

Development of Workflow Changes

On March 23, 2020, before the peak of the pandemic and before elective procedures had resumed in New York City, the department began planning for when outpatient imaging centers would be permitted to re-open. A “post-surge” planning committee was established that was open to all faculty and staff interested in participating. 167 individuals responded, including front desk staff, technologists, scheduling and precertification staff, nurses, administrators, IT staff, and radiologists. The goal was to develop new workflows and policies allowing for social distancing and limiting the time patients spent in our facilities, while preserving image quality, the patient experience, and limiting any negative effect on our imaging capacity to ensure sustainability of any changes implemented.

Nine sub-committees were formed, including MRI, CT, US, breast imaging, PET-CT and/or nuclear medicine, radiography, radiologists, waiting room and/or front desk, and scheduling and/or precertification and/or medical records teams. Team members within each sub-committee included both faculty and staff, a mixture of different seniority and experience, and both subject matter experts as well as individuals without direct experience in that area to provide fresh perspectives. The goal for each team was to develop methods to ensure the safety of our patients and staff by allowing for proper social distancing, limiting patient wait times and total time in our centers but without any decrease in image quality or imaging capacity. Each team was asked to do an initial brainstorm and propose any ideas to modify our operations to safely provide services even if they were a stretch or completely radical. After the initial brainstorm phase, all teams continued to meet individually as well as one entire group to identify overlapping ideas and determine the best

initiatives that should be implemented. By mid-April 2020 when it became apparent that elective procedures would resume at the beginning of May, planning was accelerated and implementation began. All meetings were held virtually. Policy changes related to the use of personal protective equipment (PPE) and disinfecting machines were not considered within the scope of these committees as they were mandated by institutional policy.

Workflow Changes Implemented to Maintain Social Distancing

Scheduling

At our outpatient imaging centers, we eliminated all non-essential exams from mid-March 2020 until May 1, 2020. We resumed performing necessary, but non-emergent imaging exams on May 1, 2020 and on May 18, 2020 began performing screening examinations.

A series of screening questions were developed for our scheduling team to assess the potential of patients to be either COVID-19 positive or potentially COVID-19 positive due to symptoms or potential exposure to COVID-19 positive contacts. If such a risk existed, our schedulers used an electronic messaging system to contact an appropriate sub-specialist radiologist to determine the urgency of the examination. If the examination was deemed necessary to be performed urgently, the examination was scheduled with a notification placed in our electronic medical record (EPIC, Verona, Wisconsin) that the patient was COVID-19 positive or potentially COVID-19 positive. This allowed our “door screeners” to isolate that patient when they arrived and ensure that they were given appropriate PPE. In order to allow the screening of all patients, all walk-in examinations were discontinued in order to allow all patients to be screened prior to entering our centers.

We shortened all patient arrival times to 15 minutes before the scheduled start times of examinations. This was done to limit the time patients were in our waiting rooms to ensure appropriate social distancing. Patients were also instructed on appropriate clothes to wear for each examination to decrease the need for patients to use our dressing rooms to change their clothing once they arrived for their examination.

In addition, our schedulers were given a script describing to patients the potential uses of our electronic patient portal including the ability to schedule future examinations, fill out any necessary screening or safety forms necessary for their imaging examination, the ability to find out any necessary preparations for their examination, and the ability for patients access their reports and images, including the ability to download and share their reports and images. More recently, we have also added the ability for patients to perform “contactless check” in on the platform. Schedulers could see if patients were already subscribers to our portal and if they were not, patients were offered the opportunity to be transferred to a dedicated customer service representative to help them register for the portal.

Front Door, Waiting Rooms, and Dressing Areas

At each site, a staff member wearing personal protective equipment was designated as a front door screener. This screening repeated all screening questions to confirm that patients' answers had not change since the examination was scheduled. Patients were permitted entry to the outpatient imaging facility only if they arrived within 15 minutes of their scheduled exam arrival time and only if it was possible to maintain social distancing in the waiting room. Waiting rooms chairs were arranged so that patients could remain six feet apart, and any unused space in waiting rooms was designated for patients. In order to reduce the census in waiting rooms, no visitors were allowed to accompany the patient unless the guest was needed to assist the patient or if the patient was a minor.

After completion of check-in, patients were brought directly to exam rooms when available if they did not need to change into a gown. Otherwise, they were first brought to an available dressing room. For any studies involving oral contrast, if patients had driven to their appointment, they were asked to drink the oral contrast in their cars rather than in our waiting room.

