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Special Article

Lessons Learned From Hurricane Maria in Puerto Rico: Practical Measures to Mitigate the Impact of a Catastrophic Natural Disaster on Radiation Oncology Patients

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Abstract

Purpose: Although the wind, rain, and flooding of Hurricane Maria in Puerto Rico abated shortly after its landfall on September 20, 2017, the disruption of the electrical, communications, transportation, and medical infrastructure of the island was unprecedented in scope and caused lasting harm for many months afterward. A compilation of recommendations from radiation oncologists who were in Puerto Rico during the disaster, and from a panel of American Society for Radiation Oncology (ASTRO) cancer experts was created.

Methods and materials: Radiation oncologists throughout Puerto Rico collaborated and improvised to continue treating patients in the immediate aftermath of the storm and as routine clinical operations were restored gradually. Empirical lessons from the experience of radiation therapy administration in this profoundly altered context of limited resources, impaired communication, and inadequate transportation were organized into a recommended template, applicable to any radiation oncology practice. ASTRO disease-site experts provided evidence-guidelines for mitigating the impact of a 2- to 3-week interruption in radiation therapy.

Results: Practical measures to mitigate the medical impact of a disaster are summarized within the framework of "**P**repare, **C**ommunicate, **O**perate, **C**ompensate." Specific measures include the development of an emergency operations plan tailored to specific circumstances, prospective coordination with other radiation oncology clinics before a disaster, ongoing communications with emergency management organizations, and routine practice of alternate methods to disseminate information among providers and patients.

Conclusions: These recommendations serve as a starting point to assist any radiation oncology practice in becoming more resiliently prepared for a local or regional disruption from any cause. Disease-site experts provide evidence-based guidelines on how to mitigate the impact of a 2- to 3-week interruption in radiation therapy for lung, head and neck, uterine cervix, breast, and prostate cancers through altered fractionation or dose escalation.

Introduction

Hurricane Maria was a catastrophe that affected multiple layers of the complex, interdependent, and modern infrastructure on which we have become dependent, both in Puerto Rico and on the U.S. mainland. In addition to being an island in the Caribbean Sea, Puerto Rico was particularly vulnerable to systems disruption and delayed reconstruction because of its preceding 11 years of economic recession, a concurrent population exodus of nearly half a million people over the past decade to the U.S. mainland[1] in search of jobs and more affordable cost of living, and a $72 billion public debt.[2] Even as the reconstruction of Puerto Rico's utility infrastructure continues, the lessons learned during the past months invite reflection and demand preparation for all those who care for the most frail and vulnerable among us—those who are ill.

Although a near-total disruption of services such as occurred in Puerto Rico is unlikely in the U.S. mainland, a similar degree of cascading local or regional dysfunction is indeed possible consequent to earthquakes, hurricanes, tornados, wildfires, tsunami, flooding, cyberattacks, terrorism, nuclear war, and other calamities that can disrupt the electric power grid, water supply, transportation, and distribution networks of food, medicine, and other critical supplies. The experiences with Hurricane Maria in Puerto Rico in 2017, Hurricane Katrina in New Orleans in 2005, and Hurricane Andrew in Florida in 1992 provide lessons that can inform preparations and increase resiliency when facing the most probable risks in any locale.

Two weeks before Maria struck, category 5 Hurricane Irma skirted the coast of Puerto Rico on September 6, 2017 and left >1 million people without power. It caused proportionately more damage in the Virgin Islands.[3] The HIMA Health Group Radiation Oncology clinic in Puerto Rico received 22 patients from the U.S. Virgin Islands who were affected by Hurricane Irma.

Just days after Hurricane Irma, Hurricane Maria made landfall in Puerto Rico on the morning of September 20, 2017 as a category 4 hurricane, with sustained winds of 155 mph, just 2 mph below the threshold for being designated a category 5 storm. Based on the observed wind impacts, approximately half of the island experienced peak gusts between 96 and 129 mph, and except for the southwest corner of the island, the other half experienced peak gusts between 74 and 95 mph (Fig 1).[4] In addition to wind damage, heavy rains and flash floods exacerbated the widespread devastation (Fig 2).[5] In a 48-hour period, from September 19 to 21, 2017, some areas in Puerto Rico received as much as 35 to 40 inches of rain, with most of the island receiving >10 inches of

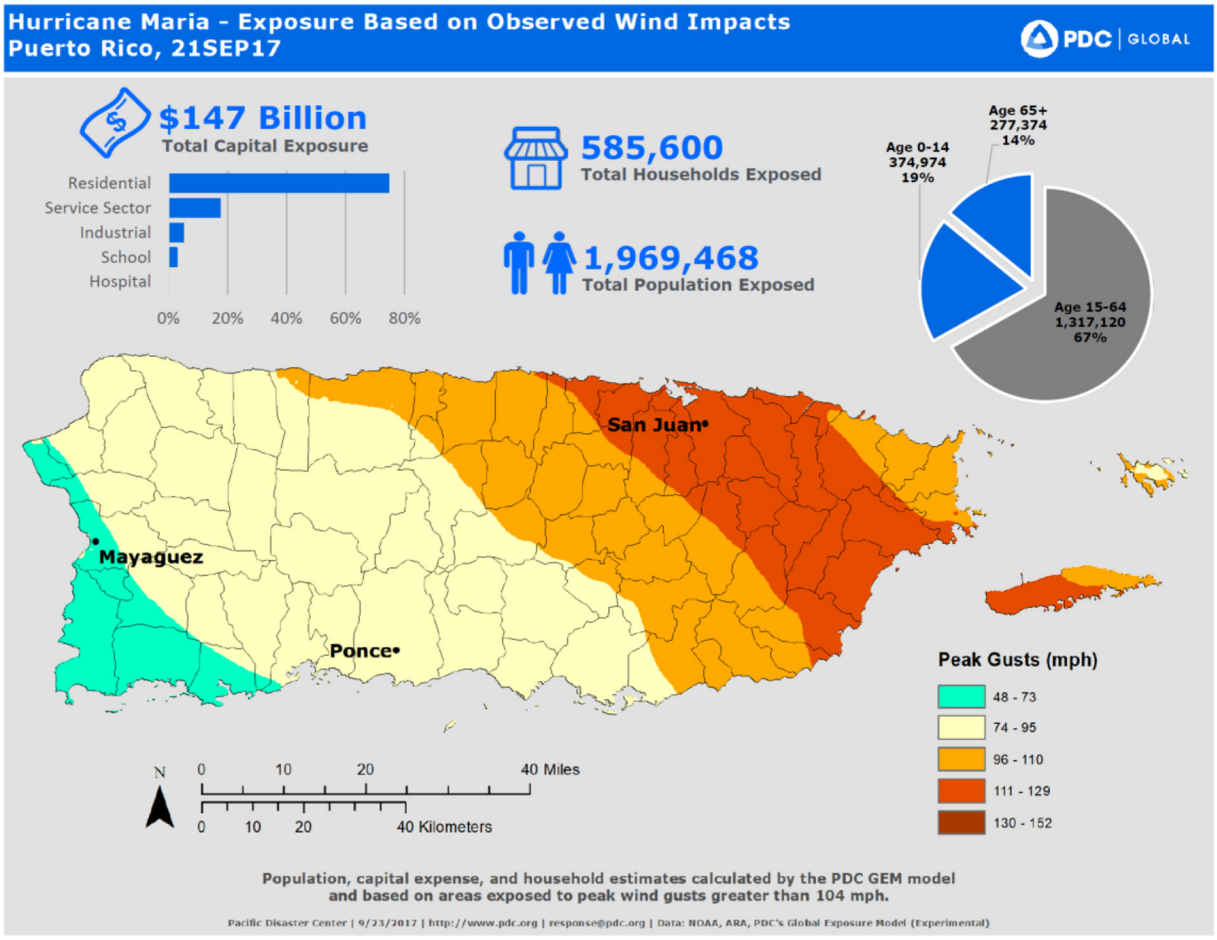

Figure 1 Hurricane Maria—Exposure based on observed wind impacts.[4]

rain.[6] Landslides were extensive and severely compromised transportation in the weeks to come; it is estimated that landslides occurred at a rate of fewer than 25 landslides per square kilometer across half the island's area and at a rate of more than 25 per square kilometer in 5% of the landmass (Fig 3).[7]

After Hurricane Maria, 100% of Puerto Rico was without power.[5] As of March 2018, 16% of Puerto Ricans still lacked electricity, making this the longest blackout in U.S. history.[5,8] Furthermore, some residents still are without access to plumbed water or need to boil municipal water before drinking because of contamination and water advisories. As of December 2017, 60,000 houses were roofless. Overall, an estimated $94 billion in damages was incurred.

