

Disaster Series: The Abrupt NICU Evacuation – Disasters without a Plan

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Abstract:

An abrupt disaster brings the environment physically into the NICU. We describe immediate evacuation measures taken because of a ruptured water pipe, hospital fire, unexploded WWII bomb, and two earthquakes. These abrupt changes thrust the Neonatologist into an environment with new structures, rules, and threats. The intruding environment dictates actions at first as the Neonatologist addresses safety for the neonates and staff while continuing medical care for the infants. The environment has just become the pathology, a new comorbidity. Operations during abrupt change mean the Neonatologist must hand off direct minute-to-minute care for the neonates, trust staff, then begin the more demanding work of figuring out next and future steps. Personal stress and fear responses must be modulated while supporting staff during the uncertainty. While these events at first appear disparate, they share the common problem of rapid movement of neonates to safety, ensuring the safety of infants and staff while solving problems embedded in a threatening environment. Faced with an abrupt environmental threat, we must maintain awareness that disaster and medical professionals will not appreciate the unique responses of the neonate to the raw environment. We must accept and rely on our colleagues' strength, fortitude, and creativity in the NICU to resolve problems embedded in the environment.

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Introduction

An abrupt disaster brings the external environment physically into the NICU environment (1, 2). The environment acts as a pathol-

ogy directly affecting the neonate and as a comorbidity complicating medical care (3). This article describes immediate evacuation measures for infants due to a ruptured water pipe, hospital fire, unexploded WWII bomb, and earthquakes.

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Abrupt change thrusts you into a physical environment with new structures, rules, and threats. You are also thrust into a system of multiple, distinct disaster infrastructures that arise from pre-existing infrastructures – emergency and disaster transport and operations while you strive for continuity of neonatal care. When misunderstood, the disaster infrastructure can quickly become your difficulty rather than enabling your success (2).

The brain responds to abrupt change immediately through the amygdala by creating and retrieving emotional memory. Not memory in the sense of recall, but memory with strength drives behavior and thought. Working in dangerous contexts, the individual comes to control the more common situations, an ability created in slack times and controlling one's temper. Those who become angry from frustration during routine operations are not fully trusted in situations with a dangerous context (4).

This place is the liminal zone, where we feel we do not belong. Cold air entering the NICU. The lack of lighting. The silence. Relying on learned behaviors or models unproven in a dangerous environment can become deadly (5-7). It is easy to assume that the stress will disrupt thinking or that protocols, lists, and leadership will move the unit through events.

On the contrary, certitude and specialized knowledge are less predictive than doubt and generalizable knowledge (8). Experts following the rules perform poorly (9-11). Discrete concepts and standardized protocols cannot align with continuous perceptions and interacting elements in flux (12), and we cannot disregard the necessary functions of stress and fear (13). Stress develops from novelty, uncertainty, and uncontrollability, while fear responds to the proximity of threat (14).

Neonatologists encountering abrupt changes will neurologically reset what they had learned, effectively starting anew, though some will resist these changes. This neurologic process appears mediated by norepinephrine (NE) and the locus coeruleus (LC) (15-17). Under severe stress, the LC impairs top-down attentional control while enhancing sensory functions, sending interrupt signals to disengage from current task sets. Quick adaptation comes about by rearranging network activity, including enhancement of the dopamine salience network. The NE-LC stress response drives a reallocation of neural resources toward attentional reorienting, vigilant perceptual intake, and autonomic-neuroendocrine control (18). The NE-LC system is how we think under severe stress.

The environment becomes the pathology that will most quickly kill the infant in the moment of change. The Neonatologist begins 'treating' the team and the NICU as the means to treat all infants in the NICU (1). From this 'outside' frame of reference, the Neonatologist surveys for the environment impinging on care while maintaining vigilance for those flurries of activity indicating disruption of that care. Decision and authority migrate to bedside staff, freeing communication for only those situations requiring the Neonatologist. *The high or mutual trust component of Lean (19), Keiretsu* connects the Neonatologist and staff for early notification of disruptions and support for decisions and actions. This component can occur within existing scopes of practice.

At the moment of abrupt change, the Neonatologist cannot select which rules apply and which do not, nor can the Neonatologist begin selecting new protocols and algorithms. The NICU becomes an open system that interacts with other, often nonmedical, systems and infrastructures such as FEMA, EMS, the fire department, and the air traffic control system. For the *Neonatology Today: Disaster Series*, we present High Reliability Organizing to continue operations across the gulf created by these abrupt changes to form an effective response toward High-Reliability Operations.

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Operations at Abrupt Change

One of the first things taught for fire rescue ambulance operations is surveying the scene before physically treating patients. The rookie too quickly stops at the first seriously injured or most anguished victim without realizing worse can be just out of sight. Triage is the first of a continuous series of movements, and the most challenging step is to leave a patient alone that you had just evaluated. There is no looking back, rechecking, and re-evaluation. It is the subtle part of triage – not only deciding but acting by leaving a patient in serious need for another more seriously ill or injured patient (DvS, personal experience). In Paris, France, physicians staff EMS in the field (SAMU, *Service d'Aide Médicale Urgente* or Urgent Medical Aid Service). At a terrorist incident, physicians are taught to step over the first body they encounter. Physically step over the body. This breaks any contact with the victim. Otherwise, as a physician, they have the drive to treat each patient rather than care for the group of victims in front of them (Pierre Carli, MD, medical director, SAMU of Paris, personal communication). The firehouse saying applies here, “When the captain picks up a firehose, he’s no longer a captain, he’s a firefighter.”

