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Radiology Imaging Volume Changes During Discrete COVID-19 Pandemic Waves: Implications for the Delta Variant of Coronavirus and Future Pandemics

Adam Schwertner, MD^{a,b}, John McMenemy, MD, MBA^{b,c}, David M. Naeger, MD^{b,d}

Abstract

Purpose: The aim of this study was to evaluate radiology imaging volumes at distinct time periods throughout the coronavirus disease 2019 (COVID-19) pandemic as a function of regional COVID-19 hospitalizations.

Methods: Radiology imaging volumes and statewide COVID-19 hospitalizations were collected, and four 28-day time periods throughout the COVID-19 pandemic of 2020 were analyzed: pre-COVID-19 in January, the “first wave” of COVID-19 hospitalizations in April, the “recovery” time period in the summer of 2020 with a relative nadir of COVID-19 hospitalizations, and the “third wave” of COVID-19 hospitalizations in November. Imaging studies were categorized as inpatient, outpatient, or emergency department on the basis of patient location at the time of acquisition. A Mann-Whitney *U* test was performed to compare daily imaging volumes during each discrete 28-day time period.

Results: Imaging volumes overall during the first wave of COVID-19 infections were 55% (11,098/20,011; $P < .001$) of pre-COVID-19 imaging volumes. Overall imaging volumes returned during the recovery time period to 99% (19,915/20,011; $P = .725$), and third-wave imaging volumes compared with the pre-COVID-19 period were significantly lower in the emergency department at 88.8% (7,951/8,955; $P < .001$), significantly higher for outpatients at 115.7% (8,818/7,621; $P = .008$), not significantly different for inpatients at 106% (3,650/3,435; $P = .053$), and overall unchanged when aggregated together at 102% (20,419/20,011; $P = .629$).

Conclusions: Medical imaging rebounded after the first wave of COVID-19 hospitalizations, with relative stability of utilization over the ensuing phases of the pandemic. As widespread COVID-19 vaccination continues to occur, future surges in COVID-19 hospitalizations will likely have a negligible impact on imaging utilization.

Key Words: COVID-19 pandemic, medical imaging utilization, emergency department imaging, chest imaging, DVT ultrasound

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^aDepartment of Radiology, Denver Health Medical Center, Denver, Colorado.

^bDepartment of Radiology, University of Colorado School of Medicine, Aurora, Colorado.

^cAssistant Director of Service, Department of Radiology, Denver Health Medical Center, Denver, Colorado.

^dDirector of Service, Department of Radiology, Denver Health Medical Center, Denver, Colorado.

Corresponding author and reprints: Adam Schwertner, MD, Department of Radiology, Denver Health Medical Center, 777 Bannock Street, MC 0024, Denver, CO 80204; e-mail: adam.schwertner@dhha.org.

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INTRODUCTION

Coronavirus disease 2019 (COVID-19) had a major impact on health care system operations throughout 2020 [1]. At the beginning of the COVID-19 pandemic (ie, the “first wave”), institutions restricted the number of imaging studies performed in an attempt to preserve personal protective equipment, contribute to social distancing, and slow the spread of the disease. Studies have shown that imaging volumes were significantly reduced in March and April 2020, particularly outpatient imaging, which fell by 68% in one single-institution retrospective analysis [2]. Similarly, inpatient imaging was seen to decline, with a trend toward increased use of radiography versus cross-sectional imaging in the early stages of the pandemic [3].

Health care systems' safety protocols have adapted throughout the COVID-19 pandemic to ensure social distancing while maintaining access to necessary medical care, including medical imaging. Studies comparing actual imaging volumes with estimated models of recovery during the summer of 2020 suggest that medical imaging had made a swift recovery to near pre-COVID-19 levels [4]. What remains uncertain is how medical imaging volumes changed as subsequent COVID-19 case surges occurred (eg, the second and third waves). In late October and November 2020, COVID-19 cases began to surge in many US locations. In our region, the number of daily COVID-19 hospitalizations, a marker of total COVID-19 cases, exceeded April 2020 levels in November 2020 [5]. How medical systems handled subsequent COVID-19 case surges in 2020 could be relevant to future case surges as new, more infectious strains of COVID-19 are being discovered, such as the delta variant (B.1.617.2), which became the dominant strain in the latter half of 2021 [6]. At the time of writing, this strain is leading to waves of infections, even among vaccinated persons [7]. Should our data show substantial delaying of care during multiple waves, the cumulative amount of imaging and medical care being deferred may also have implications for the volume of services needed once the majority of the population is vaccinated.

