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Coping with complexity in the COVID pandemic: An exploratory study of intensive care units

Tarcisio Abreu Saurin[1] | Priscila Wachs[1] | Wagner Pietrobelli Bueno[1] | Ricardo de Souza Kuchenbecker[2] | Márcio Manozzo Boniatti[3] | Carolina Melecardi Zani[1] | Robyn Clay-Williams[4]

[1]Industrial Engineering and Transportation Department, Federal University of Rio Grande do Sul (DEPROT/UFRGS), Porto Alegre, Rio Grande do Sul, Brazil

[2]Faculty of Medicine, UFRGS, Porto Alegre, Rio Grande do Sul, Brazil

[3]Hospital de Clínicas de Porto Alegre, UFRGS, Porto Alegre, Rio Grande do Sul, Brazil

[4]Australian Institute of Health Innovation, Macquarie University, North Ryde, New South Wales, Australia

Correspondence
Tarcisio Abreu Saurin, Industrial Engineering and Transportation Department, Federal University of Rio Grande do Sul (DEPROT/UFRGS), Av. Osvaldo Aranha, 99, 5. Andar, Porto Alegre, RS, CEP 90035-190, Brazil.
Email: saurin@ufrgs.br

Abstract

Although the COVID pandemic has challenged the resilience of health services in general, this impact has been most visible in intensive care units (ICUs). This paper presents an exploratory study of how ICUs in Brazil have coped with the complexity stemming from the pandemic. Five guidelines for coping with complexity were adopted as analytical framework. The guidelines were concerned with slack resources, diversity of perspectives, visibility, work-as-done, and unintended consequences. There were three main sources of data: (i) a survey with respondents from 33 ICUs, which indicated their agreement with 23 statements related to the use of the complexity guidelines; (ii) semistructured interviews with seven survey respondents and two public health officials; and (iii) 20 h of observations of the meetings of a municipal bed management committee. Seventy resilience practices were identified from these data sources. Most of these practices ($n = 30$) were related to the guideline on slack resources, which were commonly obtained from other hospital units. As for the survey data, the statement related to the availability of extra or standby human resources obtained the lowest score, reinforcing the key role of slack resources. Five lessons learned for coping with complexity in ICUs were drawn from our data; one lesson for each guideline. Furthermore, the survey questionnaire is a potential ICU assessment tool, which can be adapted to other health services.

KEYWORDS
Brazil, complexity, COVID, intensive care units, resilience

1 | INTRODUCTION

Health services are widely recognized as complex sociotechnical systems (CSSs) due to the large number of diverse and interacting elements, such as caregivers, patients, and supplies (Braithwaite, 2018). The COVID pandemic has scaled up that complexity to unprecedented levels, with intensive care units (ICUs) as the ultimate battleground for struggling people and systems.

This study uses the lens of resilient health care for analyzing ICUs during the pandemic. Resilient health care is the "ability of the healthcare system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions" (Hollnagel et al., 2013, p. xxv). Indeed, the pandemic has made the need for resilient systems in general, not only in health care (e.g., in supply chains and education), dramatically visible (Ivanov, 2020).

In line with others (e.g., Hollnagel, 2014; Wachs et al., 2016), this study regards resilience as emergent phenomena, which means that it cannot be directly assessed. Thus, we adopt proxies of resilience, namely five guidelines for coping with complexity which are logically connected to resilience and expected to positively influence it (Bueno et al., 2019). These guidelines were originally devised from a literature review conducted by Saurin et al. (2013), which was based on seminal human factors and system safety studies. Since then, the guidelines have been used as analytical framework both in health care and in other sectors (Bueno et al., 2019; Mahmoud et al., 2021). In this paper, we use those guidelines for an exploratory analysis of how ICUs have coped with the pandemic.

The pandemic has distinctive complexity characteristics such as its global impact, long duration, high uncertainty, and interconnections with several dimensions of society, such as supply chains, education, economics, and politics. Thus, it offers a unique scenario for the investigation of complexity and resilience from the viewpoint of human factors. This implies in learning opportunities by confronting existing theory with a new empirical reality. Indeed, resilience and complexity research in human factors is usually focused on individual companies and acute disasters (Patriarca et al., 2018). Furthermore, although other human factors studies have adopted a system-oriented perspective of the pandemic (Araz et al., 2020; Jackson, 2020; Saurin, 2021; Slater et al., 2022), they have neither been based on primary empirical data nor focused on ICUs.

Against this backdrop, two research questions are addressed by this study: (1) What is resilience like in ICUs during the pandemic? (2) What are the practical and theoretical lessons learned for coping with complexity? These questions are investigated in the context of Brazilian ICUs, which are a relevant context as Brazil has been one of the most affected countries by the pandemic. Factors at the macro level are particularly relevant in Brazil, in which the federal government has been severely criticized for disseminating misinformation and scientific negationism (Bastos et al., 2021).