The Neonatologist continues treating the neonates through the abrupt change but in a different manner. One of the authors (DvS) experienced five children admitted to the PICU in overlapping succession over about an hour. The author assigned an objective for

each RN and RCP with several ways to reach the objective. One RN could manage continuously dropping blood pressure following a prolonged operation; an RN and RCP could manage mechanically ventilated reactive airway disease with an acute CO₂ about 100 mm Hg; a nurse practitioner, RN, and RCP could manage a newly transferred infant with a diaphragmatic hernia; the pediatric resident and RN could manage inotropic and fluid support for early sepsis; plus, an RN and RCP could manage another somewhat “minor” emergency. This process allowed the author to move amongst the patients freely, observe the team performance, therapy responses, and adjust objectives.

The Neonatologist modulates personal stress and fear responses (4, 13), recognizing that showing fear reactions will weaken everyone. However, this does not mean to decontextualize, misplace abstractions as concreteness, or suppress the affective domain, a common error that shifts the person’s thinking from being a participant-operator in context to a spectator relying on abstractions (1, 19, 20). No one feels alone. To feel supported at the moment is a more powerful force than we give credit. Vigilance for early heralds of stress or fear reactions allows the Neonatologist to support individuals and give meaning to their actions. This makes visible the beneficial consequences of the individual’s actions. Having a positive impact develops and reinforces prosocial behaviors (21), assisting leaders in maintaining motivation and finding meaning in their experiences (22-25).

“It’s not your emergency.” When a fire medic or rookie firefighter became too involved with the victim, from one author’s (DvS) experience, a veteran would tell them, “It’s not your emergency.” The rookie was not injured; the rookie did not lose anything. The rookie did not start the fire or build the swimming pool. This distancing underscores that we were there to help those who could not help themselves, the mantra the fire service held close. While they did not make the problem, their presence let the citizens know the process has stopped, that someone was there to help. For staff in the NICU, their presence represents all humanity – the family is not alone.

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The Neonatologist does not treat the team psychologically; instead, the Neonatologist reframes the situation, decomposes objectives, identifies stress and fear reactions, and gives meaning to events and actions (22, 23). There are no ‘errors’ in a disaster (26). An error for the HRO is transient because it reveals gaps in knowledge that serve as a sign for continual engagement. In the entropic, stochastic environment (27), a decision becomes a cycle of reciprocal decisions and actions for ‘error identification and correction’ that also corrects heuristic bias (28). Motor cognition emerges from error engagement as ‘thinking by acting’ to generate information and structure even as the activity itself reduces the maladaptive effects of stress and blunts the feeling of fear (29, 30). By becoming motor cognition, decision making reduces the maladaptive stress responses (14)

Within the turmoil, the distance gained by standing back allows the Neonatologist mental room to reframe the situation for staff, decompose objectives for decision making, and plan in real-time

toward the desired end-state (28). The Neonatologist will be the first to tell people, “You can do it.”

How the individual classifies or frames and gives meaning to events and actions has serious ramifications (31). The ability to make meaning of traumatic and stressful experiences, death awareness, and ‘mortality salience’ promotes a positive growth state and resilience and can mitigate post-trauma stress and feelings of ‘burnout’ (25, 32, 33).

Leadership had occurred long before the disaster (34, 35) and has now freed the Neonatologist to care for the neonates as a group, to support staff psychologically and to develop improvisations, move to protect the NICU, organize the safe evacuation of infants and staff, and develop information for parents of the circumstances.

We reviewed published accounts containing first-person experiences (36-38). From these articles, we extracted and collated the actions and words of participants. Rather than listing models and tools that the participants stated they had used, we describe *how* they used the models and tools. This understanding follows James P. Spradley’s description of culture – *how* people use social knowledge to interpret the world (39).

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People use social knowledge to enact future states (40), critical processes for the event that abruptly collapses our sensemaking (31). Looking at the actions described in this paper as an outsider facilitates the “I wouldn’t have done that” response. This reaction is not hindsight but a thoughtful discourse to reach an effective conclusion. What that approach lacks is one of the necessary High-Reliability Organizing (HRO) values identified by two of the authors (DvS and TAM) as necessary to make HRO operational (34). “That could be me.”

Internal Flooding from a Ruptured Water Pipe (41)

A water pipe break caused flooding of the floor above a NICU and Immediate Care Unit (IMC) with 26 premature and newborn babies. Eight minutes after the break, a strong water flow on the floor began dripping through the ceiling onto incubators, medical devices, and ventilators in the NICU below. Water flow alarms notified the fire department, who arrived nine minutes after the break. The hospital emergency team was alerted and reached the NICU 35 minutes after the first alarm. Five minutes after arriving, the senior Neonatologist decided to evacuate the NICU.

The Neonatologist and emergency team needed to find accommodations for the infants and a means to transport the infants as gently as possible. They discarded evacuation to external clinics because nearby centers could not quickly accept that many patients, there were only three ventilator-capable transport incubators available, and the necessary transport time would delay the evacuation of some infants.

The Neonatologist and Chief Anesthesiologist identified internal

bed availability: the central operating recovery room equipped for intensive care, the PICU, and the Infant Unit on the 6th floor.

The Neonatologist changed the status of nine spontaneously breathing NICU infants to ‘infant status.’ Staff then moved the nine infants to the infant station on the 6th floor of the same building. While evacuation plans include methods to take infants *down* a stairway rapidly, these infants had to be carried up the stairway because water had penetrated the elevator shafts, rendering the elevators inoperable. Evacuating *upwards* required different techniques, which they developed in the moment.