Even more devastating than the catastrophic property damage was the loss of life directly related to the hurricane (eg, drowning, flying debris, building collapse, and electrocution) or the ensuing unsafe conditions that contributed to injury, illness, or unavailability of services.[9] Although the official death toll was officially reported by government authorities as 64, difficulties in communication, major population movements off of the island, and disruptions in routine services, including government records, medical death certificates, and mortuary services, may have contributed to a substantial underestimate of the true mortality as a result of Hurricane Maria.

Several independent analyses have suggested that the true number of deaths could be in excess of 1000. A Harvard-led team conducted an extensive survey of 3299 households throughout Puerto Rico and produced an all-cause mortality estimate of 14.3 deaths per 1000 between September 20, 2017 and December 31, 2017. This value was 62% higher than the well-documented rate from the corresponding period in 2016, suggesting that the true number of excess deaths from hurricane-related debris, drowning, illness, injury, or lack of access to medical facilities was 4645 (>70 times the official value of 64).[10] Because "interruption of medical care was the primary cause of sustained high mortality in the months after the hurricane," the authors noted that closing their analyzed period in December may have led them to underestimate the total impact of the previously severe but still ongoing difficulties patients face in accessing medicine, physicians, and advanced life-sustaining treatments, such as

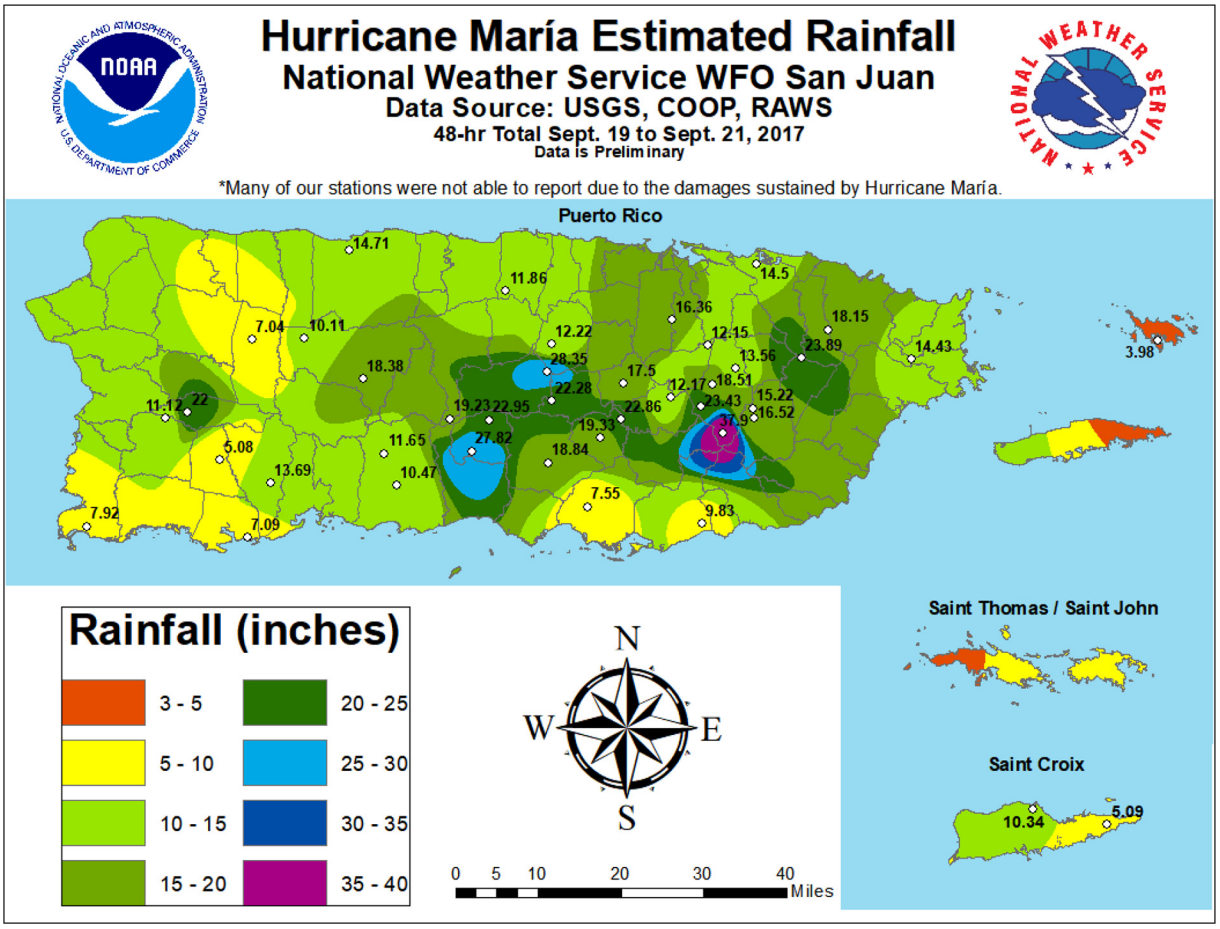

Figure 2 Hurricane Maria estimated rainfall.[6] (A color version of this figure is available at https://doi.org/10.1016/j.prro.2019.03.007).

hemodialysis and pulmonary support. "Chronically ill patients are particularly vulnerable to disruptions in basic utilities, which highlights the need for these patients, their communities, and their providers to have contingency plans during and after disasters."[10]

The impact of a major catastrophe, such as Hurricane Maria, on a radiation oncology (RO) practice and, most importantly, its patients, cannot be overstated (Fig 4). Because of the daily nature of radiation therapy (RT) treatments, any significant gap in treatment may affect patients' locoregional control and survival. The goal of an RO practice responding to a catastrophe should be to restart patient treatments as soon as possible. Mitigating the devastating impact on patients requires 4 key elements: rigorously preparing before the catastrophe, establishing effective channels of communication with patients before and after the disaster, rendering the RO facility operational as soon as possible, and compensating for treatment gaps (prepare, communicate, operate, compensate [PCOC]).

The damage done by Hurricane Maria in Puerto Rico and the subsequent harm to RO patients could not be avoided, but the disaster does provide an opportunity to increase the preparation and resiliency of our own practices. Most U.S. RO practices are unlikely to experience a hurricane, and total failure of the electrical grid is less likely on the mainland, but many mishaps could impair the smooth functioning of our infrastructure on a local or regional level to a similar degree. The critical challenges faced by RO facilities in Puerto Rico fell into the following broad categories: power, communication, and patient access to facilities. In addition to previous challenges, both patients and staff faced the following critical challenges: water, food, transportation, and shelter. By increasing awareness of our vulnerabilities and making sensible preparations that are appropriate to our disparate circumstances, we can ameliorate the effects of stochastic disasters for the benefit of our patients, our practices, and ourselves.