2 | GUIDELINES FOR COPING WITH COMPLEXITY

Table 1 presents the five guidelines for coping with complexity that have been adopted as a basis for this study. Earlier studies of these guidelines in health care (Bueno et al., 2019, 2021; Mahmoud et al., 2021; Righi & Saurin, 2015; Saurin et al., 2018) addressed the micro (e.g., clinical care at the bedside) and meso levels (e.g., hospital or hospital unit), even though results were not explicitly categorized according to those levels. The macro level, which is concerned with regulations and networks of health services at the regional and national level (Berg et al., 2018), was not focused on by the previous studies.

The guidelines are underpinned by a critical realist perspective of complexity. It combines positivism and constructivism (Archer et al., 1998). The implications of this perspective are twofold (Fletcher, 2017): (i) some complexity attributes are independent on the observer, in line with realism—for example, size of slack resources such as the number of extra beds in an ICU; and (ii) there are multiple valid descriptions, while incomplete, for other attributes, in line with constructivism—for example, diverse perspectives of different professional groups of caregivers.

Similar to other human factors design principles (Clegg, 2000; Hollnagel & Woods, 2005), the guidelines are contingent in the sense that their relevance depends on the context. In this case, the guidelines grow in relevance as complexity increases. Thus, the guidelines are relevant for the context of health services during the pandemic, which is highly complex (Slater et al., 2022). The guidelines also play a role for operationalizing complexity thinking as a structured analytical approach in human factors research, which is uncommon according to Walker et al. (2010).

3 | METHOD

3.1 | Research strategy

A mixed-method approach was adopted, involving: (i) an exploratory survey for the assessment of the complexity guidelines in ICUs, addressing the micro and meso levels; (ii) semi-structured interviews with health care professionals representing the micro, meso, and macro levels; and (iii) non-participant observations of the regular meetings of the ICU bed management committee in a capital city in Southern Brazil.[1] These observations contributed to the assessment at the macro level. The joint analysis from all data sources supported the identification of five lessons learned, one for each complexity guideline. Data collection occurred from late September 2020 to mid-February 2021, which encompasses the tail of the first wave and the second wave in Brazil but not the explosive rise in cases during March and April 2021. There was no formal implementation of the guidelines in the settings where this study was undertaken. Thus, our research might be framed as an assessment of the studied settings against the domains identified in the guidelines, which are thought to be supportive of resilient performance to cope with complexity. The research project was approved by the ethics committee of the teaching hospital linked to the first author's university and informed consent was obtained from all participants.

3.2 | Survey questionnaire

The questionnaire was based on an earlier version proposed by Righi and Saurin (2015) for the assessment of the complexity guidelines in an emergency department. Although the overall structure of both questionnaires is the same, there were changes as a result of: the better understanding of the guidelines in the meantime, due to their application in other studies; the ICU context, which implied the need

[1]This city, which was severely hit by the pandemic, was chosen as the authors live there and had ease of access to the municipal health department.

TABLE 1 Guidelines for coping with complexity (Bueno et al., 2019; Saurin et al., 2013)

Guidelines	Main aspects of the guidelines	Complexity attributes[a] addressed by the guidelines
Provision of slack resources	Slack is a mechanism for reducing interdependencies and slowing down or eliminating the propagation of variability (Safayeni & Purdy, 1991). This may be obtained through spare resources (e.g., human and technical) which can be called on in times of need (Nohria & Gulati, 1996)	This guideline aims at making processes loosely coupled, and thus absorbing or dampening the propagation of *variability*. As a drawback, slack may increase the *number and diversity of elements* in the system
Encouraging diversity of perspectives when making decisions	Diversity of perspectives may help tackle uncertainty. Agents involved in decision-making should hold complementary skills. Some requirements for the implementation of this guideline are: high levels of trust, reduction of power differentials, and identification of apt decision-makers (Page, 2010)	*Diversity* (e.g., demographics of people, level of automation of equipment, etc.) is a key attribute of complexity, and it may offer complementary perspectives of system functioning
Supporting visibility of processes and outcomes	Systems should be intuitive and visibility should be given to both formal and informal work practices (Clegg, 2000). Informal practices may encompass either useful innovations or latent hazards. Visibility should allow for real-time performance monitoring and the free sharing of information (Galsworth, 2017)	This guideline may be useful for coping with any complexity attribute, making these more salient and distinctive from each other. Visibility can also reduce perceived complexity
Monitoring and understanding the gap between work-as-imagined and work-as-done	Monitoring and understanding the gap between work-as-imagined and wok-as-done may shed light on variability sources that otherwise may be taken for granted. Reasons for the gap should be investigated, as well as its implications (Hollnagel, 2017)	Due to the *dynamic interactions between a large number of diverse elements*, and the resulting *variability*, work-as-imagined is different from work-as-done in CSSs
Monitoring unintended consequences of improvements and changes	Improvements and changes interact between themselves and with the environment, and this poses opportunities for unintended consequences (Perrow, 1984). These consequences may be benefits, problems, failures, or costs associated with the intervention (Ogrinc et al., 2015)	CSSs have *tightly coupled* processes *interconnected as a network*. Also, these systems are always *evolving* and *interactions* are *dynamic*. Thus, any changes may propagate in unexpected ways and *nonlinearly*—that is, consequences may be disproportionate to the causes