Patient Texting

To further decrease crowding in our waiting room, we implemented texting via our EMR to inform patients if sites were running more than 15 minutes behind schedule. Patients were instructed not to arrive until they received a second text indicating their new arrival time and then again when it was time to arrive on site. Texting was also used for patients who did not want to use the patient portal to access their images but who requested CDs of their examination. All patients requesting CDs were requested to wait outside our centers while the CD was prepared and then a text was sent when the CD was ready so the patient could return and receive the CD from our front door screener.

Shortening MRI Scanning Protocols

The MRI subcommittee determined that the pandemic offered an opportunity to review all of our MR protocols to eliminate unnecessary sequences, optimize parameters such as interecho spacing by taking full advantage of higher gradient strengths and slew rates on our newer scanners, and introduce advanced pulse sequences such as compressed sensing and simultaneous multi-slice. The guideline for instituting these changes was that they could not compromise image quality. To accomplish this task, a group including radiologists from each section that interpreted MR and also some advanced practice technologist specialists was formed. As our MR scanners were significantly underutilized during the surge, there was ample time for new sequences and parameters to be developed and tested to ensure image quality. The technical details of these changes and the subspecialty specific impact on different exams will be described in a separate paper. Our goal in this paper is only to describe the overall impact on

patients' time spent in the MRI exam room in aggregate and at each site (see operational outcomes in the following).

Scheduled Exam Lengths

We initially increased scheduled outpatient exam appointment durations in order to ensure that patients could be spaced out and equipment could be cleaned and disinfected between patients. Based on feedback from technologists and staff at each site, X-ray (XR), CT, US, MRI, and mammography exams each received an additional 5, 5, 10, 10, and 15 minutes, respectively.

However, a few weeks after resumption of outpatient imaging, the staff at our outpatient imaging facilities provided feedback that this increase in exam time was not required to ensure social distancing for staff and patients. As a result, all scheduled diagnostic exam lengths were reverted back to their pre-COVID values.

Operational Outcomes Assessed and Statistical Analysis

For the months of February 2020 (old workflow) and June 2020 (new workflow), we evaluated three outcomes across all 17 outpatient centers in aggregate and at each center individually. First, we assessed the effect of the workflow changes on pre-exam wait times for patients. The mean pre-exam wait time, or the length of time from the patient's arrival was defined as the time recorded in EPIC when the front desk staff checks in or "arrives" the patient to the start of the patient's exam (the time recorded in EPIC when the technologist starts the patient's exam, which we have operationally defined across the enterprise as being when the patient enters the room). The second outcome was mean MRI exam time, which was defined as the length of time from the start of a patient's MRI exam to the completion of the MRI exam (the time recorded in EPIC when the technologist ends the patient's exam, which we have defined operationally across the enterprise as when the patient exits the room). Third, we evaluated patients' mean overall time on site or the length of time from the patient's arrival to the completion of the patient's exam. Across all centers in aggregate and at each center, we performed two sample t-tests (Excel v15.4, Redmond, Washington) to determine whether the differences in the mean values in June 2020 compared to February 2020 were statistically significant. We used a p value < 0.05 to denote statistical significance.

Finally, for the months of February 2020 and June 2020, we also evaluated two other outcomes: 1) the proportion of patients who had enrolled in MyChart, the digital patient portal, and 2) the proportion of patients who completed forms prior to arrival. Across all centers in aggregate and at each center, we performed a two-sample z-test to determine whether the differences in the monthly proportions in June 2020 compared to February 2020 were statistically significant (6). We used a p value < 0.05 to denote statistical significance.

TABLE 1A. Comparison of all Outpatients' Pre-exam Wait Times (Time of Patient Arrival to Start of Patient exam) Using the Pre-pandemic (February 2020) Versus the Post-pandemic (June 2020) Workflow

Site	All Modalities Pre-Exam Wait Times			
	% Change From Feb 2020 to June 2020	Mean Pre-Exam Time (Mins) Feb 2020	Mean Pre-Exam Time (Mins) June 2020	t-Test p Value
1	-30.1%	46.7±30.6	32.7±23.8	<0.00001
2	-26.9%	45.2±32.4	33.0±26.4	<0.00001
3	-24.8%	35.8±32.5	27.0±24.4	<0.00001
4	-14.5%	29.6±26.3	25.3±26.7	<0.00001
5	-22.9%	34.1±31.1	26.3±26.0	<0.00001
6	-26.7%	34.1±30.4	25.0±24.5	<0.00001
7	-16.5%	22.9±21.8	19.1±21.7	0.0001
8	-22.7%	28.2±25.5	21.8±23.4	<0.00001
9	-15.4%	21.0±21.8	17.8±25.0	<0.00001
10	-27.8%	26.6±26.6	19.2±20.4	<0.00001
11	-13.0%	25.2±37.7	21.9±21.4	0.0001
12	-27.8%	31.2±27.6	22.6±21.6	<0.00001
13	-24.7%	30.4±47.9	22.9±22.7	<0.00001
14	-26.3%	21.1±21.1	15.6±16.8	<0.00001
15	-16.9%	24.4±24.8	20.3±22.1	<0.00001
16	-17.8%	26.0±24.5	21.4±21.3	<0.00001
17	-22.5%	20.9±21.4	16.2±19.4	<0.00001
All	-23.1%	29.4±28.0	22.6±22.9	<0.00001

At 17 out of 17 sites and across all sites, there was a statistically significant reduction in patients' pre-exam wait times for all modalities.