Basement corridors connect buildings on the campus. The team selected foot transport for travel rather than the use of vehicles. Because the corridors are not regularly used, the fire brigade and security service investigated passageway conditions for travel. They judged that the premature babies could be moved in their mobile incubators.

For the ventilated infants, the Chief Anesthesiologist evaluated the anesthesia recovery area to ensure safe transport, sufficient staff to provide care, and ‘warm packs’ as a heat supply for the incubators. They would use the special transport ventilators and avoid vibrations by moving very carefully and slowly.

For the safety of the infants, the team secured catheters and endotracheal tubes, obtained sufficient reserve oxygen and compressed air, and checked battery capacity, charging the batteries where necessary. They have an existing emergency backpack containing special equipment with the capability to attend to accidental extubation. They created several more for use during parallel transports. They transitioned the infant receiving HFO ventilation to conventional ventilation.

Transport staff consisted of a direct care team of a nurse and a Neonatologist. The incubator team had five people. Two pushed the incubator, one pushed the cart with monitoring and medical devices, and two monitored the ventilator and external gas supply. They could transport a maximum of three incubators at the same time. The number of people required to move a premature infant in the incubator was more than expected, typical for emergency evacuations given the limited number of staff available in the NICU (42, 43).

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The infants were then moved through the passages, with three infants evacuated to the PICU and fourteen infants evacuated to the recovery room. Five infants went to the ‘wake up’ area that was also used for operations. Nine infants went to the recovery room for the central operating room, which had just been completed. Though pre-equipped, it had no monitors. The medical technology service installed monitors that night.

Evacuation started at 0005h, and the last incubator was situated at 0430h. For the infants evacuated through the basement corridors, the team’s time from departure to return averaged 40 minutes. Following the decision to evacuate, with no plan, people interacting with others they had not previously worked with, solving problems they had not previously encountered, the team moved

twenty-six premature and newborn babies in four hours.

Internal Structure Fire (44)

A high voltage power transformer in the hospital basement exploded, igniting a high-intensity fire that burned for two hours. Smoke and soot entered the hospital ventilation system. Polychlorinated biphenyls burning in the electrical vault could produce toxic gases. The south side of the building and the NICU with twenty-nine infants were most affected by smoke.

The nursing coordinator notified the units on the north side of the hospital to prepare for patients from the hospital's south side. Twenty NICU infants were evacuated in their incubators to the north side, upstairs to the fifth floor.

The hospital across the street with a level three NICU accepted nine high-risk neonates. Normal movement between the hospitals is through a connecting underground tunnel which had filled with smoke. The outside air temperature was frigid.

Fire and police personnel created a human corridor crossing the street between the hospitals. Two or three nurses, a respiratory therapist, and a physician evacuated the neonates in their incubators through the protective human corridor.

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Unexploded WWII Bomb (45)

A construction worker discovered an unexploded “five hundredweight” (560 pounds) aerial bomb buried since World War II. An excavation crew had been excavating to expand the clinic, finding the bomb near three fuel tanks. The hospital had 626 patients, and the NICU had six neonates, all receiving mechanical ventilation. It was raining with an outside temperature of 50° F (10° C).

An Operations Center was set up in accordance with rehearsed evacuations. The anesthesia director was the clinical directing service and assigned priorities for various categories of patients. Newborns and mothers were the first priorities. The chief of operations of the fire brigade managed the technical operations with police physically present to shorten information channels. The fire chief ordered the immediate internal evacuation of patients in rooms facing the bomb.

The Operations Center informed nursing stations by phone or direct contact. Because the time of the evacuation had yet to be determined, physicians and surgeons began discharging those patients that could leave. The Chief Neonatologist reported confirmation that two NICUs had accepted all six neonates. The time was 90 minutes after initial contact. The evacuation was the responsibility of the Neonatologists. The six neonates were evacuated by neonatal ambulances the day after discovery.

The ordnance clearance service arrived and reported no acute risk of an explosion but did recognize an evacuation radius of 1,600 ft (500 m). The following Sunday, three days after discovery, they would defuse the bomb to limit exposure to schools and kindergartens and give public safety services time to evacuate residents. The bomb was defused within 15 minutes without prob-

lems.

Earthquake in Cold Weather (46)

A Level 3 NICU experienced two earthquakes of magnitude 6.5 M_J 6.2 M_w and 5.8 M_J without damage and a subsequent 6.4 M_J earthquake without damage. NICU staff reviewed the routes and priorities to evacuate the infants. Twenty-six hours after the first earthquake, an earthquake of magnitude 7.3 M_J 7.0 M_w caused extensive damage, disabled the elevators, and rendered the internal stairway impassable. Twenty minutes later, a 5.9 M_J aftershock prompted the decision to evacuate the NICU.

[The magnitude (M) of energy released in an earthquake is measured locally (the well-known Richter Scale) or by ‘moment,’ the total energy. The Japan Meteorological Agency (JMA) measures magnitudes in several ways. M_J (“J” for Japan) measures the magnitude of *ground shaking* as ‘local magnitude,’ the maximum amplitude of ground displacement for *horizontal* ground motion. M_w measures the magnitude of work (“W”) of an earthquake as rocks slide past each other, the friction dissipating as heat into the earth’s crust. Ground shaking results from the energy not dissipated as heat, radiating instead as seismic waves causing structural damage. Most earthquakes in western Japan are shallow strike-slip earthquakes with surface wave motion propagating long distances. M_J is larger than M_w and more accurately measures surface wave energy. The sedimentary basin of northeastern Japan attenuates ground motion, and M_J equals M_w (47).]

