Disaster Series: Elements of a Disaster

Daved van Stralen, MD, FAAP, Sean D. McKay, Thomas A. Mercer, RAdm, USN

Abstract

A disaster is an environmental disruption of medical care, a victim generator that disrupts the ability to treat multiple patients. Death can come from physiological, physical, social, or behavioral threats within the disaster environment. Legal or administrative definitions of disasters are necessary for out-of-area resource allocation. Topological dynamical systems describe the continuous transformations within the topological space of a disaster. A functional description of disasters focuses on the damage produced by the disaster rather than how the damage was caused. An ecological description underscores how damage creates a new environment within our familiar, formerly safe work environment. The disaster environment can have a latent effect on physiology in several ways. The disaster forms an embedded problem, an ill-structured problem embedded in the environment. We extend operations into disasters by developing capabilities rather than assessing risk.

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Introduction

A disaster is an *environmental* disruption of medical care, a *victim generator* that disrupts the *ability to treat* multiple patients. This functional and ecological definition directs our attention to the immediate environment inside the NICU and around the neonate. No longer does the Neonatologist have control over the environment around the infant. We respond to the immediate area to ensure safe conditions, correct abnormalities, then consider sheltering or an immediate evacuation. The disaster environment has disrupted our familiar concept of medical care.

The environment of a disaster will self-organize, confounding our efforts to predict and plan a response.

“Technological systems become organized by commands from the outside, as when human intentions lead to the building of structures or machines. But many natural sys-

tems become structured by their own internal processes: these are self-organizing systems, and the emergence of order within them is a complex phenomenon that intrigues scientists from all disciplines.”

Eugene F. Yates (1)

The environment becomes a pathogen distinct from physiological pathogens. The Neonatologist, thus, responds to the environment, not to an earthquake, hurricane, ionizing radiation, etc. The Neonatologist protects neonates from uncontrolled energy in a disaster, including cold, heat, water, and contamination. The Neonatologist now collaborates with outside people who are unaccustomed to the care of a premature infant.

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Environmental threats are physical, social, and behavioral. In the field, death can come from any one or a combination of the three threats. While physicians focus on physiological threats (inadequate tissue oxygen delivery), in the prehospital environment, death can come from a vehicle driving into an accident scene or an angry individual physically assaulting the medics, situations one author (DvS) has experienced. In those instances, the physiological threat and the ABCs may have to wait. Death can come from physiological, physical, social, or behavioral threats during a disaster.

- Physical threats from uncontrolled energy
- Social threats from outside groups impeding care (2)
- Behavioral threats from situational cognitive distortions due to stress, fear, or threat (3-5)

With a disaster, the environment becomes an open system with an unimpeded flow of energy and the entry of outside people and resources. Thermodynamic entropy describes the dissipation of outside energy into the NICU and the energy within the NICU dissipating outward. We experience this entropy in five forms of energy: thermal, chemical, electrical, kinetic, and less commonly, ionizing radiation. Information also has entropy that follows the thermodynamic entropy equation. Information, rather than dissipating, becomes corrupted through its transmission to others (6).

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During a disaster, the NICU becomes an open system that interacts with other, often nonmedical, systems such as FEMA, EMS, the fire department, and the air traffic control system. In the Neonatology Today: Special Disaster Series, we will present High-Reliability *Organizing* as a means to describe disasters and develop an effective response toward High-Reliability *Operations*.

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Functional description

A functional description of disasters focuses on the damage produced by the disaster rather than how the damage was caused. Neonatologists in situations within the disaster space respond to local threats to create a trajectory of stabilization and recovery. At the same time, they maintain medical care for their patients. This Lagrangian flow specification is in contradistinction to the Eulerian specification from a fixed point of reference outside the flow of events (7). This also facilitates practical descriptions of what to expect, such as the nature of increases in demand, the appearance of novel demands, and the decrease in resource availability. Operators within a disaster focus on context and what they can learn; outsiders will focus on what they already know.