RESULTS

Since many of our workflow changes affected pre-exam operational processes, we first assessed pre-exam wait times. Across all outpatient imaging centers in aggregate, patients' pre-exam wait times decreased 23.1% (-6.8 minutes, $p < 0.00001$) using the new workflow (Table 1a). When individual centers were analyzed, 17 out of 17 demonstrated statistically significant reductions in pre-exam wait times ranging from 13.0% (-3.3 minutes) to 30.1% (-14.1 minutes) ($p \leq 0.0001$ for all).

Since pre-exam processes can differ between modalities (e.g., types and amount of registration paperwork, need to drink oral contrast or have an intravenous catheter placed), we assessed changes in pre-exam wait times for each modality, also across all outpatient imaging centers in aggregate and at individual centers. For MR (Table 1b), across all outpatient imaging centers, patients' pre-exam wait times decreased 28.4% (-10.3 minutes, $p < 0.00001$). On the individual center level, 17 out of 17 centers demonstrated reductions in MR patients' pre-exam wait times ranging from 11.4% (-3.3 minutes) to 46.3% (-14.7 minutes) ($p \leq 0.0001$ for all). For CT (Table 1b), across all outpatient imaging centers, patients' pre-exam wait times decreased 16.5% (-6.7 minutes, $p < 0.00001$). On the individual center level, the majority of centers (11 out of 15) demonstrated reductions in pre-exam wait times ranging from 13.2% (-7.1 minutes, $p = 0.008$) to 30.3% (-9.0 minutes) ($p < 0.026$ for all). Three sites demonstrated increases in pre-exam wait times ranging from 19.2% (5.2

minutes) to 39.9% (3.4 minutes) ($p < 0.017$ for all). At the final center, changes in pre-exam wait time were not statistically significant.

For ultrasound (Table 1c), across all outpatient imaging centers in aggregate, patients' pre-exam wait times decreased 25.3% (-7.7 minutes, $p < 0.00001$ for all). On the individual center level, the majority of centers (14 out of 16) demonstrated reductions in pre-exam wait times ranging from 14.5% (-4.4 minutes) to 55.8% (-12.7 minutes) ($p < 0.018$ for all). At the other two centers offering ultrasound, changes in pre-exam wait times were not statistically significant. For x-ray (Table 1c), across all outpatient imaging centers in aggregate, patients' pre-exam wait times decreased 22.3% (-3.7 minutes, $p < 0.00001$). On the individual center level, the majority of centers (9 out of 14) demonstrated reductions in pre-exam wait times ranging from 16.2% (-2.4 minutes) to 47.4% minutes (-13.1 minutes) ($p \leq 0.003$ for all). At the remaining 5 centers that offered x-ray, changes in pre-exam wait time were not statistically significant. For mammography (Table 1c), across all outpatient imaging centers in aggregate, patients' pre-exam wait times decreased 23.9% (-5.0 minutes, $p < 0.00001$). On the individual center level, all centers (9 out of 9) demonstrated reductions in pre-exam wait times ranging from 10.8% (-2.3 minutes) to 40.3% (-10.2 minutes) ($p < 0.0017$ for all).

Third, we evaluated the impact of implementing accelerated MR protocols on patient throughput by assessing changes in patients' MR exam times across all outpatient imaging centers in aggregate and at individual centers

TABLE 1B. Comparison of MRI and CT Outpatients' Pre-exam Wait Times (Time of Patient Arrival to Start of Patient Exam) Using the Pre-pandemic (February 2020) Versus the Post-pandemic (June 2020) Workflow