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With the elevators disabled and internal stairs damaged, the only egress was the external emergency staircase from the third floor to the outside parking area. The outside air temperature was 14° C (57° F).

The NICU had thirty-eight infants, seven receiving mechanical ventilation and nine on nasal oxygen/ventilatory support. Another fourteen infants were receiving continuous intravenous infusions. Some nurses had finished an early night shift and stayed to assist, twenty nurses in all. Three Neonatologists were available for this primary evacuation out of the NICU. They took the infants out by way of the outside stairs. Upon reaching the parking area, they immediately transferred the infants to the ground floor rehabilitation room. Infants shared the four oxygen cylinders available.

Forty-five minutes after the decision to evacuate, the Chief Neonatologist contacted neighboring NICUs to arrange evacuation and the Japan Society for Neonatal Health and Development (JSNHD) disaster-communication secretary. JSNHD supports a network of remote NICUs through an online directory and communication tools, including internet phone and text messaging.

Coming to Their Aid

Shortly after the first earthquake, the Disaster Medical Assistance Team (DMAT) arrived with five or six members, including a doctor, a nurse, and a logistician. DMAT establishes a prefectural command post at the Kumamoto prefectural office, creating the

initial command hierarchy during the acute phase of a disaster. The DMAT operations include status checks of disaster-affected hospitals, evacuation of 1,400 hospitalized patients from eleven damaged hospitals, and utilization of doctor-staffed helicopters.

A Level III NICU 75 km (47 miles) away arranges a helicopter to evacuate several infants. DMAT intervenes, requisitioning the helicopter for other missions, and commandeers all ground ambulances that are not part of a hospital. The Chief Neonatologist requests DMAT assistance in obtaining helicopter evacuation of the sick infants. There will be no helicopter, but DMAT will arrange for five *general* ground ambulances to evacuate thirteen low-risk infants. The neonatal ambulances that did evacuate the infants were attached to their respective receiving hospitals outside the affected disaster region. The one helicopter transport that took place was arranged outside of DMAT (46).

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Two hours after evacuation, a neonatal ambulance arrives from a local Level III NICU to transfer infants. At the same time, three outlying NICUs respond to their neonatal ambulances to transport six infants, arriving three hours later. Three and a half hours after evacuation, a neonatal ambulance from a local hospital transports three infants with congenital heart disease to an outlying NICU. Five hours after evacuation from the NICU, a helicopter arrives for transport. After seven and a half hours, one infant remains – awaiting long-distance helicopter transport to its hospital of birth.

The majority of patients are evacuated locally within eight hours. Ambulances carry 1-2 infants with intubated infants grouped with a stable infant. Thirteen infants are evacuated by general ambulance, twenty by neonatal ambulance, three by helicopters arranged outside of DMAT, and two by private vehicle. One very-low-birth-weight infant develops hypothermia, 33°C (91.4°F).

Earthquake Affecting Multiple Hospitals (48)

An earthquake of magnitude 6.7 M_w , followed one minute later by an aftershock of 6.0 M_w . Lasting 10-20 seconds, the ground motion was felt in cities 220 miles (350 km) from the epicenter.

Less than one mile from the epicenter, a NICU on the fifth floor of a damaged hospital had 22 newborn and premature babies. The day before, one neonate had been admitted following delivery by Cesarean section. The “earthquake cracked the nursery and sent some incubators toppling over, some with newborns inside.” No infants were injured (48). The NICU had shattered glass, cracked flooring, damaged walls, and exposed wiring (49). NICU staff evacuated the infants to the Emergency Department. Nurses held some babies while sitting under counters for safety (48).

The hospital had lost power, disabling elevators. The hospital itself suffered major damage (48). Eight hospitals sustained significant damage from the earthquake, causing six to evacuate patients

immediately. All six hospitals requested the EOC to dispatch vehicles for evacuation. The EOC reserved helicopters for patients receiving mechanical ventilation. A television-news helicopter transported a patient with potential intracranial bleeding (50).

Four of the six evacuating hospitals contacted nearby facilities directly to receive patients, while the other two sought assistance from the County Emergency Operations Center (EOC). The Neonatologists could evacuate 17 neonates to regional NICUs, leaving five without a disposition.

California hospitals are required to have contracts with area hospitals to receive patients in an emergency. Because of the earthquake, the contracted hospitals were either damaged or already receiving neonates from other damaged NICUs. The EOC was unable to help with placement. This may have been the reason for other hospitals seeking help from the EOC (personal communication during the incident, James P. Denney, EMS Captain, LAFD, retired).

One of the Neonatologists contacted a Neonatology faculty member at the university in another county where he had trained, 60 miles (100 km) away. The university hospital accepted the five neonates but had no means of transporting them (48). One Neonatologist at the damaged NICU inquired with the LAFD about using fire department rescue ambulances or helicopters to transfer the neonates. The department couldn’t oblige because of earthquake-related missions (personal communication during the incident, James P. Denney, EMS Captain, LAFD, retired).

The university Neonatologist called a nearby US Marine Corps helicopter base for assistance. The base commander sent the request up the military chain of command, and it was granted. The two UH-1N Huey helicopters’ flight time was 30-40 minutes each way. The helicopters landed in a nearby parking lot rather than the roof because of the disabled elevators. About 12 hours after the earthquake, the last neonate was admitted to the NICU (48).