The aim of this study was to evaluate our institution's imaging volumes during discrete surges of COVID-19 hospitalizations. The temporal volumes of multiple types of medical imaging were evaluated, including inpatient examinations, outpatient examinations, emergency examinations, and targeted modality-specific examinations. We hypothesized that the institution of safety protocols and the general public's increasing familiarity with safety protocols resulted in less drop-off in imaging volumes during later surges in the fall of 2020 compared with the initial surge.

METHODS

Setting and Data Collection

Institutional review board approval was obtained for this study. Our institution is a 525-bed public hospital and level I trauma center in a centrally located urban setting with a large catchment area. All imaging studies performed at our institution were recorded and categorized from January 1, 2019, through November 23, 2020. Each imaging examination was categorized on the basis of patient location at the time of acquisition: inpatient, outpatient, or emergency department. Additionally, each examination was categorized by the body part being imaged and imaging modality (eg, CT of the head, MRI of the abdomen, ultrasound of the extremity).

COVID-19 Wave Definition

The number of hospital admissions attributed to COVID-19 infection for the state of Colorado is publicly available at <https://covid19.colorado.gov/data>, which is managed by the Colorado Department of Public Health and Environment. From this governmental website, the number of new COVID-19 hospital admissions per day was recorded from March 9, 2020, to November 23, 2020.

Using the data on COVID-19 hospital admissions, four distinct 28-day time periods were selected from the 11-month time span to act as equally sized, representative periods of time during the COVID-19 pandemic on the basis of regional COVID-19 hospitalizations. The four 28-day time periods were characterized as pre-COVID-19, first wave, "recovery," and third wave. Colorado did not experience significant case increases during a broad second wave in the summer of 2020. Although the summer 2020 period was indeed not a durable recovery, the terminology was ubiquitously used to describe the period, with a drop-off in cases, so we have used it here as well. The pre-COVID-19, 28-day time period was selected as January 6, 2020, to February 2, 2020, and serves as a baseline for imaging volumes before the onset of the COVID-19 pandemic. The second 28-day time period was assigned on the basis of the largest number of total COVID-19 hospitalizations in Colorado during the first wave of infections in a 28-day time period from March 27, 2020, to April 23, 2020 (Table 1). A recovery 28-day time period was assigned on the basis of the smallest number of COVID-19 hospitalizations in Colorado after the first wave during a 28-day time period, which occurred from August 11, 2020, to September 7, 2020. The final 28-day time period is the most recent spike in COVID-19 hospitalizations occurring between October 27, 2020, and November 23, 2020 (Fig. 1).

The third wave of COVID-19-related hospitalizations in our region, as was common throughout the United States, was larger than the first wave [8]. To define the third-wave time period, a running 28-day total of COVID-19 hospitalizations was calculated, and the third wave was defined as the time when the 28-day total matched that of the first wave. This threshold was reached on November 14, 2020, but daily hospitalizations were still on the rise at this time point, and an additional 9 days of data were collected to assess if the peak of COVID-19 hospitalizations would be reached. The peak in daily COVID-19 hospitalizations was reached in the next 9 days, and the third-wave time period was defined as October 27, 2020, to November 23, 2020, to most accurately represent the severity of the third wave by encompassing the peak of COVID-19 hospitalizations in our region.

Table 1. Total number of COVID-19 hospitalizations during 28-day periods during the first wave, recovery, and third wave

First Wave		Recovery		Third Wave	
COVID-19 Hospitalizations	28-Day Date Range	COVID-19 Hospitalizations	28-Day Date Range	COVID-19 Hospitalizations	28-Day Date Range
2,988	3/23 to 4/19	459	8/7 to 9/3	3,100	10/17 to 11/13
3,010	3/24 to 4/20	459	8/8 to 9/4	3,208	10/18 to 11/14
3,034	3/25 to 4/21	459	8/9 to 9/5	3,305	10/19 to 11/15
3,056	3/26 to 4/22	445	8/10 to 9/6	3,454	10/20 to 11/16
3,118	3/27 to 4/23	442	8/11 to 9/7	3,579	10/21 to 11/17
3,094	3/28 to 4/24	450	8/12 to 9/8	3,709	10/22 to 11/18
3,062	3/29 to 4/25	446	8/13 to 9/9	3,804	10/23 to 11/19
2,970	3/30 to 4/26	449	8/14 to 9/10	3,891	10/24 to 11/20
2,908	3/31 to 4/27	447	8/15 to 9/11	3,953	10/25 to 11/21
2,836	4/1 to 4/28	448	8/16 to 9/12	3,974	10/26 to 11/22
2,772	4/2 to 4/29	457	8/17 to 9/13	4,053	10/27 to 11/23

Note: The 28-day period with the largest number of hospitalizations was used to select the 28-day time period for the first wave and the third wave, whereas the 28-day period with the smallest number of hospitalizations was used to select the recovery period. The selected date ranges are in boldface type. COVID-19 = coronavirus disease 2019.