Table 1: Eulerian and Lagrangian Specifications (8)

Eulerian, quantitative	Langrangian, qualitative
Decontextualized	Contextual
External, fixed point	Within flow
Focus on the specific location	Focus on the individual moving parcel
Flow	Trajectory
Multiple, fixed positions	Continuous measure with position and pressure
Rate of change of system	Individual parcels

Ecological description

An ecological description underscores that damage from the event creates its own environment. The damage is unpredictable. The severe damage or penetration of the elements within a hospital may be predictable, but damage to a specific area of the NICU is not predictable. This uncertainty may contribute to planning that focuses on what caused the disaster, for example, a hurricane or an internal water leak. An ecological approach brings to the Neonatologist’s attention the more open environment and the need to identify new or hidden risks to the neonate. Taken together, the Neonatologist can better identify methods to increase the capability for the NICU and staff to evacuate or shelter neonates during the disaster.

An ecological description also helps differentiate plans in the context of the disaster environment. Planning for structure and order fits a Euclidean space, the three-dimensional space comprising points and distance measurements that readily accommodate

classification and categories. We have quantitative measures, hierarchy, metrics as points and lines, and discrete representations from the Euclidean space and Newtonian physics. We use classical logic and deductive reasoning to make the necessary inferences (9).

On the other hand, an ecological environment has more of a topological orientation based on relations, contiguity, and relative position rather than actual metric measurements that would indicate an absolute position. In a topology, elements maintain continuity of connectedness despite deformations. The focus is on how the elements are connected, for example, the closeness of connection or overlapping connection (10). Topology replaces precise characterizations with a topological differentiable state that represents possible variable states. Ecology has made use of object-oriented network topology and dynamic system field-oriented topology (11).

Disaster topology

Network topology describes the form of disaster planning and response system. A network is a discrete, object-oriented model that involves objects, nodes, edges, and connections. The topology leads to network system properties such as connectivity, directedness, closeness, betweenness, degree, characteristic path length, small worlds, and giant components (11, 12). Note that in a topological network, the strength of relations between nodes has a greater influence than the distance between nodes that we see in a Euclidean network. Topological networks are invariant, meaning that if the network is deformed, the relations do not change,

“Our presence in or out of a system is more than a different frame of reference. We have different perceptions and capabilities. For Newtonian mechanics, physicists must make specific the frame of reference when they study natural phenomena.”

and the formula remains true. Graph representations of network topologies include line, ring, mesh, star, tree, bus, and the fully connected mesh topology. The Incident Command System is a tree network topology.

Topological dynamical systems describe the continuous transformations or flow within a topological space. The ‘topological mixing’ of two topological systems or the effects of external noise from a stochastic environment can cause a spontaneous breakdown of topological supersymmetry. Chaos is the resultant phenomenon of this breakdown, which is an intrinsic property of these systems. It has become common knowledge that chaos is sensitive to initial conditions. But not all initial conditions result in chaos. What is less known is that chaos requires topological mixing, that is, mixing without using distances. Chaos as “sensitivity to initial conditions” is better expressed as a consequence of ‘topological mixing,’ that is, it is more relation-dependent (13).

During critical illness, the interactions, or mixing, of topological systems within the human body can generate unexpected, abrupt chaotic changes in physiology. A disaster also has topological mixing between the event and the city. As the disaster develops, the blending of multiple topological systems creates the severity and unpredictability that have become hallmarks of disasters.

Purpose of a legal definition

The legal definition of disaster is necessary for out-of-area resource allocation. Declaration of a disaster by government authorities will bring outside resources to aid the hospital and NICU. In the US, the local jurisdiction must send a declaration of disaster to the state governor to bring in state resources. The governor can request a disaster declaration by the President to bring in federal resources. This coordination takes time for the respective authorities to collect the necessary information for a disaster declaration and the government to mobilize resources. For an internal disaster, such as a fire, the insurance adjuster may become involved early for claims documentation (14).

In medical care, a disaster explains the uncontrolled addition of pathology and constraints on providing care. In some situations, the Neonatologist must act immediately such as an earthquake, internal water leak, or hospital fire. If a disaster is predicted, such as a hurricane or wildland fire, the Neonatologist must still begin a disaster response while awaiting further determinations regarding sheltering and evacuation. This article is for that initial experience when demands approach or have breached the limits of the NICU resources. While this may occur with sufficient preparation time, it may happen abruptly, negating disaster plans and routines.