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Not from a plan, protocol, or government agency, the evacuation of these five neonates occurred solely because of the initiative, drive, and collaboration of Neonatologists working from two NICUs with the cooperation of the US Marine Corps. In California, the county has financial responsibility for the medical care of indigent residents, even when the county resident is treated in another county. Even during emergencies or disasters, county and state agencies closely monitor “out-of-county” medical transfers. This out-of-county helicopter transfer was not included in patient evacuations tracked by the county EOC (50). The NICU had gained access to a Marine Corps helicopter unknown to the controlling government agency and unreported in the published literature.

Parents

The NICU transport teams left notes and maps for the parents.

The mother, who was delivered by C-section, was transferred to another unknown hospital. The information did not travel with her

infant. The father could not be reached by phone or through his employer (51). Other families lived in homes without electricity or heat because of power outages.

One mother learned of the evacuation the day after the earthquake when she visited. The family had stayed at an evacuation center and did not know where they would sleep that night. The infant was being treated for a blood disorder that must be controlled before being discharged home. The Neonatologists did not have experience discharging a baby with medical needs to a homeless mother (51).

Volcanic Eruption in a Tropical Storm (52)

The Mount Pinatubo eruption of June 15, 1991, in the Philippines gave little warning of the damage's severity, location, and extent. The eruption coincided with the arrival of a tropical storm. From the minor initial eruption, Ash dusted nearby Clark Air Base, and 13,000 personnel were evacuated to the US Naval Facility at Subic Bay, sixty miles distant by road. The second main eruption occurred as winds from a tropical storm blew heavy, wet ash onto Subic Bay, precluding the air evacuation of personnel.

Three days later, the mountain blew its top (1,600 feet of elevation was lost, forming a crater over a mile wide). The winds from a passing tropical storm brought ten inches of heavy wet ash to the US Naval Facility at Subic Bay, 23 miles south of Mt. Pinatubo, which had been considered a haven from the effects of the eruption for the 13,000 Clark Air Base personnel who had been evacuated to Subic Navy Base.

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The wet ash destroyed over 200 buildings, interrupted the power and water supply, and damaged the runway at Cubi Point Naval Air Station. The 20,000 Navy and Air Force dependents then had to be evacuated by Navy ship to Cebu, 300 miles south, where they could be airlifted back to the United States. Multiple trips by two aircraft carriers and a large amphibious ship completed the evacuation within a week after the eruption. One author (TAM) was the Rear Admiral who commanded the US Naval Facility at Subic Bay and these operations.

Medical Preparations for a Volcanic Eruption

The following describes a large, organized response to an abrupt disaster, comparing what is 'needed' for neonatal care during a disaster with what is available, described in this article—individuals working together and improvising care filled that gap. Planning for structure and resources comes at the risk of emphasizing what we believe we will need while under-emphasizing the development of

capabilities and support of our assets. *The person operating in the flux of events becomes an asset.*

“With Mount Pinatubo becoming more active over the prior two months, several potentially complex neonatal cases were flown by weekly USAF medical evacuation flights to Japan, Hawaii, or the US mainland. After Mount Pinatubo erupted and the 20,000 evacuees were streaming into Subic Bay, it was decided that the majority of the medical personnel, their families, and all near-term pregnancies among the evacuees would depart on USS Peleliu (LHA-5).”

The US Naval Hospital at Subic Bay, fondly called “Jungle General” by the medical staff, was the designated primary care facility for all military personnel and families at both Clark AFB and Subic Bay Naval Facility. With Mount Pinatubo becoming more active over the prior two months, several potentially complex neonatal cases were flown by weekly USAF medical evacuation flights to Japan, Hawaii, or the US mainland. After Mount Pinatubo erupted and the 20,000 evacuees were streaming into Subic Bay, it was decided that the majority of the medical personnel, their families, and all near-term pregnancies among the evacuees would depart on USS Peleliu (LHA-5). Peleliu was selected because, as a sizeable amphibious helicopter carrier and Marine assault vessel, it was equipped with three operating rooms and could provide more extensive medical care and birthing wards than the aircraft carrier USS Abraham Lincoln (CVN-72), with only one operating room and a smaller number of assigned medical personnel. The large troop-carrying Marine helicopters (H-46s) were also more suitable for transporting non-military personnel ashore upon arriving in Cebu. Coming two months after the First Gulf War, the USNS Hospital Ship Mercy was still deployed to the Persian Gulf region. While it would have been a suitable vessel to transport the personnel potentially requiring medical care during the trip, it does not have the extensive helicopter lift capability. The medical evacuation was accomplished efficiently with no additional problems. Seven babies were born on USS Peleliu during the thirty-six-hour transit to Cebu. One baby boy was born on the USS Lincoln during its first trip south. He was appropriately named Abraham.

Immediate Response

Internal communications were maintained by armed forces radio and television and police and community meetings. Because of the diverse locations of the damage, neighborhood captains were identified. The situation also required the care and feeding of a diverse population, two-thirds of whom were from Clark Air Base forty miles from Subic Navy Base.

Evacuation and recovery plans had been developed over the previous two months that would involve airlift and sealift operations, with the sealift requiring a three-hundred-mile trip because of the lack of available port facilities. A significant contributor to the smooth response was the presence of several large US Navy ships with recent operational experience from the First Gulf War.

HRO characteristics informed the entire response of the US Navy, US Air Force, and US Government aid and support to the Philippine people.

While there is much experience with dry volcanic ash, there was little with wet ash. The trees were cut back from the above-ground power lines at Subic, surrounded by jungle in a typhoon-prone area. However, the conductivity of the ash required using lift trucks with a firehose to wash down the insulators and all wires and transformers before power could be restored.

