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Solving Problems Due to Hurricane Maria and COVID-19: CT Trends in Puerto Rico Before, During, and Beyond Public Health Crises

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Introduction

Hurricane Maria struck the northeast Caribbean Sea in September 2017, making its landfall in Puerto Rico (Estado Libre Asociado de Puerto Rico) on September 20 in Yabucoa, a small town on the southeastern coast of the island. It is considered the worst natural disaster to have struck the island, a self-governing commonwealth in association with the United States of America, in recorded history, and the deadliest natural disaster in the U.S. in the past 100 years.1 Such devastating events exert pervasive effects throughout a society. The healthcare community shifts into full crisis mode in such circumstances, often impaired by the damage to infrastructure that a major storm causes. As the world has come to realize, a global pandemic such as COVID-19 can engender as much, if not a great deal more, damage to the social fabric and public health. We consider here computed tomography (CT) trends in Puerto Rico a year before Hurricane Maria, in its immediate aftermath, and 1 and 2 years later as well as before and during COVID-19 to ascertain how CT radiology services were affected by this monumental category 4 hurricane and the worst global viral pandemic in the last century. We considered these particular events as a result of discussions on the increasing incidence of major natural disasters exacerbated by climate change and, consequently, the greater incidence and likelihood of facing concurrent or consecutive public health crises in short order. Both Hurricane Maria and COVID-19 affected a great number of people in Puerto Rico, and imposed a notable toll on Puerto Rican society at large as well as on the healthcare community and its resources.

Our hypothesis was that the COVID-19 pandemic would likely have some adverse effects on diagnostic radiology services in Puerto Rico. Given the wide variations in the U.S. response to the health crisis, it is reasonable to expect differences in the impact on radiology services. Medical literature contains much more data on the impact of epidemics and the continuing COVID-19 global pandemic as compared to the effects on medical care delivery, specifically radiology services, of hurricanes. The effects of earthquakes have been better characterized, particularly the infectious disease aftermath of the 2010 earthquake in Haiti.2 Longer range studies have also evaluated the impact on public health and public health programs of the devastating natural disaster there and addressed the condition of the healthcare sector before and after the earthquake and subsequent cholera epidemic.3,4 A 2014 report about how medical services were affected by the Great East Japan Earthquake and subsequent Fukushima Daiichi nuclear power plant accident indicated that hospitals located within the 30-km evacuation zone of the nuclear power plant were isolated.5 Based on some of the widespread effects on medical infrastructure exacted by natural disasters and public health crises in general, we hypothesized that there would be some measurable impact on radiology diagnostic...
services in Puerto Rico due to Hurricane Maria as well as the COVID-19 pandemic.

Background

Effects of Hurricane Maria on Public Health in Puerto Rico

A cross-sectional study analyzed the results from 2 other previous cross-sectional experiments, Puerto Rico Assessment on Diet, Life-styles, and Disease (PRADLAD) and Puerto Rico Observational Study of Psychosocial, Environmental, and Chronic Disease Trends (PROSPECT), conducted prior to Hurricane Maria in 2015 and post-Maria in 2019, respectively. Statistical analyses evaluating both studies revealed higher incidence of chronic diseases, including abdominal obesity, hypertension, high cholesterol, and arthritis, as well as unhealthy behaviors such as binge drinking and sedentarism, among Puerto Ricans after the hurricane. A report completed by the Homeland Security Operational Analysis Center (HSOAC) highlighted the unsafe living conditions in Puerto Rico following Maria with debris, mold, waterborne vectors, and pests present in affected areas. Research identified an increased incidence of influenza and conjunctivitis, gastrointestinal outbreaks, and even deaths caused by leptospirosis. More specifically, according to a survey by the Kaiser Family Foundation and Washington Post, 23% of Puerto Ricans reported that either themselves or a family member had a new or worsened medical condition. Furthermore, reports assessing the effects of Hurricane Maria on Puerto Ricans’ mental health outcomes revealed higher incidences of post-traumatic stress disorder (PTSD), anxiety, and depression, as 7.2% of children displayed clinically significant symptoms of PTSD, and 22% of individuals indicated that they or a household constituent had received or needed mental health services. Unfortunately, the few medical facilities that managed to remain operable were limited in the services they could provide due to substandard communication, electrical, and water infrastructure, lack of proper staffing, and restricted access to patient records.