This paper draws upon the experience of radiation oncologists attempting to care for patients in the aftermath of Hurricane Maria and proposes some initial steps, therapeutic approaches, and minimal guidelines to address the shortcomings and needs that proved most urgent in the first weeks of recovery. In essence, this is a list of what we wish we had done beforehand and what we needed most afterward. The authors include Puerto Rican radiation oncologists and disease-site experts, all of whom hope

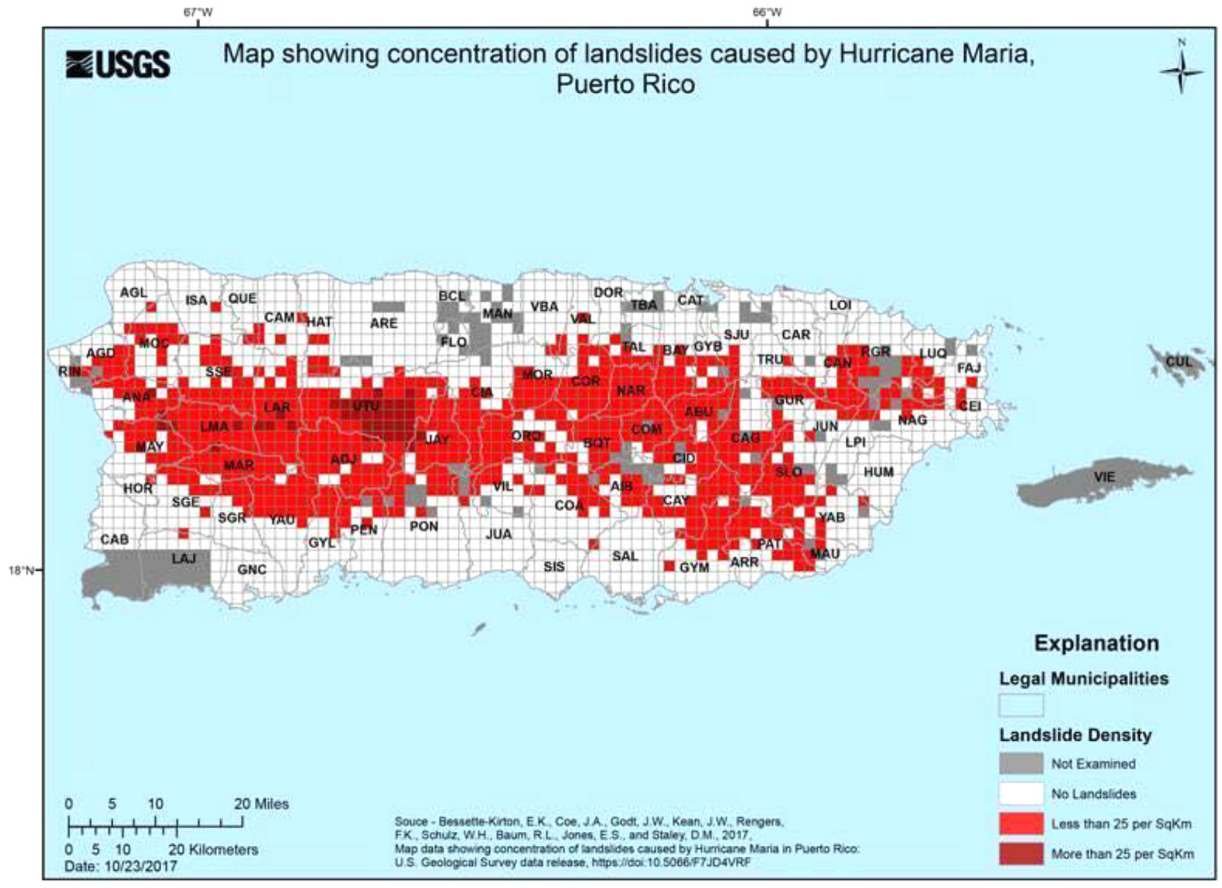

Figure 3 Concentration of landslides caused by Hurricane Maria.[7]

that this document can serve as a first step toward establishing more structured preparations for disaster, tailored to the circumstances of all our practices as we attempt to serve our patients.

Prepare: Step 1 of PCOC

The preparation phase is critical in minimizing the treatment delays that may result from a natural disaster. Table 1 describes the consensus preparation checklist from radiation oncologists in Puerto Rico and can be adapted for other disasters and locations. Many books and online resources on emergency preparedness are available, including www.ready.gov, which has a section on hurricane preparedness. Of note, the recommended minimum 3 days of supplies would have been vastly insufficient given the breadth of disruption in Puerto Rico. We will focus on the emergency preparedness of an RO facility for a disaster similar to Hurricane Maria. Having the most accurate information available on the hurricane before landfall is essential. Accurate hurricane forecasting is very important. The hurricane forecast maps provided by the National Hurricane Center may be useful to depict the general path, timeline, and strength of the hurricane. Some prefer the European Center for Medium-Range Weather Forecasting model,[11] which can be viewed at www.windy.com or the Windy app for iOS or Android.

The Emergency Operations Coordinator (EOC) would be expected to serve as the primary point of contact with emergency management personnel, with whom contact should be made beforehand, and would facilitate communication between RO facilities and patients. It is highly recommended that the EOC obtain free online training through the U.S. Federal Emergency Management Agency (FEMA) Emergency Management Institute in the Incident Command System and Community Emergency Response Team (available at https://training.fema.gov/emi.aspx). The EOC need not be a physician or other medical provider, but the office does require intimate knowledge of the clinic's medical operations, material needs, and local resources.

Multiple clinics relying on centralized servers to treat patients may be vulnerable if linear accelerators cannot communicate with the server. Given the technologic sophistication of RO, this need is quite acute. Patients should be given USB flash drive copies of their medical records and Digital Imaging and Communications in