Classification of the disaster, such as earthquake or hurricane, has administrative and academic purposes (15). For the Neonatologist, however, who has become accustomed to working in a controlled environment, any abrupt, forcible encroachment of the environment into the NICU creates a disaster regardless of the cause. In the *Neonatology Today: Disaster Special Issue*, we will present High-Reliability Organizing as a means to use routine operations as the disaster response toward High-Reliability Opera-

“When the logic of practice is made visible, other factors lead to its suppression. Leaders and managers may believe field operators cannot grasp the necessary content or exercise the necessary judgment. This becomes self-fulfilling when the organization maintains operators at the competence skill level, the level of abstract learning, and below the practice of the particular situation.”

tions.

The Environment

A disaster creates two environments – the physical environment and a mental environment. The physical environment of uncontrolled energy is experienced as volatility, uncertainty, complexity, ambiguity, threat, and time compression (VUCA-2T). The resulting change creates a new mental environment characterized as a liminal zone of abrupt new structures and rules.

Physical environment

The environment becomes an open system. The NICU environment becomes open to environmental energy, and staff become open to interactions with other, often nonmedical, systems. The environmental insulation the hospital gave the neonates is lost.

Thermodynamics now govern the exposure of neonates to the five

forms of energy: thermal, chemical, electrical, kinetic, and less commonly, ionizing radiation. The thermal energy of fires creates toxic fumes or inspired particulates. The kinetic energy of earthquakes or hurricanes exposes neonates to cold temperatures. The kinetic energy from moving neonates can become damaging energy within the neonate's body.

Information also has entropy that follows the calculus thermodynamic entropy equation. Increasing entropy for energy is its dissipation; for information, increasing energy is its corruption within the message. This corruption occurs during transmission to communicate with others (6).

Outliers, however, pose a problem in disasters. Accustomed to using probabilities and *p* values from medical research, healthcare providers may too easily disregard outliers as random, independent events. High-Reliability Organizations and those working

“The imperfect external view represents someone outside the situation but without full knowledge of the situation. This models leadership more closely from a distance. We assume these operational models could be wrong.”

in dangerous contexts evaluate the outlier as a possible precursor event, an early herald of further crisis. “If it happened once, it could happen again; if it happens again, it will happen worse.”

There also may be a tendency to rely on Bayes' Theorem for predictions or to update probabilities of events. Bob Bea, Professor Emeritus, Civil Engineering, University of California, Berkeley (8/8/2007, personal communication), (16) underscored that Bayes' Theorem “should only be used to update *epistemic* or model-parameter uncertainties.” These are ‘information-sensitive uncertainties from imperfections of the model. Increasing information reduces uncertainty. In a disaster, uncertainties are “inherent or natural uncertainties that are fundamentally information insensitive” (Bob Bea, 8/8/2007, personal communication). Acquiring more information does not necessarily reduce uncertainty.

Mental experience of the environment

Disasters create a new environment within our familiar, formerly safe work environment. We can better understand this change using the military concept of “VUCA,” an acronym to describe threats to national security – Volatile, Uncertain, Complex, Ambiguous (17, 18), to which we add Threat and Time Compression. VUCA is a military concept with the implicit assumption “threat,” which we make visible (3). Time compression is the operational component of volatility, the quality of instability (3, 19, 20).

- *Volatility* comes from rapid and abrupt changes in events.
- *Uncertainty* describes the lack of precise knowledge about the situation, our need to obtain more information, the unavailability of the necessary information.
- *Complexity* refers to the large number of interconnected and changing parts that come together to create the situation.
- *Ambiguity* describes how multiple interpretations, causes, or outcomes may be possible for one situation.
- *Threat* impairs cognition and decision-making.
- *Time compression* describes the limitations on acquiring in-

formation, deciding, or acting before consequential changes in circumstances. Time compression is not a quality of time dependence or time-limitation.

The VUCA-2T environment disrupts order and bedevils classification systems. We can borrow from art historians to evaluate the visible amount of structure and degree of randomness present (21). The structure is a measure of complexity that identifies discrete objects through borders and edges, demarcating change and flat surfaces denoting continuity. Randomness is a measure of entropy that measures disorder and uncertainty, a fuzziness that disconnects various parts of what we can observe, making invisible the causes and effects (22).

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Being thrust into a disaster situation, particularly in our routine workplace, discomfits us – we are not meant to be there. The discomfort arises from the loss of context and the unrecognized triggering of the sympathetic nervous system. Such ‘liminal zones’ expose us to other, quite different experiences. The liminal zone is that space between a world we know and a world we don’t, where our old rules don’t apply, and we haven’t learned the new rules (23). The liminal zone challenges our leadership and us. We cannot rely on plans or our experience (24). In a disaster, we find that we must engage circumstances whether we stay or leave, but we don’t yet know what works (24).