Analysis

Cumulative imaging studies performed during these four distinct 28-day time periods were calculated. Subgroup analysis on the basis of patient location (eg, outpatient) at the time of imaging acquisition was evaluated within these predefined 28-day time periods. Median daily imaging studies were calculated for each group. Additional subgroup analysis of chest imaging and deep venous thrombosis (DVT) ultrasound studies of the extremities were investigated, because severe COVID-19 infections are characterized by respiratory symptoms and hypercoagulability resulting in DVT [9,10]. DVT ultrasound examinations were selected for the analysis of hypercoagulability because this examination was believed to most directly reflect referring physicians' concern for patient hypercoagulability. When comparing daily imaging volumes among 28-day time periods, a Mann-Whitney *U* test was performed because the data are nonparametric with significant variance from the normal distribution. The Mann-Whitney *U* test allows comparison between daily imaging volumes in one 28-day time period and those of another 28-day time period. The deviation of the data from the normal distribution was most pronounced in the outpatient setting, with a significant decrease in studies performed during weekends and any included holidays. Each of the four 28-day time periods contained one US holiday occurring on a weekday. Statistical analysis was performed using SPSS Statistics (IBM, Armonk, New York.) Statistical significance was defined as $P < .05$.

RESULTS

Imaging volume at our institution during the first wave of COVID-19 infections was 55% (11,098 vs 20,011; median

daily cases, 426 vs 815.5; $P < .001$) of pre-COVID-19 imaging volumes. Imaging volumes during the recovery time period and the third-wave time period returned to the pre-COVID-19 level, at 99% (19,915 vs 20,011; median daily cases, 806 vs 815.5; $P = .725$) and 102% (20,419 vs 20,011; median daily cases, 827 vs 815.5; $P = .629$) of pre-COVID-19 imaging volumes, respectively (Fig. 2). To assess for potentially substantial seasonal variation in imaging studies, these same 28-day time periods in 2019 were analyzed. Within 2019, the time periods occupying the winter and spring showed fairly static volumes (2% higher in the spring), which is a dramatically different pattern from the dramatic drop seen in the spring in 2020. The fall and early winter periods within 2019 did show higher volumes than earlier in 2019, suggesting a gradual and mild seasonal increase in the latter half of the year. These data are displayed visually in Figure 1.

Imaging studies performed in the outpatient, inpatient, and emergency department settings all decreased in the first wave compared with the pre-COVID-19 time period, with the most significant decrease in the outpatient setting. Outpatient examinations decreased to 38.7% (2,949 vs 7,621; median daily cases, 132 vs 373; $P < .001$) of pre-COVID-19 volume, emergency department examinations to 63% (5,640 vs 8,955; median daily cases, 202.5 vs 318.5; $P < .001$), and inpatient examinations to 73% (2,509 vs 3,435; median daily cases, 89 vs 125; $P < .001$) of pre-COVID-19 volumes (Fig. 3).

Emergency care imaging was the most significantly affected by the third wave, with a decrease to 88.8% (7,951 vs 8,955; median daily cases, 285 vs 318.5; $P < .001$) of the pre-COVID-19 volume. Outpatient imaging was significantly increased at 115.7% (8,818 vs