Imaging During the COVID Pandemic

An ACR/RBMA 48-question survey of members of the ACR and Radiology Business Management Association late in 2020 revealed that a significant majority (56.4%-63.7%) of radiology practices experienced marked declines in imaging volumes during the beginning of the pandemic. A 2020 retrospective study of a large health care system by Naidich et al. considered imaging in volumes pre-COVID-19 (weeks 1-9) and during COVID (weeks 10-16). Results indicated broad declines in imaging volumes during the early stages of the pandemic as compared to 2019, with the most significant decrease seen at the end of the focus period, at week 16 for outpatient imaging (88%). All imaging types decreased, with CT falling 46%. Early in 2022, Sreedharan et al. reported on the influence of the first wave of COVID-19 on diagnostic imaging services in Australia, with statistically significant decreases in total imaging services identified in March through May 2020. General radiography, ultrasound, and MRI were more greatly affected than CT and nuclear medicine; in June 2020, statistically significant increases in CT and nuclear medicine services conducted were reported in comparison to predicted frequency.

In 2021, Xu et al. conducted a systematic review, identifying 14 pertinent studies, finding that interventional radiology caseloads were reduced between 16.8% and 80% (emergency work was affected less than elective procedures) and case volumes for trainees declined between 11% and 51.9%. Similar reductions in interventional radiology procedures have been reported in Canada, also, particularly elective cases. An online survey of Italian radiology units yielded comparable findings, with 88.1% of 2,136 responding radiologists reporting lower elective imaging volumes. Also, a 2021 retrospective multicenter study in Germany revealed expected sharp declines in CT and MRI examinations in 2020 as compared to 2019. Similarly, as expected, COVID-19 impacted the use of radiology emergency department imaging, with 1 retrospective study showing a drastic reduction in ultrasound exams in the radiology department of an urban healthcare system during the 8-week time period of the first peak of the pandemic in New York City. Reduced volumes of emergency head CTs in tertiary academic centers in Ontario, Canada, accompanied by significant increases in acute findings, were ascribed to changes in the health-seeking patterns of patients and the decision-making choices of ordering physicians in a 2020 study by Agarwal et al.

Dual Disasters in Puerto Rico

One goal is to learn from the experiences of these disasters in order for the Puerto Rican health system and others with similar infrastructure to establish robust pre-pandemic protocols to prepare for such events in the future. In 2020, Rios et al. set out to evaluate the structure and potential resilience of the health system of Puerto Rico in relation to disasters such as Hurricane Maria in the setting, now, of the COVID-19 era. The investigators concluded that several important weaknesses in the Puerto Rican health system were exposed by Hurricane Maria, including no awareness regarding the limited capacity of backup generators and the disruption of care for patients suffering with chronic conditions. They concluded that the added stress on the health system engendered by COVID-19 highlights the need for a resilience framework to pinpoint weaknesses in the system that can be bolstered to help manage ongoing and future disasters. In 2021, García et al. reported that human suffering has been exacerbated and disparate burdens imposed on older island-dwelling Puerto Rican adults by multiple simultaneous crises, including the reverberating effects of Hurricane Maria and COVID-19, longstanding fiscal austerity, increasing income and wealth inequality, substantial emigration, and a dysfunctional healthcare system.

Methods

In order to understand and compare the effects of Hurricane Maria and the COVID-19 pandemic on the field of radiology in Puerto Rico, the number of CT scan studies for 2 of Puerto Rico’s 5 major private hospital groups—Donal R. Wood Health and Doctors’ Center Hospital—were gathered and analyzed. Puerto Rico’s other hospital groups include Metro Pavia, Menonita, and HIMA Health, each accounting for 12, 6, and 5 of the island’s 68 hospitals, respectively. After contacting hospitals’ radiology departments across the island, we obtained monthly data, which was categorized into emergency room, outpatient, and hospitalized patients, from January 2016 to March 2021 for 2 of Dorado Health Inc.’s 4 hospitals: Mayagüez Medical Center (MCCW), and Manati Medical Center (MMCN), located on the island’s western and northern coasts, respectively, as well as Doctors’ Center Hospital in Manati (DCHM), one of the group’s 4 hospitals, also located on the northern coast. We quantified both the short-term and long-term impacts of Hurricane Maria and the COVID-19 pandemic by calculating the month-to-month and year-to-year percentage change for MCCW (218 staffed beds), MMCN (270 staffed beds), and DCHM (258 staffed beds) individually and for all 3 hospitals combined, for the dates leading up to, in the immediate aftermath, and following these major events. Specifically, given Hurricane Maria’s instantaneous impact after making landfall in Puerto Rico in September 2017, we compared September 2016-August 2017, September 2017-August 2018, and September 2018-August 2019. On the other hand, despite the fact that the COVID-19 pandemic was officially declared a global pandemic by the World Health Organization (WHO) on March 11, 2020, and a strict lockdown was enforced in Puerto Rico on March 15, 2020, we chose April as our start date due
to its more gradual effect; thus, we compared April 2019-March 2020 and April 2020-March 2021 in order to account for a full pandemic year.

