The Covid-19 pandemic has created a multitude of acute challenges for health care delivery organizations, including inadequate capacity, supply shortages, the need for care redesign, and financial loss. Complexity science views health care delivery organizations as complex adaptive systems that operate in highly complex and unpredictable environments. The perspective assumes that much of organizational life is unknowable, uncertain, or unpredictable and thus cannot be standardized and controlled.

The Covid-19 pandemic is a powerful reminder that we live in a highly complex and unpredictable world. For health care delivery organizations, effective responses to the pandemic have required departures from many conventional practices. The Covid-19 pandemic has presented an array of novel and acute challenges, from managing the supply chain for personal protective equipment (PPE) to adjusting workforce capacity to coping with financial loss.

In the midst of these challenges lies an opportunity for health care leaders to better position and transform their organizations for a future of unpredictable surprise. In the present article, we discuss the key challenges facing health care organizations during this pandemic and review the complexity science perspective, which offers a framework for creating resilience and agility when the future is unknown. We then describe a number of examples in which the actions of health care delivery organizations to effectively respond to the Covid-19 pandemic have reflected the tenets of complexity science.

**Characteristics of the Covid-19 Pandemic**

The Covid-19 pandemic is a clear illustration of the ability of a small, surprise event in one part of the world to have a massive influence on the daily operations of hospitals and medical practices.
around the globe. A surprise event can be characterized in three dimensions: the complexity of its source, the speed of its spread, and the unpredictability of its scale and impact. Surprises with the most complex etiologies, most rapid spread, and most unpredictable scale provide the greatest challenges. The Covid-19 pandemic, like major environmental disasters and terrorism, is representative of all of these peak challenges.

The exact source of the Covid-19 virus remains a mystery. However, the massive and rapid spread of this virus is unprecedented. Within ten months after the first cases were reported in China in December, 2019, over 30 million people had a confirmed diagnosis of Covid-19 and close to 1 million people had died worldwide. The clinical manifestations continue to evolve and have become increasingly complex. The list of manifestations has expanded from flu-like symptoms to covering almost every body system (e.g., eye, nose, brain, lung, heart, gastrointestinal tract, and kidney). Clinicians and research scientists are still learning the natural history of the infection and the resulting damage on various body systems. The virus may continue to mutate, which is a challenge to the development of an effective vaccine and treatment. This pandemic is unlikely to dissipate in the foreseeable future. Most importantly, surprise events with similar characteristics (complex etiology, fast spread, unpredictable scale) are likely to continue to occur and to remain relatively unpredictable. Health care organizations need to prepare for the next ones.

Key Challenges for Health Care Delivery Organizations

Health care delivery organizations have faced a myriad of important management challenges during the Covid-19 pandemic. Some of the challenges are idiosyncratic to the individual organization; others, however, are broadly faced by almost every health care delivery organization and are likely to be faced in any major disaster.

The first key challenge is the lack of adequate capacity to handle the surging patient volume. In many places, the need for intensive care unit (ICU) beds and ventilators as well as staffing far exceeds the maximum capacity. For example, the number of ICU patients treated at the New York City Health + Hospitals (NYC H+H) during the peak was over three times the system’s ICU capacity.

A second challenge is the need for real-time redesign of care models for patients. Given the highly contagious nature and severity of the infection, it is necessary for physicians, nurses, and other clinicians to discover the appropriate care model and room design. A related challenge is protecting the physical and mental health of frontline staff. Hospitals and clinics have to ensure an adequate supply of PPE for their staff. In addition to the risk of contracting the virus, frontline staff have to cope with tremendous mental stress, which some may find unbearable. There have been anecdotal reports of frontline staff dying by suicide.