Imaging Throughout The COVID-19 Pandemic

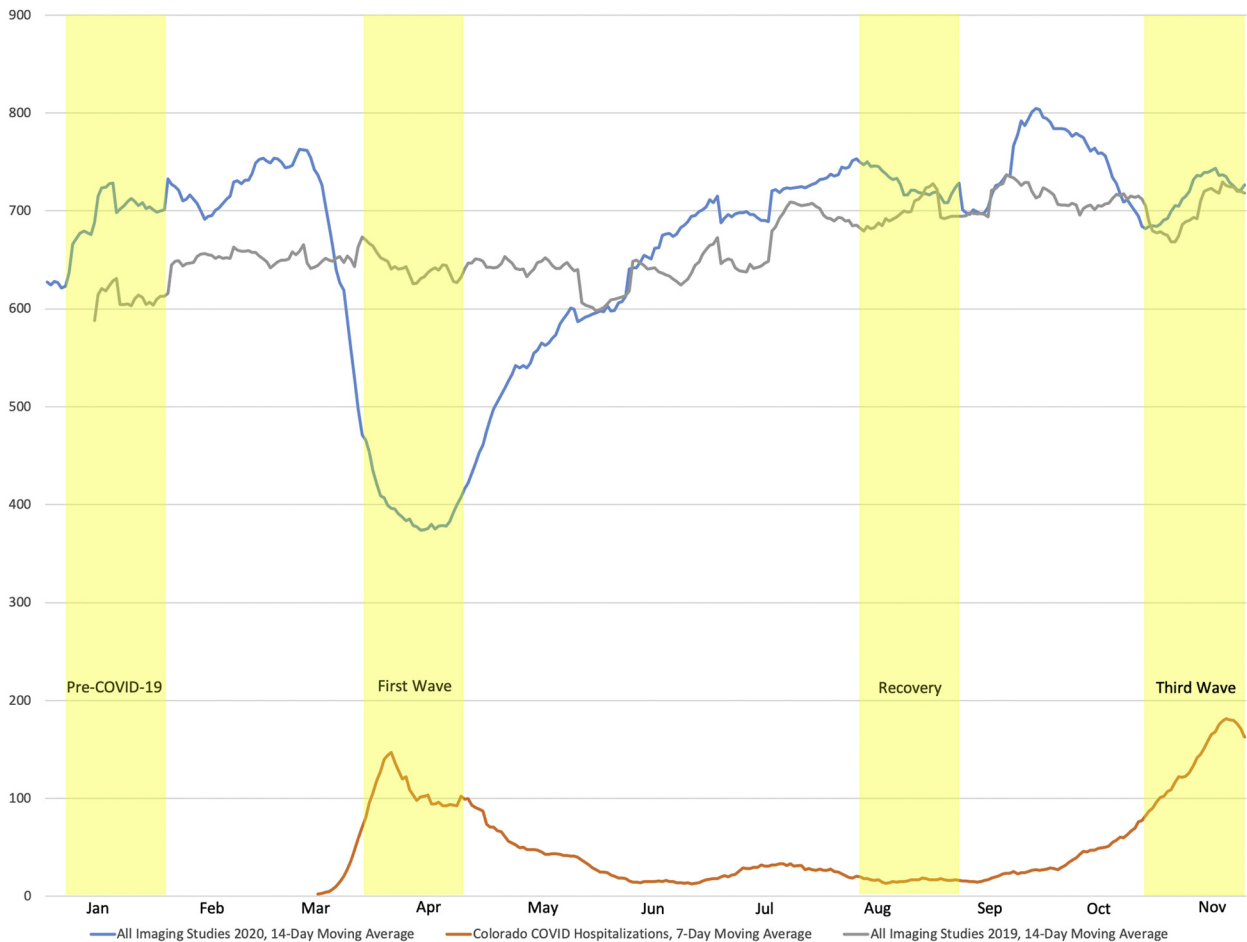


Fig. 1. Fourteen-day moving average of the total number of imaging examinations performed per day at our institution in 2019 and 2020 (gray line and blue line, respectively) and 7-day moving average of the number of daily hospitalizations per day related to coronavirus disease 2019 (COVID-19) infection in the state of Colorado from January 1, 2020, to November 23, 2020. Each of the four representative 28-day time periods is represented by a yellow rectangle. Moving averages were used to display the data because of variations in imaging volumes between weekdays and weekends.

7,621; median daily cases, 410.5 versus 373; $P = .008$) during the third wave compared with the pre-COVID-19 time period, suggesting a backlog in outpatient examinations related to decreased outpatient examinations performed during the first wave of the pandemic. Inpatient imaging was also increased at 106.3%, although to a statistically nonsignificant level (3,650 vs 3,435; median daily cases, 130.5 vs 125; $P = .053$) when comparing the third wave to pre-COVID-19. As stated previously, aggregate third-wave imaging volumes were stable compared with prepandemic values.

The total number of chest imaging studies performed at our institution declined significantly when comparing the first-wave and pre-COVID-19 time periods, resulting in a drop to 68.4% (3,089 vs 4,518; median daily cases, 110.5 vs 169.5; $P < .001$). During the recovery period,

the number of chest imaging studies remained significantly decreased compared with the pre-COVID-19 time period, with a drop to 84.3% (3,808 vs 4,518; median daily cases, 135.5 vs 169.5; $P < .001$). The number of chest imaging studies performed during the third wave is nearly identical to that of the pre-COVID-19 time period at 99.5% (4,495 vs 4,518; median daily cases, 159.5 vs 169.5; $P = .606$) (Fig. 4).