**Results**

**Effects from Hurricane Maria**

Our data indicate that Hurricane Maria had an immediate impact on the number of scans performed across Mayagüez and Manatí Medical Center, as well as Doctors’ Center Hospital Manatí. For example, when comparing the percent change of scans performed at MMCW in September 2016, a year before the hurricane, to September 2017, scans fell by 45%; conversely, a year after, in September 2018, the number of scans increased by approximately 88%. In fact, the effect of Hurricane Maria at Mayagüez was such that September only accounted for 4.78% of total studies done during the 1-year period of September 2017-August 2018, compared to 8.38% the same month the year before and 6.41% the subsequent year (Table 1A). Equivalently, the other 2 hospitals experienced similar trends. Manatí Medical Center and Doctors’ Center Hospital Manatí, suffered losses in CT imaging when comparing the month of September in 2016 and 2017, with each reporting decreased percentage changes of 29% and 28%, respectively. Inversely, both institutions experienced an augmentation of CT scan studies when comparing September 2017 and September 2018 as MMCN each noted 5% and 11% drops, respectively, when analyzing the total CT studies done in a year (Tables 2B-2C).

Nonetheless, despite the evident short-term impact visible throughout the month of September as a result of Hurricane Maria, when analyzing and comparing the number of CT cases between September 2016 and August 2017, September 2017-August 2018, and September 2018-August 2019, showed less than a 10% change. Furthermore, when combining all three hospitals’ CT studies, there was a 1.59% decrease from September 2016 to August 2017 and September 2017-August 2018, and a 13.89% increase from September 2017 to August 2018, and September 2018-August 2019 (Table 1D).

**Effects from COVID-19**

Unlike the “short-term” impact of Hurricane Maria, the consequences of COVID-19 demonstrated immediate yet prolonged effects on the number of CT studies performed with all 3 hospitals indicating a decreased percent change between a full pandemic year and the year prior. For example, when comparing the total number of CT scan studies performed by all 3 hospitals combined pre- and post-COVID-19, the total number of cases decreased by 11.05% (Table 2A). More specifically, when comparing year-to-year differences between April 2019 and March 2020 and April 2020-March 2021, MMCW and MMCN each noted 5% and 11% drops, respectively, when analyzing the total CT studies done in a year (Tables 2B-2C). Similarly, DCHM reported a 14% decrease. Additionally, both March and April 2020 highlighted the instantaneous impact caused by COVID-19 as the data displayed notable drops in CT studies as both months contributed less than 6% of the total yearly scans done between April 2019 and March 2020 and April 2020-March 2021, for each hospital individually (Tables 2B-2D).

**Discussion**

Our results indicate that the continuing COVID-19 pandemic has had a more protracted impact on radiology CT capacity in select Puerto Rican hospitals and hospital systems. Evidently, there was a clear short-term impact on CT studies performed at MMCW, MMCN, and DCHM, visible throughout the month of September 2017 as a result of Hurricane Maria. However, when considering that the *New England Journal of Medicine* reported a 62% increase in mortality rate between September 20, 2017, and December 31, 2017, when compared to the same period in 2016, as well as an estimated death toll of 4645 (over 70 times greater than the government reported rate), the large-scale impact of Maria is undeniable. Possibly the most salient factor contributing to the lasting effects of the category 4 hurricane was the island’s fragile electrical grid system. According to the *New England Journal of Medicine*, as of December 31, 2017, the