Another challenge for hospitals and clinics during this pandemic is the financial loss due to the cancellation of elective procedures and the disruption of routine care, particularly for hospitals already in financial difficulty. In 2018, hospitals at the 25th percentile had −4.4% operating margins and 7.6 days of cash on hand (compared with median values of +2.0% and 53.4 days, respectively). Lacking sufficient liquid assets could put these health care organizations at risk of bankruptcy.
To manage capacity, financial loss, and care redesign, health care organizations have made the critical decision to release or reduce workforce or to shift many employees to remote work, including clinicians working with telehealth technologies. Rightsizing and retraining workers is difficult in normal times and is even more difficult when changes need to be implemented expeditiously.

These four challenges are likely to arise again in any future surprise event. Whether the event is a natural disaster, terrorism, or a pandemic, health care delivery organizations will be challenged to suddenly adjust capacity, redesign care, manage financial loss, and redeploy staff.

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**Tenets of Complexity Science**

Faced with this unprecedented combination of acute challenges, health care organizations can draw guidance from the field of complexity science. Complexity science is the multidisciplinary study of complex systems that are composed of interacting agents and units within a boundary. These systems are complex in the sense that the agents and units within the system are highly interdependent, heterogeneous, and dynamic. Complex systems include organizations such as hospitals, health systems, and medical practices, as these organizations are comprised of highly interdependent, heterogeneous, dynamic, and interacting agents and units.

Of particular interest in complexity science is how complex systems change over time, or adapt, in response to external environmental changes. From a complexity science perspective, the external environment is interrelated to and coevolves with the organization instead of being independent of it. The environment is highly unpredictable because of the complex and nonlinear relationships among many of the environmental elements. A complex system’s adaptation to sudden change in the environment is hastened when agents and units in the system are qualified and empowered to react to external events and to supply real-time feedback to decision-makers. Complex adaptive systems exhibit feedback loops between agents and the environment through which information travels and leads to small changes, nurturing learning capacity and continuous adaptation. Complex adaptive systems are similar to an organism, with self-awareness, the desire to survive, and the ability to adapt to environmental changes.

The view of organizations as complex adaptive systems is fundamentally different from the traditional view of organizational systems as machines with the purpose of producing outputs through tightly controlled and standardized processes. Complex adaptive systems, instead, are built for adaptation, flexibility, and learning.
“Simple rules” such as underlying values and cultural norms help to ensure that agents and units react to change in a timely and coordinated manner. Relatively broad guidelines or constraints are imposed on the system from the top down, so that agents and units have substantial autonomy to respond to change. This means that responses will vary from system to system, as local conditions are inevitably different. In effective complex adaptive systems, response is “customized” to local conditions.

Examples of management guidelines consistent with complexity science, from five different sources, are summarized in Table 1. All of the guidelines begin with the assumption that much of organizational life is unknowable, uncertain, or unpredictable and thus cannot be standardized and controlled. This assumption is due both to the complex nature of the system and the fact that its environment can change radically at any time. The advice to “explore,” “encourage different views and diversity,” “deal with surprise,” “develop mindfulness,” and “let direction arise” reflect this assumption that surprises will happen and that they are largely unpredictable.

As reflected by several guidelines in Table 1, sensemaking is a key activity in complex adaptive systems. Sensemaking is the process by which people give meaning to their collective experiences: “the ongoing retrospective development of plausible images that rationalize what people are doing.” Sensemaking is particularly important in times of distress and uncertainty.

The guidelines of “use simple rules,” “set simple rules,” and “provide minimum specifications” demonstrate the futility of trying to micromanage events that are unpredictable and emergent. The notion of simple rules was popularized in health care with the “Ten Simple Rules for the 21st Century Health Care System” promulgated by the Institute of Medicine’s (IoM’s) Crossing the Quality Chasm report in 2001. Paraphrased examples of the IoM’s ten simple rules include “establish the patient is the source of control,” “use evidence-based decision making,” and “consider safety as a system property.”