As previously described, total emergency department imaging studies were significantly lower when comparing the third-wave and pre-COVID-19 time periods, but there was no significant difference with regard to emergency department examinations performed of the chest. Chest imaging studies performed in the emergency department in the third wave were 96% (2,620 vs 2,720; median daily cases, 94.5 vs 97.5; $P = .325$) of the pre-COVID-19 time period. This

All Imaging Exams Per 28-Day Period

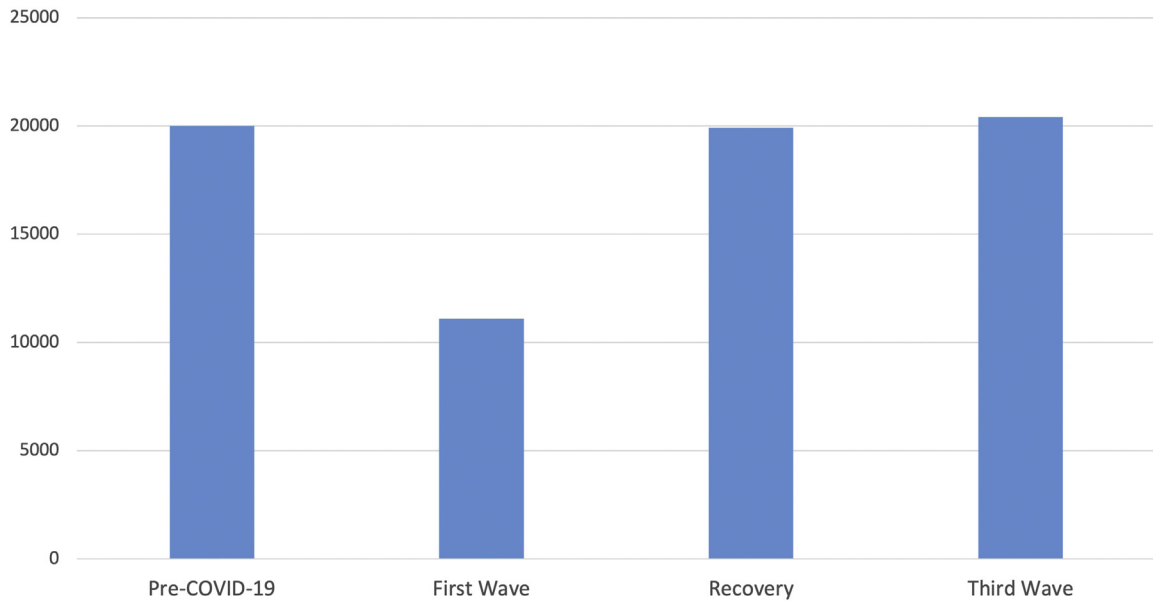


Fig. 2. Sum of all imaging examinations performed during each of the representative 28-day time periods during the coronavirus disease 2019 (COVID-19) pandemic.