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**TABLE 1A**

Mayaguez medical center CT scans Hurricane Maria

| Month         | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | Aug-17 | Total  |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ER            | 902    | 934    | 824    | 875    | 990    | 872    | 974    | 902    | 895    | 824    | 802    | 866    | 10660  |
| OPD           | 117    | 131    | 77     | 89     | 75     | 114    | 127    | 98     | 133    | 127    | 143    | 130    | 1361   |
| Hospitalized  | 118    | 142    | 126    | 114    | 125    | 145    | 166    | 122    | 120    | 124    | 127    | 114    | 1543   |
| Total         | 1137   | 1207   | 1027   | 1078   | 1190   | 1131   | 1267   | 1122   | 1148   | 1075   | 1072   | 1110   | 13564  |
| Percentage    | 8.38   | 8.90   | 7.57   | 7.95   | 8.77   | 8.34   | 8.34   | 8.27   | 8.46   | 7.93   | 7.90   | 8.18   | 100.00 |

| Month         | Sep-17 | Oct-17 | Nov-17 | Dec-17 | Jan-18 | Feb-18 | Mar-18 | Apr-18 | May-18 | Jun-18 | Jul-18 | Aug-18 | Total  |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ER            | 499    | 954    | 905    | 857    | 817    | 698    | 856    | 859    | 858    | 904    | 917    | 878    | 10022  |
| OPD           | 52     | 107    | 135    | 143    | 163    | 154    | 145    | 157    | 177    | 147    | 152    | 165    | 1717   |
| Hospitalized  | 74     | 117    | 116    | 96     | 124    | 101    | 99     | 120    | 109    | 103    | 124    | 148    | 1331   |
| Total         | 625    | 1178   | 1176   | 1096   | 1104   | 953    | 1100   | 1136   | 1144   | 1154   | 1213   | 1191   | 13070  |
| Percentage    | 4.78   | 9.01   | 9.00   | 8.39   | 8.45   | 7.29   | 8.42   | 8.69   | 8.75   | 8.83   | 9.28   | 9.11   | 100.00 |

| Month         | Sep-18 | Oct-18 | Nov-18 | Dec-18 | Jan-19 | Feb-19 | Mar-19 | Apr-19 | May-19 | Jun-19 | Jul-19 | Aug-19 | Total  |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ER            | 919    | 992    | 972    | 921    | 953    | 951    | 1147   | 1118   | 1491   | 1549   | 1537   | 1760   | 14310  |
| OPD           | 143    | 235    | 184    | 160    | 175    | 186    | 221    | 188    | 272    | 245    | 234    | 245    | 2488   |
| Hospitalized  | 115    | 120    | 100    | 98     | 115    | 120    | 143    | 98     | 143    | 168    | 179    | 167    | 1566   |
| Total         | 1177   | 1347   | 1256   | 1179   | 1243   | 1257   | 1511   | 1404   | 1906   | 1962   | 1950   | 2172   | 18364  |
| Percentage    | 6.41   | 7.34   | 6.84   | 6.42   | 6.77   | 6.84   | 8.23   | 7.65   | 10.38  | 10.68  | 10.62  | 11.83  | 100.00 |
average Puerto Rican household went 41 days without cellular phone coverage, 68 days without water, and 84 days without electricity. Additionally, 31% of surveyed families reported issues regarding medical services, with disruptions ranging from lack of access to medication, to absent doctors, or closed medical facilities.25 In fact, before Hurricane Maria, power outages and blackouts were a common occurrence across the island. Ultimately, at the time of Hurricane Maria, 60% of the installed systems of Puerto Rico’s generation capacity dated approximately 50 years. Following the hurricane, Puerto Rico’s complex topography, lack of resource availability, and questionable government leadership all posed serious questions regarding the electric system’s restoration process. In fact, 35 days after Maria, 44 out of 78 municipalities had no grid connections, and 84 days later, 9 municipalities were still disconnected.26 It was not until August 2018, almost a full year after Hurricane Maria made landfall in Puerto Rico, that the Puerto Rico Electric Power Authority (PREPA) reported that the island’s power had been completely restored.22 Clearly, a reliable, consistently working power grid is essential for the medical system of Puerto Rico and the health of its citizens. A review article analyzing the effects of large-scale power outages on health outcomes identified important health-related consequences on individuals worldwide. For example, the incidence of carbon monoxide poisoning increased during blackouts caused by natural disasters as a result of individuals opting for alternative fuel sources, such as gasoline-powered generators. Moreover, there was evidence of increased incidence of all-cause, respiratory, renal disease, and cardiovascular hospitalizations, which were further exacerbated as a result of electricity-dependent medical devices.27

According to an article from the Geiger Gibson/RCHN Community Health Foundation Research Collaborative, the island’s healthcare system, including the 20 federally funded centers, were dependent on diesel-fueled emergency generators for several diagnostic and treatment activities. Table 1B and Table 1C provide a summary of medical center CT scans and doctors’ center hospital CT scans, respectively, in Hurricane María affected areas from 2016-2019.