Organizations that are highly connected internally and with elements of their environment are the most adaptable, reflected in the guidelines to “connect” and “build connections.” Connections accelerate the flow of information and share resources in times of surprise.
Responses to Covid-19 by Health Care Delivery Organizations as Complex Adaptive Systems

How might we expect health care delivery organizations to behave in the face of Covid-19 if they act in congruence with the tenets of complexity science? We suggest that organizations will emphasize communication, collaboration, and innovation, all carried out expeditiously and well informed by frontline information and evidence. We examined the responses of six health care delivery organizations to the pandemic from a complexity science perspective. The examples display organizational response at the level of hospital departments (Department of Surgery at UCSF Hospital), individual hospitals (Bichat-Claude Bernard Hospital), hospital systems (Geisinger Health System, NYC H+H, Community HealthCare System), and statewide aggregates of hospitals and health systems (Arizona Surge Line).

Department of Surgery, UCSF Hospital

Lancaster and colleagues\(^\text{10}\) described how the Department of Surgery at the University of California, San Francisco (UCSF) Hospital responded at the outset of the pandemic. On March 3,
2020, the hospital’s parent health system, UCSF Health, created a Covid task force, and, on March 5, representatives from perioperative services and surgery were added to the group in recognition of the importance of adjusting perioperative care and elective surgery. On March 9, a response team (comprising division chiefs; vice chairs of education, research, faculty affairs, and diversity equity and inclusion; and residency program leadership) was created within the Department of Surgery. All meetings in the Department were changed to video conferencing, grand rounds were replaced with Covid-19 updates, and weekly town halls and weekly digests augmented daily notifications of current events. A Perioperative Leadership Team developed triage guidelines, but decisions about surgery delay “were left mainly to the discretion of the faculty,” and each specialty area developed its own triage plans. PPE guidelines were discussed at grand rounds, followed by a mandatory knowledge assessment. To address new workforce requirements, faculty from other sites in the geographic area were identified and credentialed.

Overall, Lancaster et al. reported that the hospital and department came together “as a community for the greater good of our city and patients” at unprecedented speed. For example, PPE guidelines were updated daily. Guidelines from other organizations were solicited to save time, and virtual communication permitted agility in sharing best practices. The authors argued that a key component of the Department of Surgery’s nimble approach was the use of a small, tightly knit leadership team, facilitating rapid responses to questions and rumors.

**Bichat-Claude Bernard Hospital**

The Bichat-Claude Bernard Hospital is a 1,000-bed university hospital in Paris, a member of Europe’s largest hospital system, and a major site for Covid-19 treatment. Hospital leadership and clinical staff used prior experience with the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and Ebola epidemics to rapidly respond to Covid-19. An emphasis was placed on clear internal communication through heavy use of the intranet, regular conferences that were open to all health care workers, and hospital-wide wide circulation of video interviews with experts from different departments. Extensive external communication with the media, the parent hospital system, political decision-makers, and other hospitals was also critical. In addition, point-of-care testing was rapidly installed, capacity was expanded, medical staff and nursing staff were increased (with help from other member hospitals within the system), and non-urgent surgical procedures were delayed.

Unanticipated challenges that were readily handled at the hospital included problems with hazardous waste removal, transporting infected patients to departments for services such as scanning, and dealing with a deluge of journalists and media. Collaboration with the parent health system and with political decision-makers enabled quicker responses to internal challenges.

**Geisinger Health System**

The early experience of Geisinger Health System during the pandemic is instructive. The system created workgroups for 11 core business areas (e.g., human resources, finance, pharmacy), with each workgroup including leaders from outside of the group’s focus. The groups used scenario planning to contemplate how the system has changed. The system was an early adopter of in-house
testing, contact tracing, expansion of telehealth visits (with co-payments waived for members), and mail-order pharmacy utilization. Some 7,000 employees shifted to work from home, with predictions that 30% of the workforce could work from home permanently and an additional 30% could work from both home and office locations. New partnerships included a joint effort with Stanson Health to develop an early-warning surveillance system.

Geisinger’s actions represented a host of complexity science tenets, including building connections, encouraging different views, and exploring new futures. A simple rule driving Geisinger’s response was to cast their work as an innovation initiative, not a damage-mitigation exercise. Members were instructed to carefully consider the impacts of actions on patients and frontline employees and to focus on their needs.