Imaging Volumes By Patient Location Throughout The COVID-19 Pandemic

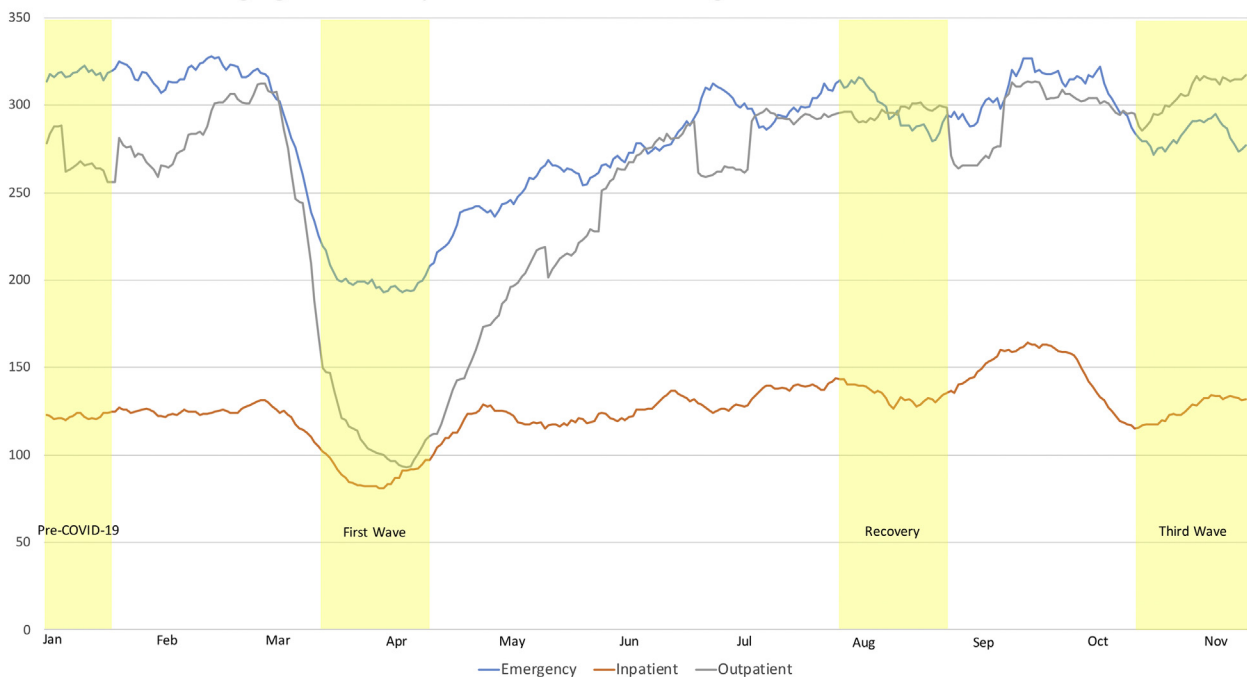


Fig. 3. Fourteen-day moving averages of imaging examinations performed per day at our institution on the basis of patient location at the time of imaging study acquisition. Each of the four representative 28-day time periods is represented by a yellow rectangle. The pre-coronavirus disease 2019 (COVID-19) yellow rectangle is less wide than the others because the data are represented as 14-day moving averages, compressing the data for early January.

Chest Imaging Studies

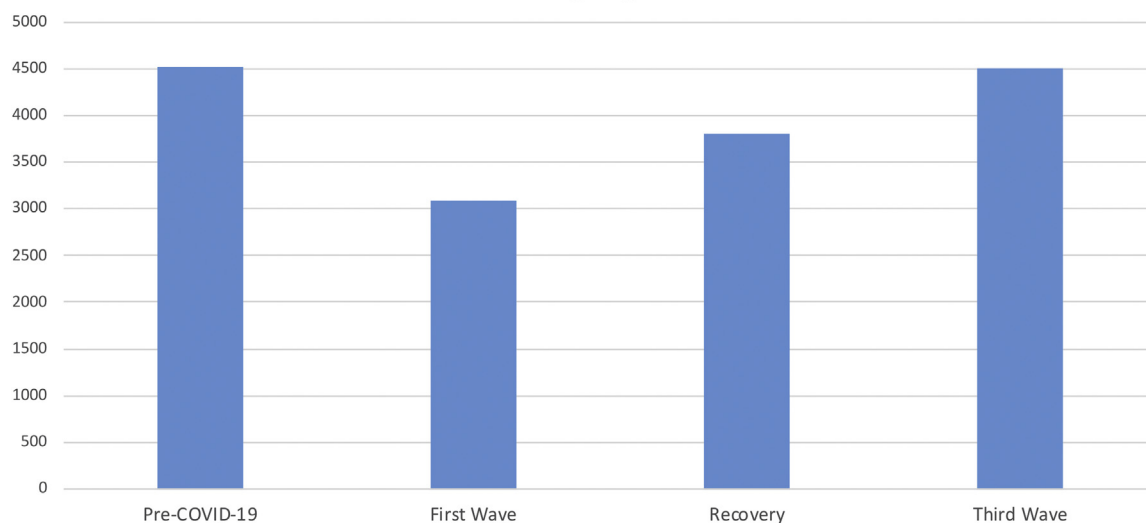


Fig. 4. Total number of chest imaging examinations performed during each representative 28-day time period, demonstrating a significant drop in chest imaging performed during the first-wave and recovery periods compared with pre-coronavirus disease 2019 (COVID-19) imaging volumes. There is no significant difference in chest imaging when comparing the third-wave and pre-COVID-19 time periods.

implies that presentations to the emergency department were likely down, but patients needing chest imaging constituted a slightly higher proportion than at baseline.

DVT ultrasound examinations performed during the first wave declined significantly compared with the pre-COVID-19 time period at 73.9% (207 vs 280; median daily cases, 7 vs 10.5; $P = .002$.) The number of DVT ultrasound studies performed during the recovery period was significantly increased compared with the pre-COVID-19 time period at 123.2% (345 vs 280; median daily cases, 11.5 vs 10.5; $P = .043$.) DVT ultrasound examinations performed in the third wave were 105% (294 vs 280; median daily cases, 11 vs 10.5; $P = .674$) of the number performed in the pre-COVID-19 time period, which is not significantly different (Fig. 5). Overall, these data suggest that DVT studies were ordered during the first wave proportionately more than other imaging, though there was still an overall drop.