### Table 1B: Manati Medical Center CT Scans Hurricane María

| Month       | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | Aug-17 | Total  |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ER          | 2078   | 2148   | 1926   | 2084   | 2146   | 1856   | 2164   | 1888   | 2057   | 2135   | 2263   | 1971   | 24716  |
| OPD         | 383    | 352    | 305    | 349    | 305    | 342    | 428    | 395    | 404    | 412    | 328    | 432    | 4435   |
| Hospitalized| 228    | 211    | 187    | 244    | 262    | 208    | 242    | 208    | 210    | 236    | 220    | 224    | 2680   |
| Total       | 2689   | 2711   | 2418   | 2677   | 2713   | 2406   | 2834   | 2491   | 2671   | 2783   | 2811   | 2627   | 31831  |
| Percentage  | 8.45   | 8.52   | 7.60   | 8.41   | 8.52   | 7.56   | 8.90   | 8.39   | 8.74   | 8.83   | 8.25   | 100.00 |        |

### Table 1C: Doctors’ Center Hospital CT Scans Hurricane María

| Month       | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | Aug-17 | Total  |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ER          | 2133   | 2081   | 1960   | 1898   | 2112   | 1756   | 2118   | 2197   | 2211   | 2107   | 2122   | 2256   | 24778  |
| OPD         | 393    | 482    | 421    | 343    | 434    | 436    | 518    | 488    | 508    | 436    | 444    | 425    | 5328   |
| Hospitalized| 231    | 225    | 208    | 211    | 252    | 228    | 280    | 245    | 248    | 292    | 254    | 245    | 2919   |
| Total       | 2538   | 2514   | 2112   | 1940   | 2171   | 2172   | 2379   | 2271   | 2334   | 2575   | 2555   | 2537   | 28198  |
| Percentage  | 6.22   | 6.54   | 8.44   | 8.29   | 8.43   | 8.01   | 9.23   | 8.91   | 9.39   | 9.00   | 8.50   | 9.04   | 100.00 |
tion oncology facilities in Puerto Rico received “patient records. Furthermore, according to reports, all but two radiation departments had limited energy availability, leading to restricted patient care.29 Moreover, a study conducted to assess the impact of Hurricane Maria on radiation oncology practices and patients across Puerto Rico highlighted the lack of telephone service, as approximately 90% of cellular sites were out of service 8 days after landfall, and the substandard internet connection. Ultimately, this led to difficulties in communication with patients, as well as between physicians, and trouble when accessing records. Furthermore, according to reports, all but two radiation oncology facilities in Puerto Rico received “access” to diesel-powered generators; however, only those facilities associated with hospital systems were given diesel, thus, independent facilities often left without power, and 100,000 without water, as a result of a fire erupting in the Costa Sur power plant.25 The effects of COVID-19 also demonstrated immediate yet prolonged effects on the number of CT studies completed with all 3 hospitals indicating a decreased percent change between a full pandemic year and the year prior. One possible explanation for the trends associated with diagnostic imaging is Puerto Rico’s strict lockdown restrictions during the pandemic. On March 15, 2020, the island’s governor at the time, Wanda Vázquez, issued swift protocols enforcing an island-wide curfew; those found guilty of violating the executive order faced a hefty fine and possibly even jailtime. In the following months, Puerto Rico transitioned into a complete lockdown, where citizens were allowed to leave their homes for emergency purposes only. In fact, Puerto Rico was one of the first U.S. jurisdictions to issue mask mandates, even sending out daily messages to its people alerting them when the curfew was approaching.30 The effects of the executive order were seen in the number of treatment services given the lack of power across Puerto Rico. In mid-October 2017, the Asociación de Salud Primaria de Puerto Rico (ASPPR) reported that only 13% of federal healthcare centers had complete power restored, 4% had intermittent power, while the remainder were still dependent on generators.28 Moreover, a study comparing 2017-2018 with 2018-2019 showed that 6248-6454 ER visits in May 2018, 6202 ER visits in June 2018, 5964 ER visits in July 2018, and 5759 ER visits in August 2018. This might explain the 40% increase in CT scans performed at Mayaguez Medical Center in September 2018-August 2019. It is possible that patients were forced to attend major hospitals such as MMCW, rather than independent diagnostic imaging facilities due to the inaccessibility of diesel. Unfortunately, as of 2022, Puerto Rico has yet to fully recover from the damages to its electrical grid system caused by Hurricane Maria. Despite Luma Energy, a private Canadian-American consortium, taking over Puerto Rico’s transmission and distribution sectors of the electrical grid, its people still face constant and unpredictable power outages with no end in sight. Most recently, on April 6, 2022, approximately 200,000 Puerto Ricans were left without power, and 100,000 without water, as a result of a fire erupting in the Costa Sur power plant.30