Site	MRI				CT			
	% Change in Pre-Exam Wait Time Feb - June 2020	February Mean Pre-Exam Wait Time (Mins)	June Mean Pre-Exam Wait Time (Mins)	t-test Feb vs. June p value	% Change in Pre-Exam Wait Time Feb - June 2020	February Mean Pre-Exam Wait Time (Mins)	June Mean Pre-Exam Wait Time (Mins)	t-test Feb vs. June p value
1	-28.4%	47.1±26.3	33.8±19.3	< 0.00001				
2	-34.9%	46.6±27.4	30.3±19.2	< 0.00001	-19.7%	58.1±35.8	46.6±32.6	<0.00001
3	-26.0%	44.4±30.5	32.9±24.8	< 0.00001	-23.2%	51.0±35.5	39.2±26.6	<0.00001
4	-46.3%	31.8±24.8	17.1±16.9	< 0.00001	+22.6%	35.8±28.8	43.9±31.9	0.0003
5	-28.6%	35.8±27.9	25.6±22.6	< 0.00001	-13.2%	54.0±33.4	46.9±29.4	0.0080
6	-28.8%	39.8±26.7	28.4±21.9	< 0.00001	-25.9%	45.6±39.0	33.8±29.0	0.0000
7	-24.5%	28.5±20.9	21.5±19.5	0.00001	-20.4%	43.4±29.7	34.6±29.2	0.0069
8	-28.6%	31.7±23.7	22.6±29.3	< 0.00001	-22.9%	39.8±30.5	30.7±26.8	<0.00001
9	-18.5%	24.4±20.7	19.9±19.3	0.00015	+39.9%	8.5±11.3	11.9±16.1	<0.00001
10	-25.5%	37.6±29.3	28.0±20.7	< 0.00001	-23.0%	35.2±25.7	27.1±24.1	<0.00001
11	-27.0%	29.8±29.0	21.8±15.4	0.00009	-19.0%	28.0±26.3	22.7±21.8	0.0257
12	-27.2%	36.1±25.3	26.3±20.4	< 0.00001	-13.4%	37.9±30.8	32.8±26.5	0.0061
13	-26.5%	34.5±23.4	25.4±18.3	< 0.00001				
14	-36.1%	16.7±17.1	10.7±12.7	< 0.00001	-26.0%	38.1±32.6	28.2±25.3	0.0011
15	-11.4%	28.5±26.0	25.3±24.9	0.02800	-30.3%	29.8±27.3	20.8±19.2	<0.00001
16	-24.6%	26.0±20.0	19.6±14.2	< 0.00001	-3.9%	29.8±34.2	28.7±29.1	0.6300
17	-22.8%	28.7±23.3	22.1±20.8	0.00001	+19.2%	27.1±28.3	32.3±28.9	0.0172
All	-28.4%	36.3±26.8	26.±26.0	<0.00001	-16.5%	40.9±34.7	34.2±38.6	<0.00001

For MRI, at 17 out of 17 sites and across all sites, there was a statistically significant reduction in pre-exam wait times. for CT, at 11 out of 15 sites and across all sites, there was a statistically significant reduction in pre-exam wait times.

(Table 2). Across all outpatient imaging centers in aggregate, patients' MRI exam times decreased 9.7% (-3.5 minutes, $p < 0.0001$). On the individual center level, 12 out of 17 centers demonstrated reductions in MR exam times ranging from 7.1% (-2.9 minutes) to 32.7% (-15.4 minutes) ($p < 0.006$ for all). At two sites, there was an increase in MR exam times ranging from 7.0% (+2.4 minutes) to 7.8% (+2.4 minutes) ($p \leq 0.02$ for both). At three sites, changes in MR exam times were not statistically significant.

Fourth, although our workflow changes focused on pre-exam processes (with the exception of accelerating MR exam protocols), we also decided to assess the overall amount of time that patients spent on site across all outpatient imaging centers in aggregate and at individual centers (Table 3). Across all outpatient imaging centers in aggregate, patients' overall time on site decreased 15.2% (-8.0 minutes) ($p < 0.0001$). On the individual site level, 16 out of 17 centers demonstrated reductions in overall time on site ranging from 9.1% (-4.5 minutes) to 23.3% (-13.0 minutes) ($p \leq 0.006$ for all). At the final site, there was no statistically significant change in this parameter (+0.3 minutes, $p = 0.24$).

Finally, we assessed the change in proportion of patients who were actively using the digital patient portal and who completed forms digitally, also across all outpatient imaging centers in aggregate and at individual centers (Table 4). Across all outpatient imaging centers in aggregate, 70.1% of patients were using digital patient portal in June 2020 compared to 56.1% in February 2020 ($p < 0.0001$), and 47.1% of patients

completed forms electronically in June 2020 compared to 24.9% in February 2020 ($p < 0.0001$). Finally, on the individual center level, 17 out of 17 centers demonstrated increases in the proportions of these two outcomes that were statistically significant ($p < 0.0001$ for all).