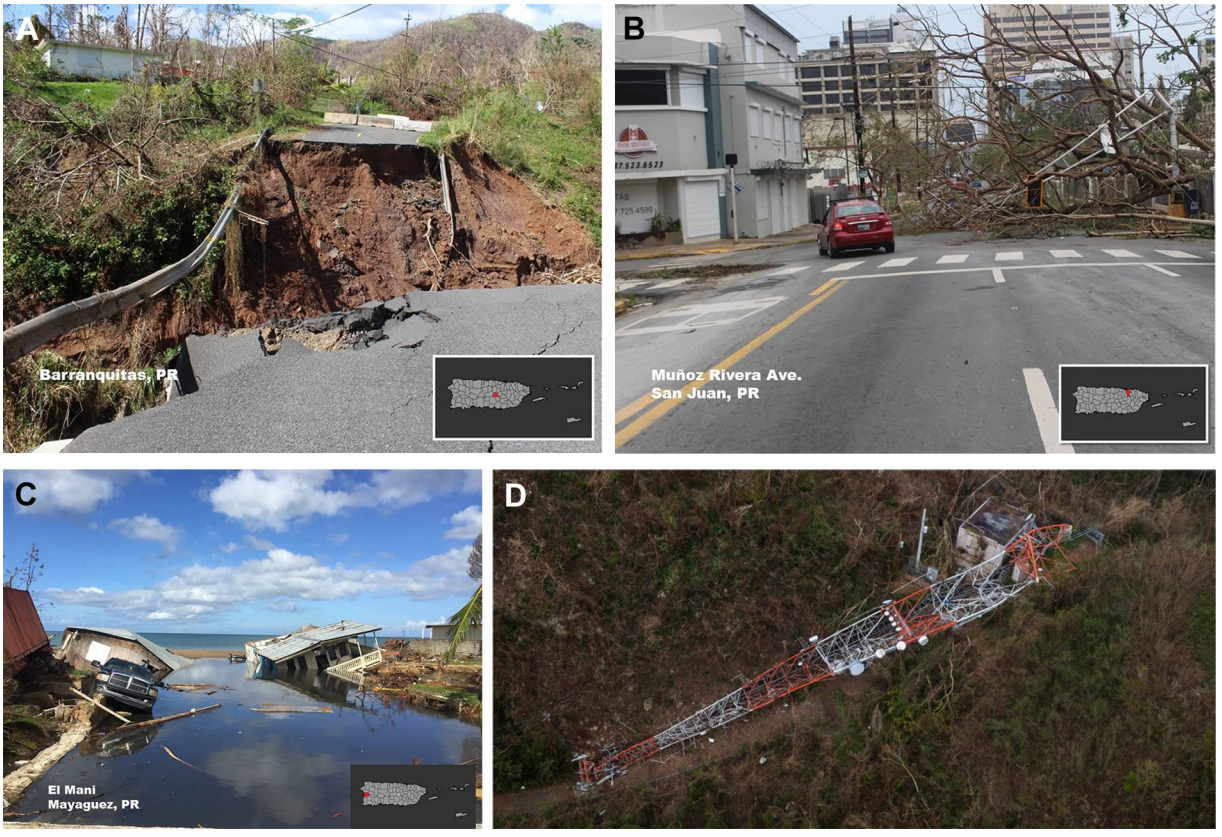

Figure 4 Representative photos of damage from Hurricane Maria (A-C).[24] Of the 1600 cellular antenna towers in Puerto Rico, only 15% to 20% continued to operate after Hurricane Maria (D). Photo: Archivo/GFR Media.[25]

Medicine data sets as described in Table 1. Flash drives are portable and robust and allow patients to optimally resume care at another local facility or abroad. Most, if not all, patients who resume treatment at another facility will benefit from a resimulation because positioning systems or treatment equipment may be different, the tumor may have changed in size during the treatment break, and the patient may have lost weight. The most recent cone beam computed tomography (CT) scan can be helpful in assessing changes between the last treatment and the new simulation. Fusing the original structure set with the new planning CT will expedite the contouring process and maintain consistency with the original intended volumes. In the ideal scenario where the gross tumor volumes (GTVs) have not changed much and are covered well by the original planning target volume (PTV), the PTV is cleaned from fusion artifacts and the skin minus a 3 mm contour is subtracted from the PTV, as in the case of a head and neck intensity modulated RT (IMRT) plan. Substantial changes in the GTV will require a new GTV, clinical target volume, and PTV. Organ-at-risk contours can be inspected and edited as necessary to reflect changes in anatomy or patient positioning.

Access to alternative power is critical to prepare for a natural disaster. Although all but 2 RO facilities in Puerto Rico technically had access to power from diesel generators, the subsequent ability to obtain and store fuel was very limited. Furthermore, even when a hospital had functioning generators, RO was in some instances not considered a priority to receive power, especially if the RO clinic building was separate from the main hospital. Partly this was an effort to conserve fuel because RO clinics are power hungry, and intensive care and emergency units were also in need of power. Nevertheless, this raises ethical questions as to how best allocate resources. Contingency plans with hospital administration should be discussed beforehand.

Communicate: Step 2 of PCOC

The communication phase (Table 2) implements the communication plan created in the preparation phase (Table 1). Communication with patients efficiently through any available means will help minimize treatment delays.

Data submitted by communication providers in Puerto Rico to the Federal Communications Commission's Disaster Information Reporting System showed that 90.3% of cell sites were out of service 8 days after

Table 1 Prepare: Step 1 of PCOC

Prepare Checklist		
Category	Item	Description
Organization	EOP	Each clinic should have a designated EOC with the responsibility of guiding the preparation of an EOP appropriate to its specific circumstances and communicating it to all employees.
	Practice	The EOC should organize opportunities to practice implementation of the EOP, including use of alternative modes of communication with patients and staff, coordination with other medical facilities, and use of alternative power and water sources.
Communication	Inform patients of EOP	Establish and routinely inform patients in writing of RO clinic's disaster management plan.
	RO clinic coordination	The EOC should share the EOP among regional RO centers to facilitate collaboration among centers in a disaster. Identify and appoint a central entity to represent all RO clinics.
	EOC	The EOC should maintain contact with local, commonwealth, and federal governmental emergency management agencies and provide them with a current copy of the EOP to expedite communications in time of need. The EOC is responsible for ensuring all contacts remain up to date.
	Staff phone list for patients and staff	The list should be printed and laminated to be waterproof. The list should contain as many communication methods as possible per staff: satellite phone, landline, cellular phone, and 1 internet option for all (eg, Skype, WhatsApp, Facebook Messenger, Zello). For patients, a subset of this list includes various staff selected to coordinate patient efforts. Ideally, the staffs' homes should not be clustered in the same area, but rather spread out to maximize the chance of successful communication. For those who live on an island or in an isolated region, the list should include a designated coordinator abroad with various methods of communication, and patients should share the list with relatives living abroad. A link to a social media page (eg, Facebook) should be provided where the RO clinic's status report and important messages can be posted to serve as a bulletin board.
	Patient phone list	A secure and up-to-date master patient list should be printed and laminated or kept in a waterproof container. Each patient should provide multiple methods of contact as well as contact information for friends or family who may be able to reach them. Patients who consider staying with a relative or going to a shelter should provide the contact and address information in advance.
	Radio and newspapers	Identification of local radio station and newspaper contacts for public service announcements should be done in advance by the EOC. Messages should be pre-recorded or written and ready to be deployed (eg, clinic X is now open and urges patients to resume treatment). RO clinics and hospitals should consider providing staff with emergency communications training and equipment that would permit similar communication with neighboring hospitals and emergency management personnel directly without any dependence on grid power or other utilities.
	Main clinic phone number	Internet telephone systems may be particularly vulnerable to communication infrastructure failure. A backup landline phone number should be considered because these may become operational first. Automated voicemail messages with instructions for patients should be recorded in advance.
	Internet presence	Radiation oncologists should update their contact information with multiple contact methods in the American Society for Radiation Oncology directory. RO practice location and contact information should be updated or created in Google, Facebook, and/or online phone directories. Hospital or individual practice webpages should be updated with contact information.
	Satellite phone	At least 1 activated satellite phone should be available for each RO clinic. These phone numbers should be shared among RO clinics to coordinate efforts.
	Nonpower, grid-dependent phone charging method	The ability to charge cell phones through a solar, mechanical, or other system for both patients and staff is invaluable once the power grid fails. These methods must be practiced routinely, both to confirm their adequacy and gain the familiarity and competency necessary to employ them during a stressful crisis.