### TABLE 1D

Combined CT scans Hurricane María

| Month       | Sep-16 | Oct-16 | Nov-16 | Dec-16 | Jan-17 | Feb-17 | Mar-17 | Apr-17 | May-17 | Jun-17 | Jul-17 | Aug-17 | Total |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| ER          | 4953   | 5092   | 4400   | 4474   | 4956   | 4363   | 4986   | 4589   | 4737   | 5011   | 5113   | 4862   | 57536 |
| OPD         | 770    | 713    | 617    | 648    | 612    | 742    | 846    | 730    | 857    | 873    | 779    | 799    | 8917  |
| Hospitalized| 641    | 627    | 540    | 573    | 606    | 604    | 648    | 565    | 599    | 594    | 570    | 613    | 7140  |
| Percentage 2017-2018 | 8.65 | 8.74 | 7.55 | 7.74 | 8.39 | 7.76 | 8.81 | 8.90 | 8.36 | 8.74 | 8.75 | 8.93 | 100.00 |

| Month       | Sep-17 | Oct-17 | Nov-17 | Dec-17 | Jan-18 | Feb-18 | Mar-18 | Apr-18 | May-18 | Jun-18 | Jul-18 | Aug-18 | Total |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| ER          | 3557   | 4199   | 4736   | 4564   | 4656   | 4061   | 4821   | 4922   | 5162   | 4179   | 5057   | 5868   | 55782 |
| OPD         | 371    | 536    | 751    | 851    | 890    | 1005   | 916    | 987    | 1083   | 814    | 829    | 895    | 9910  |
| Hospitalized| 438    | 452    | 510    | 496    | 626    | 533    | 601    | 651    | 643    | 540    | 559    | 638    | 6727  |
| Total       | 4366   | 5187   | 5997   | 5911   | 6172   | 5619   | 6338   | 6560   | 6870   | 5533   | 6445   | 7421   | 72419 |
| Percentage 2018-2019 | 6.03 | 7.16 | 8.28 | 8.16 | 8.52 | 7.76 | 8.75 | 9.06 | 9.49 | 7.64 | 8.90 | 10.25 | 100.00 |

### TABLE 2A

Combined CT scans COVID-19

| Month       | Apr-19 | May-19 | Jun-19 | Jul-19 | Aug-19 | Sep-19 | Oct-19 | Nov-19 | Dec-19 | Jan-20 | Feb-20 | Mar-20 | Total |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| ER          | 5447   | 6014   | 5354   | 5822   | 6182   | 5987   | 6056   | 5829   | 3897   | 5309   | 5511   | 3693   | 65101 |
| OPD         | 1019   | 1047   | 1067   | 946    | 993    | 1056   | 1164   | 918    | 677    | 1099   | 1100   | 647    | 11733 |
| Hospitalized| 628    | 670    | 709    | 708    | 730    | 813    | 802    | 792    | 483    | 665    | 725    | 662    | 8387  |
| Total       | 7094   | 7731   | 7130   | 7476   | 7905   | 7856   | 8022   | 7539   | 5057   | 7073   | 7336   | 5002   | 82478 |
| Percentage 2020-2021 | 8.32 | 9.07 | 8.37 | 8.77 | 9.28 | 9.22 | 9.41 | 8.85 | 5.93 | 8.30 | 8.61 | 5.87 | 100.00 |