DISCUSSION

Overall, we found that the COVID-19 workflow changes implemented at our outpatient imaging centers reduced the amount of time that patients spent in pre-exam areas (waiting rooms, dressing areas), reduced patients' MRI exam times, and reduced the overall amount of time that patients spent on site. In addition, the proportion of patients using the digital patient portal and completing registration forms prior to their appointment increased using the new workflow. In sum, the COVID-19 workflow changes were beneficial because they allowed us to increase patient throughput at our outpatient imaging centers.

Prior publications on the COVID-19 pandemic have described: the decline in outpatient radiology exam volumes (7), social distancing practices in radiology departments (8), how radiology departments have rescheduled (9) and resumed performing (10) nonurgent exams, survey results from academic radiology chairs' recovery plans (3), and how radiologists' onsite versus offsite reading workflow has changed (11). However, to our knowledge there is no prior literature describing the impact of the COVID-19 workflow

TABLE 1C. Comparison of Ultrasound, X-Ray, and Mammography Outpatients' Pre-exam Wait Times (Time of Patient Arrival to Start of Patient Exam) Using the Pre-pandemic (February 2020) Versus the Post-pandemic (June 2020) Workflow

Site	US				X-ray				Mammography			
	% Change in Pre-Exam Wait Time Feb - June 2020	February Mean Pre-Exam Wait Time (Mins)	June Mean Pre-Exam Wait Time (Mins)	t-test Feb vs. June <i>p</i> value	% Change in Pre-Exam Wait Time Feb - June 2020	February Mean Pre-Exam Wait Time (Mins)	June Mean Pre-Exam Wait Time (Mins)	t-test Feb vs. June <i>p</i> value	% Change in Pre-Exam Wait Time Feb - June 2020	February Mean Pre-Exam Wait Time (Mins)	June Mean Pre-Exam Wait Time (Mins)	t-test Feb vs. June <i>p</i> value
1	-40.4%	38.7±29.7	23.1±22.1	<0.00001								
2	-16.1%	17.1±20.7	14.3±17.9	0.018								
3	-49.6%	37.1±29.7	18.7±17.2	<0.00001	-4.2%	11.6±9.4	11.1±10.0	0.16				
4					2.8%	8.3±12.7	8.6±11.5	0.87				
5	-36.7%	29.7±27.4	18.8±17.9	<0.00001								
6	-50.6%	20.0±19.6	9.9±14.2	<0.00001	-21.4%	21.2±16.4	16.7±16.7	0.003				
7	-55.8%	22.7±19.4	10.0±15.7	<0.00001	8.4%	12.2±12.2	13.2±15.4	0.31				
8	-26.9%	37.3±28.4	27.3±21.1	<0.00001	-33.3%	14.6±18.1	9.7±14.0	<0.00001	-24.9%	21.0±18.1	15.8±15.9	<0.00001
9	-17.3%	26.8±22.3	22.1±19.7	<0.00001	-16.2%	14.7±13.5	12.3±14.0	0.00011	-20.6%	21.7±25.5	17.2±27.4	<0.00001
10	-26.1%	27.0±27.3	19.9±20.5	<0.00001	-32.8%	18.3±23.3	12.3±16.5	<0.00001	-34.4%	18.9±19.9	12.4±15.4	<0.00001
11	-4.9%	29.9±26.5	28.4±23.9	0.22	1.9%	24.5±24.6	25.0±20.7	0.73	-32.9%	19.1±25.1	12.8±16.8	<0.00001
12	-30.6%	34.0±28.9	23.6±20.5	<0.00001	-26.7%	18.3±23.6	13.4±17.8	0.0005	-40.3%	25.3±23.4	15.1±15.7	<0.00001
13	-22.8%	38.9±32.6	30.0±29.5	<0.00001	-26.2%	11.1±19.2	8.2±14.6	0.00016	-23.3%	24.0±23.9	18.4±19.5	<0.00001
14	-29.0%	29.2±23.2	20.7±17.9	<0.00001	-13.7%	12.3±11.7	10.6±10.3	0.076	-26.1%	12.2±10.2	9.0±9.6	<0.00001
15	-14.5%	30.7±28.4	26.3±26.5	0.00005	-25.8%	19.2±20.0	14.3±16.6	<0.00001	-15.5%	18.7±20.9	15.8±17.2	0.00063
16	-3.9%	28.5±27.9	27.4±24.4	0.352	-47.4%	27.6±23.9	14.6±17.8	<0.00001	-10.8%	21.3±18.1	19.0±17.2	0.0018
17	-34.3%	14.7±19.4	9.7±14.2	<0.00001	-41.0%	19.4±17.5	11.5±10.4	<0.00001				
All	-25.3%	30.5±26.8	22.8±21.8	<0.00001	-22.8%	16.9±19.0	13.0±15.4	<0.00001	-23.9%	20.9±22.1	15.9±19.1	<0.00001

Across all sites in aggregate, for ultrasound, x-ray, and mammography, there was a statistically significant reduction in pre-exam wait times. for ultrasound (14 out of 16 sites), x-ray (9 out of 14 sites), and mammography (9 out of 9 sites), the majority of individual sites also demonstrated statistically significant reductions in pre-exam wait times.