Early in a disaster, air assets are essential for rescue and damage surveys. As soon as the skies cleared, about one day, air assets flew. These are essential missions that must be done. There was little history of flying helicopters and fixed-wing aircraft in ash-filled skies, but air search and rescue in isolated areas near Mt. Pinatubo was essential. Helicopter flights were accomplished under careful supervision and frequent inspections from day one of the recovery, followed by fixed-wing aircraft three days later after a portion of the runway was cleared. Any damage to the aircraft (minimal) was documented and became part of the bank of knowledge of the hazards of flying through a volcanic ash cloud. After volcanic eruptions in Iceland, Indonesia, and Alaska, international air control authorities subsequently utilized this information.

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Numerous individuals led the eruption response and recovery efforts, often isolated and out of touch with their normal leadership chain, with a bias for action to try something and learn what would work in these unusual circumstances.

Abrupt Change is New, Even for Veterans

We have heard the lecturer say, “I have seen everything.” With more experience, we notice the rare event as something possible rather than a ‘set aside’ beyond imagination. We begin to distinguish between the problem, the environment, and how they interact, but we also identify the pervasiveness of how the environment influences problems – and that those you work with are part of your environment. The embedded problem is highly contextual, interacting with the environment to make every event a new event. This complexity does not mean we do not know what to do or wait for more information before engaging. It means that every problem in the environment is a new problem, and every solution is a new solution.

Even personnel with previous experience in disaster relief operations had never seen anything like this. All of nature seemed out of kilter, with the sky filled with ash, pitch-black for 24 hours, winds up to 45 knots with heavy rain and lightning, and frequent earthquakes rolling across the countryside, fortunately only to magnitude 5 on the Richter scale. Traveling around the base was impossible. Individuals used their training and previous experience to form teams and accomplish what they could in assessing the risk and managing their situation, often being the only source of sup-

port and encouragement to the refugees from the storm scattered throughout the base.

Problems Encountered

For healthcare, a disaster is an *environmental disruption* of medical care that disrupts the *ability to treat multiple patients*. This limitation is a functional, ecological definition (1). Environmental problems are not isolated but are embedded into each other – damaged structure, toxic air, cold temperatures, moving from one problem places the neonate into another.

These events abruptly and uncontrollably exposed neonates to:

- Water and contamination
- Smoke, soot, and toxic gases
- Cold air

Two abrupt disasters exposed neonates to cold outdoor temperatures or extended transportation through cold weather. One very-low-birth-weight infant developed mild hypothermia with a core temperature of 33° C (91.4° F) (46).

The physical structure of the NICU has full environmental control over temperature, humidity, lighting, and people. Neonates are susceptible to environmental stressors such as vibration and cold and are susceptible to kinetic activity or vibration affecting cerebral circulation or the security of endotracheal tubes and vascular access (41, 46). During these four events, smoke, water, vibration, and cold had abruptly entered the NICU to complicate care for all the neonates. It is a testament to the healthcare providers that only one adverse event, hypothermia, was reported.

The time course of a disaster

Healthcare providers had minutes to react during a situation in flux. They then had tens of minutes to develop a plan as the situation and the environment remained unsettled. Afterward, they had hours to wait. Achieving stability is an illusion for the spectator. Healthcare providers used continual reciprocal feedback to engage the environment while simultaneously supporting the infant, all the while keeping the neonate protected from an austere and adverse situation.

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Disaster infrastructure

A disaster brings together diverse infrastructures, but they are infrastructures of organizations and disciplines accustomed to collaborating. In viewing the relations, infrastructure builds a community. New for NICU sheltering or evacuation are the types of organizations and infrastructures they utilize. For example, air transport will be controlled by a central government agency, and air traffic control rules and procedures will become more visible. Boundary objects facilitate communication across disciplines and organizations while operating in a new boundary infrastructure.

You are not in one system or infrastructure – transport, emergency

operations, and continuity of care have distinct infrastructures. Disaster infrastructure is new to the Neonatologist but well used by disaster responders, hence the importance of boundary objects. For operations in austere or dangerous contexts, there are differences in language and lexicon, risk characterization, and medical care provision. Leaders work within the context of the disaster, monitoring stress and staff capability. Outliers as discrepancies or local disruptions are regarded as potential early heralds of new problems rather than disregarded as random events. One person's infrastructure can become another person's barrier (53).

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Government agencies

Government agencies generally coordinate activity and control out-of-area resource allocation during a disaster. Vehicles are resources controlled by these agencies except for those under the previous contract with a hospital. The two earthquake events demonstrate the control of transportation resources.

A study of disaster medical operations during the Kumamoto Earthquake included DMAT operations. DMAT evacuated patients from damaged hospitals, transported medical supplies, and coordinated 14 “doctor helicopters,” helicopters with an accompanying physician to transport severely ill patients. DMAT provided medical coordination management until the local medical coordination was on track. There was no mention of the combined NICU evacuation efforts or helicopter operations supporting the evacuation (54).

In the US, a DMAT (also ‘Disaster Medical Assistance Team’) is part of the National Disaster Medical System (NDMS) that provides rapid response medical care for public health and medical emergencies that overwhelm local resources.

In California, no helicopter was available for hospital evacuation except a news helicopter that transported an emergency patient (50) (personal communication, James P. Denney, EMS Captain, LAFD retired). One NICU, working with colleagues in a distant county and the US Marine Corps (48), evacuated five neonates outside of, and unrecorded by, the county EOC. Until this article, the Marine Corps helicopter transport has not entered the medical literature (50).