The liminal experience shapes the individual due to the environment (24). The more severe the environment of the disaster, the more profound the effect on the individual. Engagement of the situation, rather than passive endurance, changes the cognitive domain and the affective domain. Engagement reduces the immediate emotional load and long-term consequences.

The common themes across work domains in dangerous contexts include suppression of fear, trust, help the novice, protect your partner, recognize fear in fellow workers, and follow local leadership. Experienced workers accept the reality of the threat, taking personal responsibility to teach the new worker how to work around the threat (2). Specific to operators in liminal environments is the ethics of kindness (25). “Both the historical tradition among seafarers of all nations and the International Law of the Sea require mariners and aviators to respond to any life-threatening and significant damage events at sea, even among vessels and aircraft of adversarial countries. This responsibility to save life whenever remotely possible includes situations where there is a significant risk, cost, distance, and schedule impact on your own ship or aircraft.” Mountaineers will come to the aid of injured or stranded climbers, even at considerable risk to themselves. “And of all the principles by which we hold the first is that of mutual help,” George H. Leigh-Mallory, mountaineer, British Mount Everest expeditions (26).

One maladaptive approach to a liminal event is to remove one-

self as a participant through decontextualization of the experience (27). Becoming a dissociated spectator limits the influence of the affective domain but gives a false sense of cognitive control. Reducing emotions to only the motor component gives the feeling of objective thought and actions through the false sense of emotional control.

Environment as pathogen

The environment can have a latent effect on physiology in several ways. One author (DvS) has found that low humidity can decrease an infant’s body temperature, create abnormal respiratory secretions contributing to ineffective airway clearance, and lead to decreased blood volume in adults. According to published meteorological reports, the humidity in the region often could be lower than the humidity in the Sahara Desert. Because most US medical schools are near the coast or in higher humidity areas east of the Rocky Mountains, physicians do not learn to recognize the effect of low humidity on physiology. The author learned to treat abnormal secretions in asthma with oral fluids during his Fire Rescue Ambulance training in 1974 at Children’s Hospital of Los Angeles.

During pediatric critical care transports in a desert region (DvS), the body temperature of an infant would lose 0.5 Fahrenheit degree for every 30 minutes of hand ventilation, 1.0 Fahrenheit degree if the infant had sepsis or a head injury. The humidity of inspired air can be 10-15% while that of expired air is about 100%. This was also observed during trauma resuscitations and on hospital wards; however, an additional effect was air conditioning that lowers room temperature to below an infant’s thermoneutral zone (about 90° F).

Children with CNS impairment and tracheostomy-dependence often develop abnormal sputum with ineffective airway clearance during periods of low humidity. Despite treatment with N-acetylcysteine or mechanical chest physiotherapy, they often have multiple medical visits for low oxygen saturation or pneumonia. Hydrating with enteric fluids resolves the problem within 45 minutes. This improvement is due partly to the misconception that mucus is hydrophilic. While mucus readily absorbs water when it is within the cell, it takes on a three-dimensional shape exposing its protein backbone to become hydrophobic once secreted. A modest decrease in cell hydration creates thick, even sticky mucus.

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Low humidity also influences the medical treatment of adults. One of the authors (DvS) participated in a state committee writing EMS guidelines for paramedics. A controversy developed regarding the minimal blood pressure to administer nitroglycerine for chest pain due to possible myocardial infarction. By listening closely, it was noted that physicians from northern regions advocated a lower blood pressure than the physicians from the southern regions. The humidity in the southern part of the state is markedly lower than in the northern region, contributing to occult lower blood volume. A few years later, the author discussed the effect of low humidity on blood volume, particularly in heart failure, with a physician from the desert. The physician became visibly upset because the medical staff at his hospital had recently terminated

a physician's privileges for repeatedly giving fluids to patients in cardiogenic shock. He realized the patients likely had cardiogenic shock with hypovolemia, which explained their improvement after fluid resuscitation.

Environmental extremes can cause unrecognized disease processes in adults. A 'normal' environment for adults is an extreme environment for a premature neonate. Therefore, a disaster creates a deadly environment for the neonate. Loss of insulation from the environment places the neonate in an extreme environment with findings that may be missed or misattributed to other diseases.