TABLE 2. Comparison of MR patients' exam times using the pre-pandemic (February 2020) versus the post-pandemic (June 2020) MRI protocols

Site	MR Exam Times				t-test <i>p</i> value
	% Change from Feb 2020 to June 2020	Mean Pre-Exam Time (Mins) Feb 2020	Mean Pre-Exam Time (Mins) June 2020		
1	-12.0%	35.1±29.8	30.9±13.9	0.00003	
2	-15.3%	34.6±16.8	29.3±15.7	<0.00001	
3	-9.0%	40.2±20.9	36.6±21.1	0.00006	
4	0.2%	40.3±20.9	40.4±23.3	0.94	
5	-15.8%	26.5±12.1	22.3±14.9	0.00001	
6	-24.9%	31.7±20.4	23.8±15.9	<0.00001	
7	-10.6%	30.1±16.1	26.9±15.2	<0.00001	
8	-11.1%	36.9±18.3	32.8±20.8	0.0002	
9	-4.0%	32.8±15.8	31.5±15.1	0.15	
10	-11.7%	35.8±16.4	31.6±5.4	<0.00001	
11	-32.7%	47.1±21.5	31.7±17.4	<0.00001	
12	-6.9%	34.8±15.5	32.4±16.0	0.0006	
13	-7.1%	40.6±17.5	37.7±18.4	0.0004	
14	-13.5%	45.9±21.2	39.7±18.3	0.00004	
15	7.0%	34.4±14.2	36.8±15.3	0.005	
16	7.8%	30.8±12.5	33.2±14.2	0.02	
17	0.8%	37.8±18.9	38.1±18.2	0.78	
All	-9.7%	36±17.3	32.5±17.3	<0.00001	

Across all sites in aggregate and at 12 out of 17 sites, there was a statistically significant reduction in MR exam times.

TABLE 3. Comparison of the proportion of patients who enrolled in the digital patient portal (MyChart) and who completed registration forms prior to arrival in February 2020 versus June 2020

Site	Proportion of Patients Enrolled in Digital Patient Portal Feb 2020	Proportion of Patients Enrolled in Digital Patient Portal June 2020	z-test <i>p</i> value	Proportion of Patients Who Digitally Completed Registration Paperwork Feb 2020	Proportion of Patients Who Digitally Completed Registration Paperwork June 2020	z-test <i>p</i> value
1	72.4%	86.2%	<0.00001	32.9%	62.8%	<0.00001
2	75.2%	83.7%	<0.00001	32.8%	58.2%	<0.00001
3	66.8%	81.1%	<0.00001	30.7%	47.2%	<0.00001
4	74.2%	81.8%	<0.00001	30.3%	44.9%	<0.00001
5	59.3%	79.6%	<0.00001	23.4%	51.3%	<0.00001
6	38.5%	59.9%	<0.00001	3.0%	58.5%	<0.00001
7	53.8%	74.0%	<0.00001	17.5%	58.1%	<0.00001
8	52.5%	74.2%	<0.00001	17.5%	41.3%	<0.00001
9	53.4%	73.2%	<0.00001	20.8%	42.5%	<0.00001
10	30.8%	41.2%	<0.00001	14.5%	33.0%	<0.00001
11	26.5%	45.8%	<0.00001	9.1%	37.2%	<0.00001
12	46.6%	65.3%	<0.00001	15.1%	40.1%	<0.00001
13	59.3%	75.6%	<0.00001	19.7%	40.2%	<0.00001
14	60.7%	81.2%	<0.00001	26.6%	45.8%	<0.00001
15	28.0%	40.9%	<0.00001	13.8%	27.0%	<0.00001
16	41.2%	47.9%	<0.00001	6.9%	25.9%	<0.00001
17	32.4%	39.7%	<0.00001	10.7%	22.3%	<0.00001
All Sites	56.1%	70.1%	<0.00001	24.9%	47.1%	<0.00001

Across all sites in aggregate and at 17 out of 17 individual sites, there was a statistically significant increase in the proportion of patients who enrolled in the digital patient portal and who digitally completed registration paperwork prior to arrival.