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Table 1 (*continued*)

Prepare Checklist		
Category	Item	Description
	Centralized server alternatives	Patients are given a waterproof USB flash drive (2 GB should suffice for most patients) with the following Digital Imaging and Communications in Medicine files: planning CT, last cone beam CT if available, treatment plan, structure set, and dose. PDF copies of the treatment plan, radiation therapy treatment record, simulation setup photos and notes, and relevant medical records (eg, consultation notes, pathology reports, imaging reports, concurrent therapies [chemotherapy, immunotherapy], and laboratory results). The RO clinic should also keep a copy of these patient files in a larger-capacity, waterproof, ideally encrypted, USB drive. Paper copies stored at the RO clinic in a waterproof, locked container may be useful as a secondary backup for prolonged power outages without access to alternate power sources to charge a laptop, for example. Internet service providers that use digital subscriber lines, cable, or fiber optic lines are vulnerable to ground infrastructure damage. Satellite Internet may be explored as an option to communicate with servers once power is restored with emergency generators.
Clinic infrastructure	Linear accelerator cooling	If the linear accelerator depends on a continuous supply of water, an alternative should be engineered in advance in the event potable water is lacking.
	Water	A cistern or alternative should be considered to supply potable water to patients and bathrooms. If the building is multistory, a way to pump water to patient areas that is not dependent on the power grid should be considered. Methods for chemical or filtration purification should be available and practiced.
	Surge protection	Computers, linear accelerators, CT simulator, and other sensitive electronic equipment should be robustly protected from power surges.
	Flood protection	A solution should be engineered to protect against flooding in case of a power failure.
	Water infiltration protection	Equipment vents to the outside of the facility should be protected from water infiltration from strong winds. The roof should be well sealed to minimize the risk of water leaks, especially if constructed of concrete.
	Clinic supplies	Necessary supplies should be stored to provide radiation therapy services for a month.
	Diesel generator	The clinic should have a diesel generator of sufficient capacity and adequate duty cycle for weeks without electricity. The generator should be regularly maintained and tested. Maintenance supplies for at least 1 month should be available (eg, oil, filters), as well as onsite operators capable of providing routine service. Generator maintenance alternatives and the Federal Emergency Management Agency and/or government agency contact(s) for diesel delivery in emergencies should be previously identified. A master list of RO facilities that may need diesel should be supplied to relevant agencies.
	Fuel storage	A diesel storage tank with a 2-week supply should be available. Consider a private security guard, reinforced chains and locks, and a diesel tank security encasement in areas vulnerable to theft.
	Fuel delivery	Multiple diesel and/or gasoline delivery alternatives should be identified and/or contracts made in advance to avoid price hikes.
Patient Care Continuity	Contingency plan	Establish contingency plans with various health care plans, suppliers, contractors, hospitals, government, medical and surgical oncologists, and cancer charities (eg, ACS).
	Alternative RO clinics	RO clinics that are isolated and not part of a group are particularly vulnerable if they are unable to treat patients. In advance, the closest competing clinics should be identified and contracts established as feasible to ensure patients have a convenient RO clinic alternative. Patients should be notified in advance of these arrangements, and it is paramount that competitors not exploit this to their advantage but rather consider the wellbeing of all patients. Satellite RO clinics that are part of a larger group are also vulnerable because they are often located in remote parts of the island, possibly with less robust infrastructure, and often depend on remote server connections with the main RO center. When setting up

(*continued on next page*)

Table 1 (*continued*)

Prepare Checklist		
Category	Item	Description
		satellite clinics, it is important to highlight that machines should be beam matched. This will provide a quick solution for the patient if the main RO center is able to restart operations first.
	Alternative lodging	Coordination with a nearby Hope Lodge from the ACS that may be closer to the RO clinic or securing closer temporary housing may aid patient access to treatments.
	Patient education	Proactively educate patients, referring physicians, and other health care providers about the importance of avoiding treatment interruptions during radiation therapy and the outcome consequences.
Transportation	Gasoline	Patients and staff should fill their gasoline vehicle tanks before the hurricane. The best practice is never to allow one's tank to become less than half full. For most people, the danger of storing additional gasoline in containers at home outweighs the benefits. Check local regulations on the proper handling and storage of gasoline. Patients with cancer and medical personnel should be given priority once gasoline is resupplied at gas stations. Providing patient transportation with buses belonging to the RO clinic, contracts with private transportation agencies, or volunteers (eg, ACS) should be planned. Transportation providers should have staff and/or patient lists in advance to coordinate efforts. Patients and staff should have cash withdrawn to purchase gasoline, food, water, and other necessities because automated teller machines and credit cards may not function during a power failure.
	Patient evacuation	Government agencies should be contacted to plan the transportation of patients who may be stranded by debris, flooding, landslides, and other impediments to transportation.
	Transportation plan	A transportation plan should be already contracted in case of disaster. Patients who cannot reach treatment centers on their own can be efficiently helped.

Abbreviations: ACS = American Cancer Society; CT = computed tomography; EOC = emergency operations coordinator; EOP = emergency operations plan; PCOC = prepare, communicate, operate, compensate; RO = radiation oncology.

Maria's landfall. A large percentage of consumers lacked cable or wireline services because of a lack of commercial power or out-of-service switches. Of the 3 TV and 31 radio stations that reported to the Disaster Information Reporting System, 2 and 9 were down, respectively.[12] Communication facilities that were not initially destroyed ultimately failed as their backup generator diesel stores were depleted.

For friends and family abroad, lack of communication with loved ones can be traumatic. In the aftermath of Hurricane Maria, news outlets were inefficient in providing timely and detailed status reports, and most reporting focused on the metro San Juan area. A number of National Oceanic and Atmospheric Administration river gauges were operational after Maria and accessible online, giving a vague picture of some flooded areas. Social media became extremely important for communicating current conditions. For example, initial reports from the municipality of Mayagüez were made by a citizen in Florida who had a contact in the Mayagüez Civil Defense in Puerto Rico. She created a group in the Zello smartphone app, which operates like a walkie-talkie over the Internet, and shared her information with those in the U.S. mainland. In some municipalities, such as Mayagüez, some landline-based phone numbers resumed operation before cell phones. Weeks later, with spotty Internet access, some posted news and photos in several Facebook groups, such as Huracán María Puerto Rico or Puerto Rico Informa. A handful of radio stations in Puerto Rico were also accessible through the Internet.

The importance of commercial broadcast radio as a method of communication after a catastrophe has destroyed communications infrastructure cannot be understated. Initially, radio stations were more useful to the public because more radio stations were operational than TV stations, and personal radios can run on batteries or other methods without the need for electricity. Amateur radio operators provided essential assistance in Puerto Rico for intra-island communications, as well as to the mainland, even before the deployment of 25 two-man teams from the mainland by the American Radio Relay League in conjunction with the American Red Cross.

Because of the complex nature of daily RT, an RO practice requires effective communication between the RO facility staff and patients and between the computer servers and linear accelerators. The loss of telephone and Internet service for both RO clinics and patients delayed efforts to repair the facilities and made communication

Table 2 Communicate: Step 2 of PCOC

Communicate Checklist	
Item	Description
RO clinics coordination	The central entity appointed to represent all RO clinics serves as an advocate when dealing with authorities and key emergency response institutions to restore service, and helps coordinate efforts between RO clinics.
Emergency management coordination	The RO clinic's EOC establishes contact with local, commonwealth, and federal governmental emergency management agencies as necessary, as well as the central entity representing all the RO clinics. The EOC communicates with emergency medical services (eg, fire and ambulance), utility services (eg, water, electricity, and telephone), police, organized relief groups (eg, American Red Cross) as necessary, and, if available, volunteer organizations (eg, search and rescue squads, Amateur Radio Emergency Service chapters), and churches and schools with facilities for disaster relief.
Staff phone list for patients and staff	The communication methods established in Table 1 are activated.
Patient phone list	Patients and staff communicate as agreed upon from the suggestions in Table 1. Special HIPAA provisions apply with regard to sharing patient contact information to authorities in case of emergency: "health care providers may share patient information with anyone as necessary to prevent or lessen a serious and imminent threat to the health and safety of a person or the public – consistent with applicable law (such as state statutes, regulations, or case law) and the provider's standards of ethical conduct." Please refer to the HIPAA Privacy in Emergency Situations Bulletin for more information.[26]
Radio and newspapers	Pre-recorded radio messages with contact information highlighting the importance of continuity of care are transmitted by radio stations. Advertisements in local newspapers to inform patients about the RO clinic status are updated.
Main clinic phone number	A backup landline phone number should be available. An automated voicemail message giving instructions to patients is activated (before any predictable disaster).
Internet presence	As per Table 1, patients and staff should have various alternatives to find the status of the clinic and contact information.
Satellite phone	Satellite phone is activated (before any predictable disaster).