The problems of disasters

The embedded problem is ill-structured or ill-defined (28) embedded in the environment (29). The environment contains information while influencing the structure of the problem. Multiple objectives compete or conflict with each other. The boundary between problem and context is fuzzy and vague. Such issues have no clear problem definition, their goal state is not defined clearly, and the means of moving towards the (diffusely described) goal state are unclear.

The ill-structured problem is a problem without a clear goal. Because algorithms are not available, we must learn while problem-solving, a process Herbert Simon and Allen Newell (30) called heuristics. The 'heuristic search' is to learn and make discoveries during the process, producing a more accurate search within a complex environment (31). While there is a fear of heuristic bias, recognition of errors provides safety and guides accuracy (32). The ill-structured problem is a 'residual concept' that does not fit classification, making the boundary between ill-structured problems and well-structured problems vague. Residual concepts are defined in terms of what they are not (15, 28) by the negative space around the object that also defines and brings attention to it (21).

"The well-structured problem is amenable to rules, protocols, decision trees, and algorithms, forming a hierarchy for decisions as well as who decides. The danger is loss of information and context with the operator becoming a spectator (27, 34), unable to interact in real-time with the environment."

Well-structured problems are formulated explicitly and quantitatively and can be solved by known computational routines or algorithms (30). For tractability, we too easily convert an ill-structured problem to a well-structured problem through linearization of the curve or decontextualization. The system, however, then becomes susceptible to error from the frame problem, what does or does not change after an action (33). The well-structured problem is amenable to rules, protocols, decision trees, and algorithms, forming a hierarchy for decisions as well as who decides. The danger is loss of information and context with the operator becoming a spectator (27, 34), unable to interact in real-time with the environment.

A disaster is an environment embedded into already embedded problems. It brings together diverse organizational infrastructures that have different purposes and missions while in response to

a common threat. The diverse missions mean the organizations operate in different contexts; for example, a governmental agency that administers EMS may direct area disaster operations and task helicopters usually used by the NICU for interfacility transport with rescue operations or movement of critical supplies. Conflicts and disputes develop not from system or personality issues but from different contexts and infrastructures (15, 35, 36).

Medical care is accustomed to 'well-defined problems.' The problems in a disaster are not only ill-defined; they are embedded in the environment with the free exchange of energy. Emergency plans presuppose effective courses of action. Jens Rasmussen (37) describes the importance of people in the field:

Operators are maintained in [complex technological] systems because they are flexible, can learn, and adapt to the system's peculiarities. Thus, they are expected to plug the holes in the designer's imagination.

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Capability and Risk

We extend operations by developing capabilities rather than assessing risk. In a disaster, like resuscitation, we cannot decide to engage the situation. We evaluate the risk to match the capabilities of our team and the system (38).

Risk

Amos Tversky and Daniel Kahneman (39) described the important role 'imaginability' of contingencies has toward our view of risks. The vivid portrayal of contingencies can make the situation appear exceedingly dangerous. Tversky and Kahneman, however, focused decision-making on threats one could conjure, or even worse, of not conjuring enough threats.

Threat and capability, lexical elements for the HRO, became the business terms of risk and risk management using the standards for risk developed by the International Organization for Standardization (ISO) (40). (The following terms in quotations come from ISO 31000:2009).

- Plans and planning to *prepare* for contingencies became protocols and algorithms *restricting* operations.
- Assessing capabilities needed for a mission, an assignment that cannot be refused, became "risk" ("effect of uncertainty on objectives") and "risk-benefit assessment" ("decision-aiding techniques that weigh advantages against disadvantages in numerical terms").
- Increasing capabilities for mission requirements (training and materiel) became "risk management" ("coordinated activities to direct and control an organization concerning risk").
- Safety, as an operational element, became a distinct element and cost within risk management.

Capability

Operators in dangerous contexts seek capabilities for threats, particularly capabilities they can generalize to unforeseen perils or that extend operations into novel situations (2, 7, 25, 38). The acceptance of uncertainty and fear in an HRO is unique (2). Capability calibrates the threat response (4), and operators focus on possibility over probability. The more significant delineator between spectator and operator is the willingness to say, “I don’t know” (41).

“Common sense supports immediate action to avoid hidden consequences, thereby producing immediate results then continues that action. This results in failure avoided, sometimes invisible, and can be difficult for others to learn from these mistakes.”