TABLE 4. Comparison of patients' overall time on site (time of patient arrival to time of exam completion) using the pre-pandemic (February 2020) compared to the post-pandemic (June 2020) workflow

Site	% Change from Feb 2020 to June 2020	Mean Overall Time On Site (Mins) Feb 2020	Mean Overall Time On Site (Mins) June 2020	t-test p value
1	-19.9%	81.8±44.2	65.5±31.3	<0.0001
2	-22.6%	72.0±36.2	55.7±28.7	<0.0001
3	-16.4%	56.4±43.2	47.2±31.2	<0.0001
4	+0.55%	54.7±35.5	55.0±33.0	0.24
5	-15.3%	55.3±33.0	46.8±31.8	<0.0001
6	-23.3%	55.8±35.1	42.8±26.7	<0.0001
7	-10.8%	43.6±30.0	38.9±26.8	0.0001
8	-14.8%	50.8±60.1	43.3±33.1	<0.0001
9	-10.6%	43.3±29.6	38.7±27.9	<0.0001
10	-16.5%	54.6±58.2	45.7±34.0	<0.0001
11	-15.7%	48.5±33.7	40.9±27.6	<0.0001
12	-17.8%	52.8±32.3	43.4±32.4	<0.0001
13	-17.3%	54.9±60.2	45.4±50.4	<0.0001
14	-18.6%	44.7±30.8	36.4±37.7	<0.0001
15	-9.1%	49.7±64.7	45.2±60.4	0.0006
16	-11.7%	45.6±67.5	40.3±25.8	<0.0001
17	-11.2%	43.0±29.0	38.2±28.1	<0.0001
All Sites	-15.2%	52.6±36.4	44.6±30.7	<0.0001

At 16 out of 17 sites, there was a statistically significant reduction in patient's overall time on site. At site #4, there was no significant change in total patient time on site using the new workflow compared to the old workflow.

changes on patient throughput at outpatient imaging centers. Our investigation of this issue adds to the body of literature on the impact of radiology workflow changes implemented during the COVID-19 pandemic.

The operations management definition of throughput rate (or flow rate) is the rate at which a process delivers output (number of units/hour) (12). So, if the pre-exam process is defined as the steps required from a patient's arrival to the start of the patient's exam, then the 23.1% reduction in patients' pre-exam wait times across all sites is equivalent to a 30% increase ($1/(1-0.231) = 1.30$) in patient throughput for the pre-exam process. This is because more patients can move through the pre-exam area per a given unit of time.

The modality level analysis reveals the variation in pre-exam wait times between different modalities, with CT and MR pre-exam wait times being the longest and those for x-ray being the shortest. It is not surprising that the pre-exam wait time for CT and MR (34.2 ± 38.6 minutes and 26.0 ± 20.4 minutes, respectively in June 2020) were the longest since this includes time that patients spent having intravenous catheters placed or for CT in particular, drinking oral contrast. In contrast, X-ray pre-exam wait times (13.0 ± 15.4 minutes) were shorter because they require little registration paperwork or patient preparation. At three out of 17 sites, CT pre-exam wait times increased. Upon further investigation, the increase in the pre-exam times at these sites appears to be related to the re-allocation of staff, such that a staff member who had a patient expeditor or escort role had to devote effort to front door screening duties, thereby decreasing patient waiting room throughput. However, because we witnessed a reduction in CT pre-exam wait times at the majority of our outpatient

centers and across the enterprise, we believe that we can reduce the CT pre-exam wait times at these sites by more optimally balancing staffing efforts between front desk, patient escort, and front door screening duties.

There was variation in terms of the amount of change or reduction in pre-exam wait times across the sites. We performed a correlation analysis, and there was no correlation between the change in pre-exam wait time and number of modalities offered at each site or between the change in pre-exam wait time and volume of exams performed at each site ($r < 0.1$ for both). However, there was a strong correlation between the change in pre-exam wait times and the baseline or pre-COVID pre-exam wait time ($r = -0.92$). More specifically, the greater the baseline pre-exam wait time, the greater was the reduction in pre-exam wait time after the implementation of the new workflow. It is possible that the urgency created by the pandemic allowed us to have better compliance at all of our imaging centers in implementing improvements in our patient flow and throughput at our outpatient imaging centers than in the pre-COVID state."

For MRI, the implementation of accelerated imaging protocols resulted in a 9.7% reduction in exam times across all centers in aggregate. This is equivalent to a 10.7% increase ($1/[1-0.097] = 1.107$) in patient throughput across the enterprise. On further investigation, the two sites (numbers 15 and 16) where MR exam times increased by 2.4 minutes each and site number 17 (where there was no change in MR exam time) had not yet implemented the accelerated MR exam protocols nor had fully reverted to pre-COVID exam durations in June 2020. We note that the implementation of the complete set of accelerated MR exam protocols (those taking

advantage of high gradient strengths and slew rates and those using compressed sensing or simultaneous multi-slice methods) requires the latest MR scanners (hardware) and operating systems (software). We would also like to emphasize that a requirement of the accelerated protocols was that image quality could never be compromised. As we upgrade our fleet of MR scanners across the enterprise, we anticipate that MR exam times will only continue to decrease enterprise-wide. As mentioned previously, the technical details of the MR exam protocol changes and subspecialty specific outcomes will be discussed in a separate paper and our goal in this paper is to only to discuss global changes.