**New York City Health + Hospitals**

The New York City Health + Hospitals Corporation (NYC H+H), the largest safety-net health care system in New York City, comprising 11 hospitals and over 60 community health centers, also exemplified management principles consistent with tenets of complexity science. To address staff shortages, a group of emergency physicians initiated the idea of redeploying staff to the emergency departments and ICUs at different facilities within the system, which led to the design of a process for redeploying clinicians of various specialties. A multidisciplinary team that included representatives from the departments of patient care, information technology, human resources, and occupational health was established to facilitate the redeployment of nurses. Another multidisciplinary team was formed to engage with outside entities in the recruitment of clinicians from across the country. The system leadership gave a clear direction that the entire system would need to “become a single large ICU” through patient transfers, staff redeployments, and space reassignments. The system leadership also adopted a simple rule that Covid-19 patients should be connected with their families and that no one should die alone. To protect frontline staff from psychological stress, the clinical leadership deployed internal teams of behavioral health practitioners to offer counseling sessions.

The pandemic accelerated the expanded use of information technology to improve the connectedness of all elements within the system and facilitate real-time information sharing. Most notably, the system successfully converted all routine in-person visits to telehealth by mid-March and conducted over 55,000 billable televisits in March and nearly 83,000 in April. This response not only ensured access to care for vulnerable populations who were disproportionately affected by the pandemic but also allowed the system to receive reimbursement for these services.

**Community HealthCare System**

In contrast to their urban counterparts, rural hospitals had the advantage of gaining time in preparation for the pandemic as Covid-19 tended to hit urban areas first before reaching rural areas. Nevertheless, rural hospitals faced similar challenges as urban hospitals once the virus spread to their communities. The Community HealthCare System (CHCS) in Onaga, Kansas, which consists of two hospitals, seven health clinics, two nursing homes, one assisted-living facility, and one home health care agency, served as an example of how rural health care facilities could
effectively adapt to a new reality. Partnerships and preparedness have proven to be of paramount importance for rural hospitals. Aware of nationwide shortages of PPE, CHCS did its best to maintain the supply of PPE through all channels, including partnerships. CHCS reached out to local community members and businesses, who donated or produced gowns, face shields, gloves, and N95 masks. The hospitals took actions to acquire more ventilators and to expand their physical capacity by modifying room settings and existing spaces to isolate Covid-19 patients. Furthermore, through local, regional, state, and national partnerships, CHCS received up-to-date guidance and knowledge about testing and caring for Covid-19 patients.

Health care workforce shortages have been a chronic issue in rural settings and could be worse if existing staff become sick and take leave. Through communication, the CHCS leadership helped the staff to remain calm and balanced. Sharing a joke at meetings helped lighten up the day: “Moments of humor help us hold to purpose...we laughed, and then we got back to work.” The human resources department also implemented new options to allow for contingencies affecting the families of staff members. Meanwhile, the hospitals created an inventory of skill sets to facilitate cross-training and redeployment of staff. For instance, surgical nurses could serve on the inpatient ward, nursing aides could assist the cleaning team, and even college students returning home could take online training and serve in dietary services.

**Arizona Surge Line**

Shortly after the community spread of Covid-19 began, health care leaders in Arizona recognized the need for statewide collaboration to battle the pandemic. Through a public-private partnership, Arizona established an unprecedented statewide patient transfer center called the “Arizona Surge Line” to coordinate transfers of Covid-19 patients among the four health care systems in the state (Tenet, Banner Health, Common Spirit, and Honor Health) and other independent hospitals. Not only did these competing providers agree to collaborate, but major insurers (e.g., Blue Cross Blue Shield, Aetna, Cigna, UnitedHealthcare) also agreed not to charge out-of-network costs for transferred patients. Any hospital can call the Surge Line to request transfer of its Covid-19 patients to the appropriate level of care. The Surge Line leveraged the data capacity of a health information exchange that captured 95% of hospitals in the state to ensure efficient allocation of needed resources and load-balancing of Covid-19 patients.