| Month       | Apr-20 | May-20 | Jun-20 | Jul-20 | Aug-20 | Sep-20 | Oct-20 | Nov-20 | Dec-20 | Jan-21 | Feb-21 | Mar-21 | Total |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| ER          | 2550   | 4288   | 4733   | 4801   | 4884   | 5066   | 5442   | 4628   | 4406   | 5194   | 5167   | 5648   | 56807 |
| OPD         | 389    | 774    | 1035   | 988    | 928    | 810    | 1101   | 819    | 866    | 762    | 1154   | 1251   | 10877 |
| Hospitalized| 538    | 692    | 820    | 728    | 638    | 628    | 730    | 707    | 532    | 655    | 740    | 713    | 8121  |
| Total       | 3477   | 5754   | 6588   | 6517   | 6450   | 6504   | 7273   | 6154   | 5804   | 6611   | 7061   | 7612   | 75805 |
| Percentage 2020-21 | 4.59 | 7.59 | 8.09 | 8.60 | 8.51 | 8.58 | 9.59 | 8.12 | 7.66 | 8.72 | 9.31 | 10.04 | 100.00 |
trauma admissions at the Puerto Rico Trauma Hospital (PRTH). When analyzing and comparing the number of trauma admissions during March 15-June 15, 2020, and the historical admissions average during that same date (2017-2019), the hospital reported a 59% reduction. More specifically, the most prevalent difference in admissions was identified during the first eight weeks of the COVID-19 pandemic; in fact, PRHT received no trauma admissions during the second week of lockdown. Researchers believe that given the change in lifestyle associated with the pandemic, individuals were no longer experiencing traumatic injuries as frequently as they were pre-pandemic. Also, patients are more reluctant to go and stay in hospitals given the association with contamination.32,33 Similarly, this could account for the evident drop in CT scan studies performed in Puerto Rico when considering that the island’s residents were encouraged to remain home after facing some of the nation’s strictest lockdown restrictions, and that patients were keen to avoid contracting COVID in healthcare facilities. Our results provide additional support to the argument that there is no time like the present to fortify medical and societal infrastructure to better prepare for future natural and public health disasters. Similarly, the University of Puerto Rico School of Medicine Diagnostic Radiology Residency Program incorporated unique solutions such as Zoom and Microsoft Teams virtual meetings.

### TABLE 2B
Mayaguez medical center CT scans COVID-19

|           | Apr-19 | May-19 | Jun-19 | Jul-19 | Aug-19 | Sep-19 | Oct-19 | Nov-19 | Dec-19 | Jan-20 | Feb-20 | Mar-20 | Total |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **ER**    | 1118   | 1491   | 1549   | 1537   | 1760   | 1527   | 1635   | 1595   | 0      | 1442   | 1528   | 892    | 16074  |
| **OPD**   | 188    | 272    | 245    | 234    | 245    | 210    | 250    | 208    | 0      | 255    | 249    | 121    | 2477   |
| **Hospitalized** | 98     | 143    | 168    | 179    | 167    | 188    | 224    | 191    | 0      | 162    | 156    | 143    | 1819   |
| **Total** | 1404   | 1906   | 1962   | 1950   | 2172   | 1925   | 2109   | 1994   | 0      | 1859   | 1933   | 1156   | 20370  |
| **Percentage** | 6.89  | 9.36   | 9.63   | 9.57   | 10.66  | 9.45   | 10.35  | 9.79   | 0.00   | 9.13   | 9.49   | 5.68   | 100.00 |

### TABLE 2C
Manatí medical center CT scans COVID-19

|           | Apr-19 | May-19 | Jun-19 | Jul-19 | Aug-19 | Sep-19 | Oct-19 | Nov-19 | Dec-19 | Jan-20 | Feb-20 | Mar-20 | Total |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **ER**    | 2197   | 2211   | 2057   | 2112   | 2143   | 2304   | 2159   | 1943   | 2052   | 1981   | 2046   | 1417   | 24622  |
| **OPD**   | 488    | 508    | 436    | 444    | 425    | 472    | 583    | 416    | 449    | 519    | 492    | 309    | 5541   |
| **Hospitalized** | 245    | 248    | 292    | 254    | 245    | 250    | 272    | 277    | 276    | 283    | 289    | 260    | 3191   |
| **Total** | 2930   | 2967   | 2785   | 2810   | 2813   | 3026   | 3014   | 2636   | 2777   | 2783   | 2827   | 1986   | 33354  |
| **Percentage** | 8.78  | 8.90   | 8.35   | 8.42   | 8.43   | 9.07   | 9.04   | 7.90   | 8.33   | 8.44   | 8.48   | 5.95   | 100.00 |