Abbreviations: EOC = emergency operations coordinator; HIPAA = Health Insurance Portability and Accountability Act of 1996; PCOC = prepare, communicate, operate, compensate; RO = radiation oncology.

with patients to inform them when treatments would resume impossible. The lack of communication precluded physician-to-physician discussions of complex cases and coordination of therapy. Some patients who learned that their RO clinic was closed presented to a different RO facility that was open. The new radiation oncologist then faced the challenge of not knowing the previous dose delivered, treatment plan, and other vital medical information. As conditions improved, patients arrived at RO clinics with only written treatment and clinical history summaries.

In the San Juan area, Dr. Carlos Chévere from the University of Puerto Rico Comprehensive Cancer Center reached out to 2 TV stations, the written press, and local radio stations to exhort patients to resume RT treatments. One obstacle was that local radio stations wanted to charge for these public service announcements. In contrast with routine advertising, these attempts to assist patients in the aftermath of a major catastrophe in which lives were at stake should not have been monetized by the radio stations. Some RO clinics ran ads in local newspapers to inform patients of the RO clinic status.

As communications improved, text messaging became the most effective way of communication. During commutes to home or work, radiation oncologists would often stop on the highway emergency lane when a cell phone signal was available to communicate with referring physicians. Medical oncologists in the San Juan metro area relied on WhatsApp for communication. Once home, communication again became impossible for many radiation oncologists. Eventually, Google's balloon project Loon provided Internet connectivity to 100,000 LTE-capable cell phones.[13]

Using local radio stations to provide information on the status of RO clinics, encouraging patients to resume treatment, and providing contact information can be very useful. Communicating as quickly as possible is crucial because diesel generators providing emergency power to any communication towers and radio stations will eventually run out of fuel, and fuel resupply can be inconsistent afterward. Leaving a sign on a closed RO facility is also useful to provide information to patients, such as contact information and the anticipated reopening date and time. Closed facilities should provide provisions for

Table 3 Compensate: Step 4 of PCOC, assuming a 2-3 week delay in radiation therapy

Cancer	Clinical scenario	Impact of gap	Recommendations
NSCLC	Locally advanced, postoperative	Low	Restart therapy when possible. Given that these are usually patients with concern for microscopic disease who have already received (or are receiving) chemotherapy, the impact of a treatment break and concerns about tumor repopulation are lower than those for patients with gross disease.
	Locally advanced, definitive	High	Restart these patients sooner than the postoperative patients. **Concurrent chemotherapy group:** Recommend restarting with standard fractionation. If the patient has a prolonged delay, consider adding a cycle of chemotherapy at a systemic dose during the treatment break. **RT alone group:** RT-alone group (or sequential chemoRT group). Consider modest hypofractionation of no more than 2.53 Gy per fraction to a total dose of 63.25 Gy without chemotherapy and **no** highly conformal treatment techniques.[27] For highly conformal image guided/intensity modulated RT techniques, consider 60 Gy in 15 fractions without chemotherapy.[28] Consider these schedules especially for larger or more aggressive tumors.
SCLC	Limited stage	Very high	Restart thoracic as soon as possible (even midcycle) and preferentially switch to twice a day per Turrisi.[29] Consider following curative chemoradiation regimens of 40 Gy in 15 fractions,[30] 40 Gy in 16 fractions,[31] or 42 Gy in 15 fractions,[32] or 39.9 Gy in 15 fractions.[33] The potential advantage of these schedules is that the dose constraints are usually easily met (cord <36 Gy; V18<37%). A patient who had a few fractions followed by a long break often can safely receive this schedule upon restart with an acceptable composite plan.
	Extensive stage	Very high	If the delay caused deferment of prophylactic cranial irradiation or consolidative thoracic RT, decide on a case-by-case basis.
Head and neck	1 wk (~10 Gy) of RT, followed by a 2-3 wk break or longer	High	The tumor impact of the initial 10 Gy is essentially lost. Deliver the full prescription dose of 60-70 Gy without reduction once the patient is able to resume therapy.[21]
	Received more than a few weeks of treatment, followed by a treatment interruption	High	Consider accelerated and/or hyperfractionated schedules to try and maintain the overall total treatment time.[21]
	Received substantial radiation dose and then an extended treatment break (on the order of months)	Very High	Surgical salvage. If not feasible, consider full-dose reirradiation despite the known higher risk for late-normal tissue toxicity. In this challenging situation, only treating the gross disease while avoiding elective regions is warranted.[21]
Uterine cervix	Definitive	High	Consider adding approximately 5 Gy per wk with 3-dimensional image-based brachytherapy for each week of radiation duration beyond 7 weeks, respecting the organ-at-risk tolerance doses. This must be carefully weighed against the doses that the organs at risk will receive by adding this extra dose to the tumor.[34] For a 2-3 week interruption, strive for a minimum of 50.4 Gy instead of 45 Gy to the pelvis. Do not recommend twice a day or other altered schedule (weekend or otherwise). Do not discount any previously given dose. The use of LDR instead of HDR brachytherapy would eliminate any need for electricity. If HDR is available only, the physician can admit the patient to the hospital and administer multiple sequential HDR treatments up to twice a day to complete the therapy in a shorter period of time. Use of 4 fractions of 700 cGy rather than 5 fractions of 500-600 cGy can also be considered. Starting the

(*continued on next page*)

Table 3 (*continued*)

Cancer	Clinical scenario	Impact of gap	Recommendations
			brachytherapy during the course of external beam is feasible,[35] but external beam should not be given on the same day as brachytherapy. No treatment break should be given between external beam and brachytherapy.
B	Postoperative	Moderate	Consider adjuvant vaginal cylinder brachytherapy.
Breast	Breast-only treatment	Low	Do not change the whole-breast dose in the setting of a treatment break (continue the original 42.56 Gy in 16 fractions or 50 Gy in 25 fractions). The boost portion of the treatment dose gets adjusted as follows: • Initial treatment plan did not include a sequential boost to the lumpectomy cavity PTV: 10 Gy in 5 fractions boost. • Initial treatment plan included a sequential boost to the lumpectomy cavity PTV: Add one 2 Gy fraction per week missed up to 66 Gy; alternatively, a 2.3 Gy × 5 boost. If the intended boost was to 66 Gy, increase the dose up to 70 Gy, and consider reducing the volume to the highest risk region.
	Chest wall after mastectomy	Low	Similar to above, but substitute lumpectomy cavity PTV for mastectomy scar PTV.
	Regional nodal (supraclavicular, axillary, internal mammary chain) with breast or chest wall	Low	Dose is adjusted to a maximum of 50 Gy in 2 Gy fractions.
Prostate		Very low	For treatment delays <1 wk, no need for corrective action. ADT may safely mitigate delays up to 2 weeks. For patients receiving RT alone for whom a long break is anticipated, consider starting ADT. For patients not undergoing ADT, 1-2 conventional fractions may compensate for a 1-wk break if normal tissue tolerance allows. Accelerating treatment to 6 fractions per wk (1 twice-daily treatment per wk) or switching to a moderately hypofractionated course may help compensate for treatment gaps.[23] When hypofractionating, maintain an equal or slightly higher EQD2 for the tumor using an α/β ratio of 1.5 without exceeding the EQD2 of normal tissues using an α/β ratio of 3.