One unrecognized capability of the HRO is pragmatic common sense, the response to consequences (42). Common sense supports immediate action to avoid hidden consequences, thereby producing immediate results then continues that action. This results in failure avoided, sometimes invisible, and can be difficult for others to learn from these mistakes. This process is immediate enacted experience and ongoing action rather than deliberate reflection (43). Thinking and thought are not nouns, but “a quality of that conduct which foresees consequences of existing events, and which *uses what is foreseen as a plan* and method of administering affairs” (44).

Timelines

Having separate timelines in an interactive situation with different organizations and objectives can bring the various parties’ perspectives into view. In a disaster, we have the cause, the hospital and NICU timeline, the infant timeline, and outside agency timelines. Essentially, the event causes damage, and the hospital and NICU prepare for and respond to the damage. The infants continue receiving care, are protected, and then evacuated or sheltered.

The event or cause timeline becomes the backbone we can measure other actions from, while the infant timeline is a form of audit for the effectiveness of those actions. Timelines for EMS, public safety, and other emergency operations can illuminate the availability of outside support that can help awareness of other NICUs in disaster planning. We can also better compare disasters, even an event like Zika compared to a tornado.

Event timeline

- Approaching
- Imminent
- Passage
- Nature of damage
- Event ends

Facility timeline

- Preparation
- Damage controlled

- Return to operations

Patient timeline

- Preparation for movement
- Horizontal transfer – Away from immediate danger
- Vertical evacuation – Out of building
- Holding – Area in preparation for transport
- Transport
- Receiving hospital

Staff timeline

- Notification
- Actions
- Recall

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Conclusion

The disaster creates an acute resource scarcity, disrupting the ability to treat multiple patients. Hospital supplies may become damaged, or providers are unable to deliver new and replacement supplies. If the NICU evacuates neonates, the level of care can be markedly reduced due to equipment and space limitations in the ambulance, car, or helicopter. The Neonatologist must now treat multiple neonates with less staff and fewer resources.

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Disclosures: The authors have no relevant disclosures

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Corresponding Author

Daved van Stralen, MD, FAAP
Associate Professor, Pediatrics
Department of Pediatrics
Loma Linda University School of Medicine
11175 Campus Street
CP-A1121
Loma Linda, CA 92350
Email: DVanStra@llu.edu

Sean McKay
Executive Partner / Director, Disruptive Rescue & Austere
Medicine
Element Rescue - Response Solutions within Nonlinear Complex
Environments
Greenville, South Carolina, United States

Thomas A. Mercer
Rear Admiral
United States Navy (Retired)

Acknowledgments

Karl Weick, Rensis Likert Distinguished University Professor of Organizational Behavior and Psychology, Emeritus, University of Michigan

Dan Kleinman, Operations Section Chief, National Incident Management Organization (retired)

T. Allen Merritt, MD MHA, Loma Linda University Children's Hospital

Errol van Stralen, Ancora Education

William J. Corr, formerly with the Los Angeles City Fire Department, now deceased

SHARED DECISION-MAKING PROTECTS MOTHERS + INFANTS

DURING COVID-19

KEEPING MOTHERS + INFANTS TOGETHER

Means balancing
the risks of...

- HORIZONTAL INFECTION
- SEPARATION AND TRAUMA

EVIDENCE

We encourage families and clinicians to remain diligent in learning up-to-date evidence.

PARTNERSHIP

What is the best
for this unique dyad?

SHARED DECISION-MAKING

- S EEK PARTICIPATION
- H ELP EXPLORE OPTIONS
- A SSESS PREFERENCES
- R EACH A DECISION
- E VALUATE THE DECISION

TRAUMA-INFORMED

Both parents and providers
are confronting significant...

- FEAR
- GRIEF
- UNCERTAINTY

LONGITUDINAL DATA

We need to understand more about outcomes for mothers
and infants exposed to COVID-19, with special attention to:

- MENTAL HEALTH
- POSTPARTUM CARE DELIVERY

NEW DATA EMERGE DAILY. NANN AND NPA ENCOURAGE PERINATAL CARE PROVIDERS TO ENGAGE IN CANDID CONVERSATIONS WITH PREGNANT PARENTS PRIOR TO DELIVERY REGARDING RISKS, BENEFITS, LIMITATIONS, AND REALISTIC EXPECTATIONS.

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