### TABLE 2D
Doctors’ center hospital Manatí CT scans COVID-19

|           | Apr-19 | May-19 | Jun-19 | Jul-19 | Aug-19 | Sep-19 | Oct-19 | Nov-19 | Dec-19 | Jan-20 | Feb-20 | Mar-20 | Total |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **ER**    | 967    | 1640   | 1712   | 1803   | 1712   | 1989   | 2118   | 1879   | 1656   | 1950   | 1971   | 2094   | 21511  |
| **OPD**   | 171    | 338    | 446    | 408    | 424    | 441    | 476    | 353    | 384    | 348    | 503    | 579    | 4871   |
| **Hospitalized** | 184    | 247    | 311    | 233    | 271    | 287    | 279    | 262    | 212    | 248    | 277    | 279    | 3090   |
| **Total** | 1322   | 2225   | 2469   | 2444   | 2427   | 2717   | 2873   | 2494   | 2252   | 2546   | 2751   | 2952   | 29472  |
| **Percentage** | 4.49  | 5.55   | 8.38   | 8.29   | 8.23   | 9.22   | 9.75   | 8.46   | 7.64   | 8.64   | 9.33   | 10.02  | 100.00 |

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for read-out sessions and didactic conferences during the COVID-19 pandemic in order to comply with quarantine restrictions, without altering the duration of shifts or the number of residents on call. Radiology capacity during such ongoing crises can only be better sustained as a result. Besides the effects of Hurricane Maria and the COVID-19 pandemic on the island’s healthcare infrastructure, Puerto Rico is facing another major crisis as it struggles to deal with significant healthcare personnel shortages. In 2017, then-Governor Ricardo Rossello signed what came to be known as the Law of Incentives for the Retention and Return of Medical Professionals (Ley de Incentivos para la Retención y Retorno de Profesionales Médicos), a tax incentive where doctors pay a fixed 4% on their medical practice earnings. This law was formulated as a response to the 20.5% decrease in medical specialists on the island from 2009 to 2014, a figure that was further affected following Hurricane Maria and COVID-19. More recently, protests led by doctors, nurses, medical technologists, therapists, and maintenance personnel have erupted as employees seek fair wages, adequate retirement, and action by the government and healthcare institutions concerning staff shortages. Specifically, hospitals such as Centro Médico Rio Piedras, Puerto Rico’s only trauma center, have seen the number of surgical technicians dwindle from 80 to 30, significantly reducing the number of procedures performed. With a salary of $8.25 an hour, many technicians have opted for better paying jobs in the private health sector or even fast-food restaurants.

**Limitations**

There were several limitations to our study. Restricted data accessibility and time lag were our main obstacles. Two of the island’s largest hospital affiliation groups that had initially committed themselves to sharing their data later backed out, with one hospital claiming it did not receive clearance from their legal department, and the other failing to further respond to our inquiries, by one month and six months after the start of our study, respectively. Additionally, there was a third hospital that did not share their data approximately 6 months following our first contact and after steady back-and-forth communications. Consequently, we decided to proceed without their participation.

**Conclusion**

Hurricane Maria struck Puerto Rico on September 20, 2017, becoming the worst natural disaster to strike the island, and the deadliest natural disaster in the U.S. in the past 100 years. Such a catastrophe, though, is also believed to have been strengthened or exacerbated by anthropogenic climate change. The COVID-19 pandemic, believed to have begun in animal markets in Wuhan, China, is a natural public health disaster with more direct human influence. These human inflection points are notable as we face the prospect of juggling or being beset by more such emergencies in the near future at what stands to be an unprecedented pace. Both calamities descended on Puerto Rico within a two-and-a-half-year period, before the island had fully recovered from Maria and the earthquake swarm that struck the island’s southwest coast between 2019 and 2020. Considering such events individually and together can help to elucidate the areas of a health system in general and, specifically, in imaging services that must be shored up to weather future disasters. Both Hurricane Maria and COVID-19 have exacted a toll on the health care system in Puerto Rico and exerted a measurable impact on the use of diagnostic radiology services. Our results support the need to fortify medical and societal infrastructure to better prepare for future natural and public health disasters. Such preparations would leave health systems of all kinds, but particularly those that share the resource constraints as those in Puerto Rico, more likely to maintain steady, if somewhat diminished, radiology services such as CT for regular and emergency purposes.

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