DISCUSSION

Many aspects of health care delivery have changed throughout the COVID-19 pandemic. An analysis of how volumes of medical imaging have changed throughout phases of the COVID-19 pandemic may help inform how health care systems will respond to future surges in coronavirus prevalence including variants in COVID-19 such as the delta variant or other similar respiratory pandemics. As was seen in prior studies, imaging volumes dropped significantly during the first wave of the COVID-19 pandemic in March and April 2020, with the most pronounced decrease

in imaging volumes coming in outpatient examinations dropping to 38.7% of pre-COVID-19 levels at our institution. The decline in imaging volumes during the first wave can be attributed largely to two factors. The first is patients' unwillingness to seek care because of the risk for infection [11]. The second major factor was the intentional delaying of nonurgent examinations in an attempt to socially distance patients and staff members and limit the spread of the virus. To determine which examinations could be delayed during the first wave, the radiologists at our institution reviewed the indications for examinations and discussed with referring providers whether the examinations could safely be delayed. After the first wave of COVID-19 hospitalizations had passed in our region, outpatient examinations were no longer screened for clinical urgency, and imaging acquisition returned to pre-COVID-19 protocols, with modifications to follow hospital and government policies.

After the initial surge in COVID-19 cases in March 2020, our region experienced a recovery period with a drop in COVID-19 hospitalizations. During this time, more was understood about the virus, and strong safety protocols were enacted to limit the spread of the virus. During this recovery period, imaging volumes returned to a level that was equivalent to the pre-COVID-19 baseline. Our main area of focus was evaluating what happened during subsequent waves, specifically the fall wave, which exceeded the initial surge in number of hospitalizations; as COVID-19 hospitalizations in October and November 2020 surged

DVT Ultrasounds

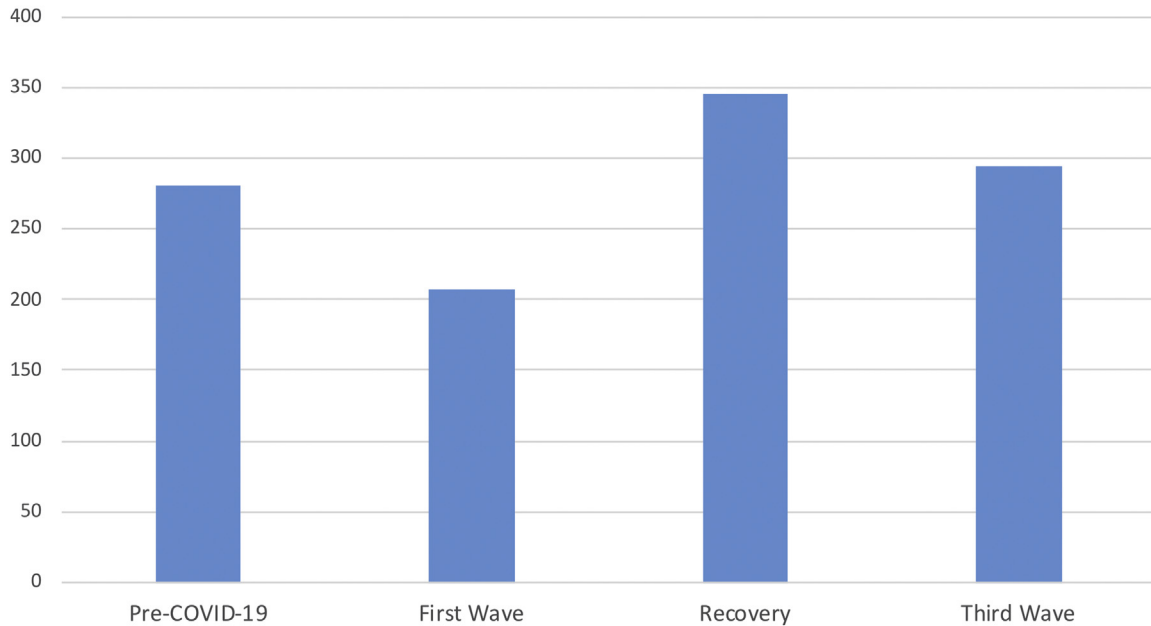


Fig. 5. Total deep venous thrombosis (DVT) ultrasound examinations performed during each of the representative 28-day time periods, demonstrating a significant increase in DVT ultrasound studies during the recovery phase compared with the pre–coronavirus disease 2019 (COVID-19) time period and no significant difference when comparing the third-wave and pre–COVID-19 time periods.

beyond the level of the first wave, imaging volumes remained at the same level as the recovery and pre–COVID-19 periods. Medical imaging services were able to be maintained at a pre–COVID-19 level despite the highest rates of COVID-19–related hospitalization seen in our region to date.