The experience of two NICUs in two countries did not find government agencies helpful (46, 48). The other three NICU evacuations in the two countries were tightly integrated beforehand with government agencies or due to the cause of the evacuation. The two with difficulty were single hospitals amongst many needing evacuations, while the three with support were single hospital events.

There was a placement problem since the receiving hospital was also damaged, and both hospitals had to compete for the same beds. At a regional disaster meeting with state representatives, the conclusion was that the Neonatologists had figured it out, so no action was necessary. Privately, two county disaster manag-

ers recognized they had listed all ICU beds as a single value – adult ICU beds. They did not know that PICU and NICU beds differed and that both differed from adult ICU beds. An agency in another county rebuffed efforts to address the problem of multiple damaged hospitals, attempting to evacuate to the same hospitals outside the area of damage (DvS and personal communication, James P. Denney, EMS Captain, LAFD retired).

In these events, the NICU staff evacuated the infants from the NICU to a collection point for ground transportation or internal transfer. During a disaster, the larger mission of public safety agencies precludes them from evacuating hospitals. Administrators of one medical center believe the fire department would evacuate patients should the hospital structure become unsafe. The fire chief stated the department would be responding to residents and did not have the staffing to evacuate a hospital (DvS, personal communication).

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Adult standards

An associated problem is adult triage methods for infants and the failure to understand the necessity of helicopter transport (46). Neonatal physiology in an uncontrolled environment is deadly. What is missed is how rapidly the environment can change neonatal physiology, making it fatal, a problem not readily recognized by healthcare providers. One author (DvS) has observed environmental hypothermia in EMS and critical care with ambient temperature below an infant's thermoneutral temperature (32° C, 90° F): (air-conditioned hospital or trauma rooms, helicopter rotor wash, oxygen administration for pulmonary hypertension, methods for hand ventilation, and body temperature loss due to extended hand ventilation).

Bed availability

Most receiving NICUs accepted 2-4 neonates, while a few could accommodate more. The individual making the request was often the Neonatologist, but it appears some hospitals gave a degree of administrative assistance. In Japan, the rapid evacuation of 38 infants came about from a disaster communication team following meaningful disrupted communication in a 2011 earthquake.

The surge capacity of receiving NICUs is not predictable. It was fortunate that receiving NICUs could absorb the surge. When this was not practical, improvisations were the PICU, anesthesia recovery rooms, and the ED (41, 48).

The acuity level of the infant affects bed availability. Placement of neonates receiving HFO, mechanical ventilation, and CPAP is a problem. One solution was to change the mode of respiratory support from HFO to conventional ventilation or decrease the classifi-

cation for oxygen administration to 'infant status' (41).

Time

Seeking receiving facilities and the medical handover of complex patients can occupy significant time for the Neonatologist. Internal evacuation reduced this load (41, 44).

We can appreciate transport time in several ways – the actual transport, loss of bedside staff, and complete evacuation. Transport time within a hospital or to an adjacent building was often 40 minutes or more (41, 44). Internal, controlled evacuations occupy 3-7 people for each infant. The time away from bedside care is doubled for preparation and return to the NICU (41, 44). When evacuating infants out of the region, flight times of 40 minutes (48) or driving times of several hours (46) are expected.

Time to fully evacuate the NICU was five hours for internal evacuation (41) to 8-12 hours following an earthquake (46, 48). **Table: Evacuation Times**

Event	Infants	Receiving	Time
Water flow (41)	26	6 internal, upstairs 20 external	4 1/2h
Bomb (45)	6	6 external	n/r
Internal fire (44)	29	20 internal, upstairs 9 external	n/r
Earthquake (46) Cold weather	38	38 external	7 1/2h
Earthquake (48, 49) Multiple hospitals	22	22 external	12h

Distance

For an internal evacuation, distance creates a problem because of the smaller magnitude of response. The time for transport to an adjacent building is nearly the same as driving to a hospital in the same city. We see this in deciding whether to move neonates internally or seek receiving hospitals (41).

“For longer distances, driving three hours increases the risk of adverse events, including hypothermia in a neonate and death (46). A disaster brings together organizations and government agencies unaccustomed to the operations of the NICU.”

For longer distances, driving three hours increases the risk of adverse events, including hypothermia in a neonate and death (46). A disaster brings together organizations and government agencies unaccustomed to the operations of the NICU. Translating the risks that extended travel poses to a premature infant is problematic for various reasons, but it can be reduced by understanding the various missions in a disaster and the use of 'boundary objects' (1, 55, 56). Description of the consequences, including *how* death could occur and accurately describing what is necessary to prevent death, along with private anecdotes, can facilitate

collaborative action by making it a common problem (57). Government agencies focus on survivability, the reduction of death *after* the event. Survivability describes the effect of the environment on mortality as comorbidity or to impede connecting necessary medical care to the victim (3). Neonatologists focus on reducing mortality, death *due to disease*. Death, then, becomes a practical boundary object for communication.

Equipment. Availability of oxygen cylinders for one NICU during an earthquake was easily solved when the infants shared a cylinder (46).

Convergent volunteers. Volunteers and returning staff will overwhelm the physical space and the ability of healthcare providers to perform (44). This crowding can occur at public safety incidents also (3). No NICU reported this as a problem.

Communications. Commonly brought up in discussions of disaster and a problem for a hospital operating during a structure fire (44); however, no NICU reported communication problems, either internal or external. *Emergency communication* was hampered when staff members were unfamiliar with portable radios, and the hospital had no shared frequency with public safety (44).