In addition, Arizona implemented the Crisis Standards of Care (CSC) plan, with an addendum specific to Covid-19, to provide health care systems and professionals with ethical guidance on the allocation of scarce medical resources during a public health crisis. The CSC plan and addendum ensured equity of care across a state that has an extremely high concentration of the population in two urban areas (Phoenix and Tucson) and a large population in the Native American tribal lands.

**Communicate, Collaborate, Innovate**

Although the six cases described above are not representative of all health care delivery organizations, and although the reports may be biased because they are likely to emphasize successes rather than failures, the cases notably cross several layers of organizational aggregation.
Extensive communication, collaboration, and innovation need to happen quickly in response to major surprises. Underlying conditions that are necessary for a quick response include pre-existing structures and cultures that encourage widespread and diverse participation on the frontlines of care. Such participation includes directing and leading response efforts. Reports of effective responses to the Covid-19 pandemic often include examples of “new” leaders emerging and a general attitude of “humility” by formal leadership. Humble leadership is requisite because the future is unknown and because sensemaking is a communal activity. Successful health care delivery leaders have the humility to share leadership activities, including with frontline workers, in times of crisis. For example, Prasad described his experiences as a clinician who “went from relying heavily on my knowledge and technical skills as an interventional cardiologist to assuming a leadership role on a Covid-19 infectious disease service.” At M Health Fairview, a large system in Minnesota, a trauma surgeon with battlefield experience was chosen to co-lead the incident command center along with the associate chief nurse executive. His “clarity and compassion” made him the right person at the right time, according to the CEO of the parent company. McWilliams argued that the pandemic has revealed physicians’ strong drive to serve. That drive can be better leveraged by health care organizations in the future and extends not just to physicians but to all health care clinicians, leaders, and managers, whose professionalism motivates them to step up “beyond the call of duty” in times of extreme patient and community need.

These findings on the emergence of new leaders as well as the humility of existing leaders during the pandemic are consistent with principles of leadership in complex adaptive systems. Uhl-Bien et al. maintained that adaptive leadership in complex adaptive systems occurs at all hierarchical levels and is defined as an “interactive dynamic through which adaptive outcomes emerge.” A role of top leaders is to create the conditions that catalyze adaptive leadership and allow for the emergence of innovative solutions by fostering interaction, interdependence, and creative tension. All of these processes have played out in health care organizations that have responded effectively to the Covid-19 pandemic.

There are limits to the application of complexity science to management. Management and leadership remain more art than science, and guidelines drawn from complexity science (e.g., innovate, communicate, collaborate) are broad and general. In addition, many organizational processes benefit from standardization, control, and reduced variation. Yet the imperative to “innovate” is critical in response to surprises. Ryu et al. detailed many examples of innovative responses to the current pandemic and emphasized the underlying importance of a “test and learn”
culture, including an increased tolerance for creative solutions that are imperfect or untested.\textsuperscript{25} The balancing of standardization and innovation are part of the art of management. James March referred to balanced organizations as “ambidextrous,” exhibiting both efficient execution of processes and innovation.\textsuperscript{26} Health care organizations need both to thrive.

**Preparing for Future Surprises**

Complexity science, with its emphasis on simple rules, open discussions, and building connections, provides an orienting framework for response to major surprise. The perspective provides an evidence-based foundation for management during disasters. During the Covid-19 crisis, health care organizations that have emphasized communication, connection, and innovation have effectively addressed the challenges to adjust capacity, redesign care models, redeploy staff, and overcome financial loss.

Complexity science also provides a framework for learning from disasters. Any future disasters will require health care organizations to face challenges that will be different in detail, even while similar in pattern. Health care organizations, particularly those that have entered the recovery and rebuild stage, can use the Covid-19 pandemic as an opportunity to transform into more agile and resilient learning systems.

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