Although all imaging volumes during the third wave of COVID-19 hospitalizations were unchanged from pre–COVID-19 levels, the number of imaging examinations performed in the emergency department during the third wave of COVID-19 hospitalizations was statistically significantly decreased compared with pre–COVID-19 levels (88% of pre–COVID-19). This observation is likely related to a number of factors, but patient reticence to present to emergency departments over concerns of being exposed to COVID-19 in the health care setting likely was the top factor. Studies evaluating emergency department visits during the first wave of the pandemic demonstrated a marked decrease in total emergency department visits, with the most significant decline in regions where the pandemic was most severe [11,12]. There was no difference in chest imaging performed in the emergency department when comparing the third wave of COVID-19 hospitalizations with pre–COVID-19 levels, suggesting that the number of patients presenting to the emergency department requiring

chest imaging represented a larger proportion of cases in the emergency department during the third wave.

Hypercoagulability related to COVID-19 infection and predilection for vascular thrombosis has been documented throughout the COVID-19 pandemic. DVT ultrasound of the extremities is the dominant imaging modality to evaluate for DVT. As with other imaging modalities, the volume of DVT ultrasound studies performed on the extremities decreased during the first wave compared with the pre–COVID-19 time period. Interestingly, the number of DVT ultrasound studies performed during the recovery statistically significantly increased beyond the number performed during the pre–COVID-19 period. This finding may be related to a growing understanding of the hypercoagulable nature of COVID-19 infection, resulting in increased testing for venous thrombosis. As more was understood about the hypercoagulability associated with COVID-19 infection, many institutions were either increasing their intensity of venous thromboembolism prophylaxis or placing patients on therapeutic anticoagulation without documented DVT, which may explain the return of DVT ultrasound examinations performed during the third wave to the pre–COVID-19 baseline [13].

There were several limitations of this study, most notably that it was a single-institution analysis, which may limit

generalizability. Institutional protocols related to preventing the spread of COVID-19 infection, and the overall prevalence, have varied across the country and world; that said, our institution is central to a medium-sized city in a state that had a typical experience with COVID-19. Also, as a medium-sized institution with a large primary care catchment area, our experience is likely representative. The results of this study would be most representative for health care delivery in the United States during the COVID-19 pandemic (and possibly other countries with similar health care systems and COVID-19 responses) and may not be valid across the globe because of variations in health care systems.

We hope that these data regarding medical imaging volumes during representative periods of the COVID-19 pandemic can contribute to knowledge of how health care systems dynamically adapt to distinct periods of a pandemic. New variants of COVID-19, such as the delta variant, are more transmissible than the original strain and may infect vaccinated persons [14]. As such, future waves of the COVID-19 pandemic, including waves caused by the delta variant, seem likely [15,16]. Overall, we have demonstrated that imaging, as an essential component of medical care, rebounded quickly after the first wave, with relative stability of utilization over the ensuing phases of the pandemic. With safety protocols in place, medical imaging use proved fairly inelastic over the long term during the COVID-19 pandemic. With increased transmissibility of variant strains of COVID-19 and vaccination hesitancy seen in many populations throughout the United States, future surges in COVID-19 hospitalizations will be possible, but on the basis of this study, additional surges in COVID-19 hospitalizations will likely have a minimal impact on imaging utilization [17].

TAKE-HOME POINTS

- A dramatic decrease was seen in radiologic imaging volumes during the early phases of the COVID-19 pandemic, most pronounced in the outpatient setting at our institution.
- Radiology imaging volumes quickly returned to pre-COVID-19 levels as more was understood about the virus and safety protocols were instituted to curb the spread of the virus.
- During the third wave of COVID-19 hospitalizations in November 2020, all imaging volumes remained at levels equivalent to the pre-COVID-19 baseline, except for imaging performed in the emergency department, which was statistically significantly lower than the pre-COVID-19 baseline, in part because of patient concerns of viral exposure in the health care

setting. Outpatient volumes were statistically significantly higher during the third wave, likely representing backlogs.

- As widespread COVID-19 vaccination continues to occur, future surges in COVID-19 hospitalizations will likely have a minimal impact on imaging utilization, including the delta variant of COVID-19.

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