Abbreviations: ADT = androgen deprivation therapy; EQD2 = equivalent dose in 2 Gy; HDR = high dose rate; LDR = low dose rate; NSCLC = non-small cell lung cancer; PCOC = Prepare, Communicate, Operate, Compensate; PTV = planning target volume; RT = radiation therapy; SCLC = small cell lung cancer.

patients to leave a message to assist with follow up; this can be as simple as a clipboard left at the front door for patients to leave their name, the current date, and the best means of contact. Please refer to the Health Insurance Portability and Accountability Act considerations in Table 2.

Operate: Step 3 of PCOC

In the aftermath of Hurricane Maria, patients faced multiple challenges and priorities that shifted from RT to survival. Automated teller machines and credit cards did not work without power, and the economy revolved around cash. Those who did not have cash on hand when the hurricane made landfall had to go to banks once banks resumed operations to withdraw money, which was initially available only in limited quantities. Without electricity, gas pumps did not work, and the refueling of gas stations was challenging because of road conditions. Diabetic patients could not refrigerate their insulin. Supermarkets faced shortages, and food spoiled from lack of refrigeration. Those most affected by flooding or structural damage to their homes relocated to designated government shelters, mainly public schools. Landslides, washed-out roads and bridges, downed trees and electric poles, debris, flooding, unpowered traffic lights, decreased gasoline availability that caused long lines, lack

of communication, and limited supplies of water and food hindered many patients and staff from returning to RO clinics. The damage to vehicles and transportation routes, the difficulty in obtaining fuel, and the displacement of refugees were significant obstacles for patients in resuming RT. Obtaining bottled water and the restoration of water utility services were significant problems during the recovery process. Both Puerto Rico's situation as an island separated from the mainland and its mountainous central territory greatly hindered recovery efforts amid the widespread devastation. The preparations of RO clinics before Maria's landfall were grossly insufficient given the scale of the catastrophe. These shortcomings were acutely experienced and have motivated their enumeration in this publication.

Initially little was known of the operational status of RO clinics in Puerto Rico. The lack of communication and limited online information on how to contact each clinic posed a great challenge. Through a slow process of trial and error, 18 RO clinics were identified: 10 in the North, 3 in the West, 2 in the East, 2 in the South, and 1 in the Central Region. Identification of these clinics was hindered by a lack of communication with the island and absent or outdated information in the American Society for Radiation Oncology (ASTRO) directory, Google, Facebook, and web pages. Of the 7 RO clinics reachable after landfall, 5 were treating between 20% and 50% of their previous census, which was very concerning. A Google map was created to identify which clinics were operational, inoperative, or had an unknown status (available at https://drive.google.com/open?id=1UHPK7cUIeSmjcCd_LtRm6hLEc58&usp=sharing) and was available to anyone through Facebook and the ASTRO website. Another Google map was subsequently created to show which clinics has access to electricity (available at: https://drive.google.com/open?id=1ztCUUiKtp9kRfskZ4KvJcvcEoRU&usp=sharing). A third Google map was made to show centers in the U.S. mainland that had expressed interest in treating Puerto Rican patients (available at: https://drive.google.com/open?id=17lM0vxENRzL31kI4CufwiyT-HJs&usp=sharing). The last 2 links were available to radiation oncologists in Puerto Rico and ASTRO officials helping with the relief efforts. Some of the centers were identified with the help of private practitioners who reached out to ASTRO, ASTRO experts working on treatment interruption recommendations and who volunteered at their academic institutions, and RO clinics in the mainland to which radiation oncologists in Puerto Rico had reached out. Patients with cancer should be given priority for plane tickets if no local treatment alternatives are available.

A Facebook group called Radioterapia Puerto Rico Huracan Maria (Radiotherapy Puerto Rico Hurricane Maria, https://www.facebook.com/groups/1476177975795089/) was created to provide details on the condition of each clinic and alternate contact methods, including staff phone numbers, e-mail addresses, and clinic phone numbers (many of which were initially unreachable). Staff from the various facilities were encouraged to post any updates on their clinic, essentially creating a bulletin board, but participation was poor. Messages encouraging patients to return to RT treatments were posted in several Facebook groups covering Hurricane Maria both in Spanish and English. Groups were selected based on number of members to have the largest impact. Similar messages were sent to local radio stations by local RO clinics and ASTRO.

ASTRO recorded public messages to run in areas in the U.S. mainland with large Puerto Rican populations. In addition, ASTRO posted the status of RO facilities in Puerto Rico at http://www.rtanswers.org and gave links to Spanish and English audio for public radio announcements. Overall, online initiatives and radio messages in the U.S. mainland were mainly effective in informing relatives or friends of RT patients in Puerto Rico and giving ASTRO, Congress, and other government agencies a better picture of the status and needs of the RO clinics, as well as generating a comprehensive list of clinics in need of diesel supplies to forward to relevant agencies. Local efforts to contact patients by the individual clinics in Puerto Rico and local radio messages had the most impact in reaching out to patients. The clinic in the hardest hit area went as far as going door to door to find patients and was successful in finding all but 1 patient, who was no longer home. If feasible and safe, this strategy can be highly effective early after a disaster.

Transportation was a major challenge for patients. Long lines of up to 12 hours were initially necessary to get fuel after many lined up at the break of dawn. Initially, only $20 of gasoline could be purchased, which made the situation more critical. This improved approximately 2 weeks after the curfew was suspended. The curfew initially began at 6 PM and later at 12 AM, assisting the unrestricted purchase of gasoline by providing increased access to pumps (Gil B., Personal communication, 2018). The American Cancer Society (ACS) coordinated transportation to many patients who could not reach their RO centers through collaboration with a commercial transportation partner.

Military aircraft were used to transfer patients from local hospitals to the USNS Comfort, a hospital ship that was anchored in San Juan and Ceiba after the Federal Patient Movement was activated.[14] The military subsequently transported supplies to various municipalities in Puerto Rico and was involved in the repair of bridges and the Guajataca Lake Dam, which was threatening collapse. The transfer of patients to the U.S. mainland was mostly done thanks to many private planes from humanitarian aid that returned with passengers who were transported free of charge. Because of the destruction of a key generator

used by the Federal Aviation Administration to power its control center and damage to communication infrastructure, managing air traffic was very difficult and required visual and physical spacing.[15]

Despite most RO clinics having theoretical access to power from diesel generators, some dependent on diesel generators from adjacent hospitals were not prioritized and remained without power. FEMA helped supply diesel to some RO clinics that were part of hospital systems. However, independent facilities in need of diesel did not receive it, and this was a significant shortcoming in patient care.

Humacao was hit hard by Hurricane Maria because of its proximity to Yabucoa, where Hurricane Maria entered Puerto Rico. The RO clinic in Humacao was continuously dependent on a diesel generator for 140 days (until February 7, 2018) with only 30-minute breaks for oil and filter changes. Continuous operation, including during the night, was necessary because air conditioning is necessary to maintain the correct temperature and humidity for the linear accelerator, CT scan, uninterruptible power supply, and servers. Early after Maria's landfall approximately 2500 gallons of diesel were stolen from the RO clinic in Humacao. FEMA helped provide diesel from October 2017 to the first week of January 2018, and measures taken to prevent the repeated theft of diesel included a private security guard, reinforced chains and locks, and a custom-made security encasement for the diesel tank. This last measure was only accomplished after a 2-month search for a craftsman to build the encasement.

Initially, staff went to each patient's house to ensure patients resumed treatment, and half of the staff's salary was paid in cash to compensate for inoperative automated teller machines and credit cards. Early in 2018 they were treating half of their average census because major hospitals in Humacao had only recently been connected to the power grid and were recovering. During this period, local surgeons temporarily relocated to San Juan and Caguas hospitals, resulting in RO referrals going to those areas. No payments had been received from insurance companies to reimburse for repairs or business interruption.