With regards to patients' overall time spent on site, the 15.2% reduction in time is equivalent to a 17.9% increase ($1/[1-0.152] = 1.179$) in patient throughput across sites. The overall time spent on site is due to both time spent in the pre-exam areas and time spent in the exam rooms. For MR, the overall reduced amount of time spent on site was due to both reduced pre-exam wait times and exam times, and for other modalities, it was due to reduced pre-exam wait times only, since we did not shorten imaging protocols for other modalities. Therefore, the main driver of higher overall outpatient imaging throughput is due to higher throughput in the pre-exam areas. We note that the throughput of an entire process is limited by the slowest step or bottleneck in the process (12). The higher overall patient throughput would in theory allow us to increase the daily capacities (total number of exams possible) for example for MRI at our outpatient imaging centers compared to our pre-COVID capacities. The ability to raise capacity without constructing a new facility or purchasing a new scanner is beneficial since it could help us accommodate any increased demand in the future.

The higher proportion of patients using the digital patient portal and filling out forms digitally prior to arrival can also improve patient throughput in pre-exam areas, as patients no longer have to linger in the front desk or waiting area to fill out registration forms or patient questionnaires. In addition, as more patients use our digital platform there will be the opportunity to decrease the number of schedulers and front desk staff needed. There is still great room for improvement as only ~70% of our outpatients are using the digital patient portal and slightly less than 50% of these patients are filling out their forms digitally in advance. We expect that there will be further reductions in pre-exam wait times as these percentages increase.

Although patient surveys were not conducted to assess patient's response to the workflow changes implemented, it is likely that the decrease in pre-exam wait time and overall time spend in the imaging center as well as the ability to perform many functions on-line using the patient portal would increase patient's satisfaction. It is important to note that none of our workflow changes led to an increase in staffing costs. If sustained, the increase use of the patient portal to schedule examinations, fill out forms, use contactless check in, and access images and reports without the need for the production of a CD should decrease staffing costs.

It is important to note that improvements in workflow to improve the patient experience should not be limited to times of crisis such as the COVID-19 pandemic but should be a constant goal of all imaging centers. Over the past several years we have implemented several such improvements such as the implementation of dockable tables for MR (13) and techniques to accelerate MR imaging protocols (14). However, crises create a sense of urgency, an important element in successfully implementing change (15).

This study has limitations. First, the EPIC time stamps of arrival times, exam start times, and exam completion times were all recorded manually by either front desk staff or technologists. However, there is no reason why this manual process would be any more or less accurate for June 2020 operational data compared to February 2020 operational data. Second, patients' pre-exam wait time (patient arrival to exam start time) does not include the small amount of time that patients spend after they enter the front door and wait in line for the front desk to check them in or "arrive" them in EPIC. Related to this, the overall time spent on site does not include the time that a patient spends after exiting the exam room and going to the dressing room to change if needed. However, the latter data are not easily measurable across all our outpatient imaging sites (we do have one site where patients wear radiofrequency identification bands so that we can track real time location, but it is financially not feasible to implement this universally). In addition, we feel that patient arrival time to exam start time and patient arrival time to exam completion time are reasonably accurate proxies for pre-exam wait time and overall time spent on site. Finally, we note that we did rely on the health system information technology team to standardize and implement the changes in patients' pre-exam arrival times, text messaging capability, and digitization of registration forms. However, we believe that all of these are measures that could be implemented to some degree by any radiology practice. Pre-exam arrival times could be set by the scheduling staff. Text messaging services for patients are now offered by a variety of third parties or could also be performed by front desk team. Finally, forms could always be uploaded as pdf files onto a website for completion in advance.

In summary, COVID-19 workflow changes have allowed us to reduce patients' pre-exam wait times, patients' MRI exam room time, and patients' overall time on site at our outpatient imaging facilities. This higher patient throughput is beneficial because it helps ensure social distancing and safety for patients and staff and allows for higher patient capacity and possible increased revenue in the future using the same resources when the pandemic is over.

AUTHOR CONTRIBUTIONS

All authors contributed to the design of the work, to the acquisition and analysis of data, and to the drafting and revising of the work. All authors approved the final version that was submitted. The authors declare that they had full access

to all of the data in this study and the authors take complete responsibility for the integrity of the data and the accuracy of the data analysis.

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