Neonatal transport with incubator support is not readily available through EMS (41, 44). One NICU used general ambulances to evacuate some of their neonates (46).

Supplies are damaged during an internal disaster. Evacuating patients internally without accompanying supplies created shortages in the new unit. Referring to evacuations as transfers rather than an evacuation may trigger normal transfer behaviors and etiquette. Accustomed to moving the patient and not taking supplies from the originating unit, staff carry the same behavior into an evacuation.

Notification of family by the media. If an internal disaster occurs, the family may not know about the problem until they see it on the news (44). The family may not realize the hospital was evacuated (51).

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The Process of Lessons Learned

A Lesson Learned process provides realistic, actionable recommendations that cause an organization to improve from the knowledge acquired after an adverse experience. It reduces or eliminates the potential for failures and mishaps or reinforces a positive result. Analytical processes discover what happened and why it happened. By identifying the root causes and remedial or corrective actions, experiences are transformed into best practices and lessons. Expert consultation from subject matter experts (SME) helps the organization understand the collected data to create informed recommendations (58).

A Lesson Learned must connect to measurable change in behavior. The organization must take deliberate corrective actions

from the Lesson Learned to enhance performance (58). Lessons learned can prepare the organization for the next disaster or improve routine operations to support operations during the next disaster.

We recommend a formal *Lessons Learned Process* with analysis of the observations, consultation with SMEs, correctional actions, and identified operations of what should be reproduced through training and simulation.

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The Lessons Learned

Evacuating for a bomb threat went smoothly. The hospital had rehearsed evacuations, and the Neonatologist could rapidly place the six neonates who were evacuated the following day.

In the other four disaster events, healthcare providers at the bedside initiated immediate and effective action to save the babies. They did not refer to a program, follow a list, or seek outside leadership. As a leader, the Neonatologist directed activity for the whole of the NICU. As the author’s group (DvS et al.) found during the After Action Review of a terrorist shooting, “Their plans were not improvised. Improvisation was the plan. Training can support this approach” (Sean McKay, personal communication, (3)).

Contributing to Success

The crisis management system identified authority and what instructions could be issued. Predefined structures and processes kept relevant decision-makers informed. An internal alarm system to clinical and facility administrators facilitated rapid recruitment of sufficient staff (41).

NICU and PICU staff were assisted by a group of doctors and nurses experienced with premature infants within the anesthesiology, operative intensive care medicine, and operating theater group (41).

The JSNHD disaster communication team facilitated a network with remote NICUs. The online directory and communication tools included internet phone, text messages that facilitated contact with outlying NICUs (46). Not having a program like this was identified as a significant deficit during an abrupt disaster (41). Such a system would benefit larger hospitals for internal communication where communication during an internal disaster became a problem (44).

What to Change

Working with government agencies “revealed covert but serious risks in relying on the adult-based coordination system of transportation” (46). Neonatologists can present to government disaster agencies the unique way the danger of a disaster brings threats to the neonate, such as hypothermia, vibration, and toxic air (41, 44, 46).

For sick infants on long-distance transportation, minimize the threat from transport by using helicopters or neonatal ambulances (46).

Consider recovery rooms or similar units as a temporary buffer in emergencies (41).

Envisage evacuation, emergency routes, and necessary actions you would take if the expected route becomes obstructed or dangerous (41). For internal evacuation of patients, bring care stock items and medication carts to the same unit (44).

Working with public safety, develop a unified, or unifiable, command structure with public safety. Obtain capability to communicate on a public safety radio frequency (44).

“Disaster infrastructures create friction for the Neonatologist. We can communicate across infrastructures through boundary objects. Death is a boundary object for communicating between those infrastructures working to increase survivability and reduce mortality.”

Conclusion

During a disaster, the environment becomes a comorbidity. We cannot plan for a granular response to abrupt change. Although past experiences assist in response to an abrupt change, every disaster is ‘ahistoric,’ that is, we can never be certain about how things came about or the effect of each element involved. Support equipment, evacuation methods, and selection of receiving hospitals become part of the environment, external to what the Neonatologist can control. Disaster infrastructures create friction for the Neonatologist. We can communicate across infrastructures through boundary objects. Death is a boundary object for communicating between those infrastructures working to increase survivability and reduce mortality.

“ These scenarios demonstrate that earnest attention to the problem, developmental physiology, and standard neonatal practices can support neonates during abrupt changes in the environment. However, we cannot rely on disaster authorities or other medical specialties to appreciate the lethal effects the disaster environment poses for premature or newborn infants.”

While planning may focus on harm and what to fear, the actors in these events focused on protecting the babies and then moving them to a safe area or outside the hospital. They controlled fear responses and kept to contextualization to improvise safe and effective evacuations (4, 13, 19). One infant developed hypothermia

out of the 121 infants evacuated.

Immediate evacuation measures taken because of a ruptured water pipe, hospital fire, unexploded WWII bomb, and two earthquakes do not follow plans or allow for lengthy evaluation. While these at first appear disparate, they share the common problem of rapid movement of neonates to safety, ensuring the safety of infants and staff while solving problems embedded in a threatening environment. The Neonatologist must separate cognitive and affective processes from the situation and environment. These scenarios demonstrate that earnest attention to the problem, developmental physiology, and standard neonatal practices can support neonates during abrupt changes in the environment. However, we cannot rely on disaster authorities or other medical specialties to appreciate the lethal effects the disaster environment poses for premature or newborn infants. We can rely on the quality of our colleagues to carry our patients, sometimes literally, to safety.

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