The Caribbean Imaging and Radiation Treatment Center (CIRT) has clinics in Ponce and Yauco, Puerto Rico. CIRT Ponce is considered the main center, and CIRT Yauco is a satellite clinic that connects remotely to servers located at the Ponce center. Because of damage to the communications infrastructure in the south of the island, the Yauco center was not able to restart operations until 5 to 6 weeks after Hurricane Maria. Connection to the remote servers was not re-established until the first week of November 2017. In an effort to mitigate treatment delays, all patients from the Yauco clinic were re-evaluated and resimulated before radiation treatment plans were redone at the Ponce center. Per the ASTRO recommendations, changes to treatment sequencing and total dose were implemented. Most patients were treated on a 6 fraction per week schedule. All patients were able to complete treatment.

The financial pressures RO clinics face after such a disaster are worth mentioning. The cost of RO equipment in Puerto Rico is similar to that in the U.S. mainland, but reimbursement is significantly lower. For example, the reimbursement for an IMRT prostate, IMRT standard, or IMRT head and neck definitive RT course in Puerto Rico is approximately $16,000, $10,500, and $14,500, respectively; in the U.S. mainland, the corresponding reimbursement would be $19,500 (+22%), $13,500 (+29%), and $20,000 (+38%), respectively.[16]

Expenditures increased dramatically after the disaster because of diesel fuel costs; facility repairs; and equipment maintenance, repair, and replacement from water damage, flooding, and power surges. In addition, income decreased dramatically because some patients ultimately discontinued treatment or resumed treatment abroad or at another local clinic where the standard of living, transportation, and/or social support might be better. Meanwhile, reimbursement from health insurance companies was delayed because of disruption on the billing and business side. Ultimately, because RO is a referral-dependent specialty, disruption in hospital and physician communication and diagnostic services can dramatically reduce the influx of new patients. Consequently, some facilities may find it challenging to meet their financial obligations. Clinics may be reluctant to share their problems out of fear of losing more business.

RT abroad may not be a realistic option for most patients unless they are treated as medical refugees with considerations given to airfare, food, housing, transportation, social support, Spanish translators, and the improbability of reimbursement depending on the specific insurance. RT costs may be easier to absorb, but chemotherapy costs may be more challenging and may require coordination at a higher institutional level. Approximately 44.4% of patients in Puerto Rico are poor,[17] have many social problems, and only have government-subsidized, very limited health insurance coverage. In 2017, the health insurance distribution was as follows: employer (23%), non-group (9%), Medicaid (47%), Medicare (14%), other public (1%), and uninsured (7%).[18,19] The Medicare Advantage health maintenance program plans only cover care in certain hospitals on the island. Most Medicare patients are economically constrained and may have significant cultural challenges when traveling to the U.S. mainland. In addition, most are elderly, have significant comorbidities, and rely on caregivers to help with activities of daily living.

Nevertheless, treatment abroad may temporarily relieve patients from housing, food, water, electricity, transportation, and other social problems and allow the

patient to focus on the arduous cancer treatment. For patients with family abroad who have some understanding of English and better health insurance and economic resources, travel is more feasible.

Having a clear understanding of when a local facility may become operational again is critical. For example, a patient with prostate cancer might be better served waiting a few days or weeks, aided by androgen deprivation therapy, before resuming treatment locally rather than waiting for a longer period of time to get a flight before encountering further delays from a second consultation, simulation, and treatment planning, potentially with incomplete local medical records. A patient with head and neck cancer, for whom time is critical and who has no realistic local option in the foreseeable future, may be better served seeking treatment abroad, depending on the situation.

Health insurance region restrictions affected patients all over the island. A formal statement from the Puerto Rico Insurance Commissioner Office was issued on September 28, 2017 with regard to preauthorizations, referrals, and claims of insured providers and subscribers, which established that organizations that provide health insurance plans should suspend preauthorization and referral requirements, not cancel policies for lack of payment, and provide other necessary accommodations for the emergency.[20] This order allowed patients to seek medical attention outside of their health care insurance region and to access specialists outside their coverage network. The order was in effect until March 15, 2018, with the exception of some insurers that were operating at full capacity before that date. This facilitated and expedited the delivery of RT treatments.

Finally, work and life balance during a time of crisis is worth mentioning. In emergency situations, emotional fatigue is as debilitating as physical exhaustion. The compassion and altruism of medical personnel are not inexhaustible, and substantial efforts must be made to support them during and after a crisis. The following are some accounts from RO clinics in Puerto Rico.

Narrative 1

"It was very difficult to balance the crisis in our homes: without water and without power, in my case for 40 days, the long lines at the very few gas stations open, lack of groceries in supermarkets, rationing of bottled water, and many other things that I do not even want to remember. Because of the crisis, one did things automatically. If you thought about it a lot you would fall into depression. In addition, we spent a lot of time without receiving payment from medical plans and the little money we had was used for major repairs and payroll. As of today, the insurance has not paid us a penny for the substantial material losses and damages to the equipment."

Narrative 2

"Like many Puerto Ricans, my personal life was significantly disrupted before Maria's landfall. The power to my home, my elderly parents' home, my children's school and many traffic lights in my area were still out since Hurricane Irma's strike two weeks earlier. During those weeks, traffic jams and fierce competition for fuel to run emergency power generators were the order of the day.

Other than minor water damage, our property was mostly spared by Maria. Many Puerto Ricans, especially the socioeconomically vulnerable, were not as lucky. In Maria's aftermath, the aforementioned difficulties worsened exponentially, the salubrity of food became suspect and there was an overall scarcity of ordinary supplies.

Although initially overwhelming, the situation brought family and neighbors together. It actually brought the Island together and the rest of the United States closer. It made many of us reflect on how much of the ordinary things in our lives are not necessary and the immense satisfaction of helping in different ways.

Once my family was safe and provided for, concentrating on getting patients back on treatment helped me not to dwell on the Island's difficulties for which I couldn't significantly contribute. Things began to improve markedly 4 months later when we were finally reconnected to the power grid. Reaching our previous normalcy took significant effort, resources, and about a year. For many, their previous normalcy is a memory they reminisce of in their new, often weakened, reality."

Compensate: Step 4 of PCOC

Under the leadership of Brian Kavanagh, MD, ASTRO president, experts in various disease sites were asked how to best mitigate the impact of a 2- to 3-week interruption in treatment. This generated an e-mail discussion among the disease site experts. The recommendations were compiled and further refined by all the experts who participated in the discussion. These are rough guidelines based on the limited evidence available. Table 3 summarizes the recommendations from the ASTRO panel of experts for lung, head and neck, uterine cervix, breast, and prostate cancer. Before this publication, a special edition of the *International Journal of Radiation Oncology • Biology • Physics* focused on Radiation Therapy in Times of Disaster and addressed RT treatment interruptions in head and neck,[21] lung,[22] and prostate[23] cancer. Table 3 makes reference to the previous head and neck and prostate recommendations and provides new concrete recommendations for managing lung RT interruptions. One radiation oncologist in Puerto Rico mentioned that the "majority of our patients gladly accepted changes in their treatment plan to compensate for treatment interruptions."

Conclusions

Natural disasters such as Hurricane Maria highlight the importance of emergency preparedness. Every RO clinic should have a robust emergency operations plan to minimize the impact of RT interruptions to patients. We hope that the recommended preparations and practices in this paper will serve as a starting point from which to further refine and disseminate strategies and mitigate future disasters in any location. Organizations such as ASTRO, the European Society for Radiotherapy and Oncology, the Sino-American Network for Therapeutic Radiology and Oncology, the Latin American Association of Radiation Oncology, the Japanese Society for Radiation Oncology, the International Atomic Energy Agency, the American Association of Physicists in Medicine, and many others representing our field should collaborate and further develop and refine these guidelines to better suit regional needs.

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