[a]The terms in Italics correspond to the attributes of complexity directly addressed by the guidelines.

to use ICU examples along with the questions; and the inputs from two experienced physicians (both are co-authors of this paper), which had not occurred in Righi and Saurin (2015). One of these professionals was an intensive care physician (12 years of experience) who was working at the front-line of care in a COVID ICU. The other (28 years of experience) was an internal medicine and epidemiologist physician that is the head of the clinical risk management department of a major teaching hospital that provided care to COVID patients. A draft of the questionnaire was developed by the other authors, all of whom had previous experience with human factors research in ICUs and other hospital settings, then critically appraised by the two aforementioned physicians. A final version was obtained after several rounds of refining the contents and wording of the questions, aiming at an instrument that was both comprehensive and not too time-consuming for respondents. The structure of the questionnaire is as follows:

(i) Introductory statements with the context of the study as well as information on research ethics;
(ii) Identification of the respondent, including their name and time of experience;
(iii) Twenty questions for the characterization of the hospital and the ICU. Several of these questions were inspired by Soares et al. (2015), which carried out an assessment of organizational characteristics, outcomes, and resource use (ORCHESTRA study) in 78 Brazilian ICUs. In this section, some of the responses were open-ended (e.g., number of ICU beds) while others required a choice from pre-defined options (e.g., ICU decision-making model, whether closed, open, or shared);
(iv) Twenty-three questions directly related to the five complexity guidelines at the micro and meso levels. These questions were described as statements on the use of the guidelines, accompanied by ICU examples if appropriate. There was a sliding bar with two endpoints: fully disagree (corresponding to zero) and fully agree (100); and
(v) An open-ended question in which the respondent was invited to describe one or more examples of resilient performance during the pandemic.

The questionnaire was made available on the Survey Monkey platform and a pilot application was conducted with three ICU professionals who were personal contacts of the authors. Next, it was sent out to potential respondents through three main channels: (i) participants of the previously mentioned ORCHESTRA project—this invitation was made by the former leading researcher of that project; (ii) a list of 25 ICU chief-physicians in the state of Rio Grande do Sul, as one of the authors was a former coordinator of the regional chapter of the society of intensive care physicians; and (iii) personal contacts of the authors. Despite these efforts, there were only 33 valid responses[2] (all from different ICUs) from 13 out of the 27 Brazilian States. Three responses were discarded as they were provided either by professionals with too little ICU experience (<2 years) or the respondent clearly did not understand the use of the scale, assigning scores of only zero or 100 to all questions. Respondents had on average 14.6 years of ICU work experience, ranging from 3 to 38 years. Their distribution according to professional group involved: 23 physicians, 8 nurses, 1 physiotherapist, and 1 nutritionist—16 respondents had a team or unit management position.

The sample size was too small to produce statistically generalizable results. As such, the purposes of the survey were: (i) to provide an exploratory assessment of the ICU characteristics against the guidelines; (ii) to work as a script for the semi-structured interviews (see Section 3.3); and (iii) to indicate salient issues (e.g., survey statements with high or low scores) that could be explored in more detail jointly with the other data sources, creating a chain of evidence. Thus, sophisticated statistical analysis was neither possible nor essential for answering our research questions. A similar approach, which did not give prominence to statistical analysis, was used by Righi and Saurin (2015) when using a questionnaire for assessing the guidelines in an emergency department. On the basis of these premises, the survey results were analyzed using: descriptive statistics; Pearson's correlation coefficient between the groups of guidelines; and Cronbach's alpha for the 23 questions with the sliding bar. An alpha of .96 was obtained, which suggests a reliable instrument (Hair et al., 2014).

3.3 | Interviews and observations

All survey respondents were invited to participate and seven agreed to be interviewed. Interview questions corresponded to the core part of the questionnaire (i.e., the questions on the complexity guidelines) with the aim of understanding the rationale for the survey responses. An additional joint interview was conducted with two public health officials who were also physicians and played a key role in the previously mentioned ICU bed management committee. Those interviews had two questions: Which are the roles and activities of the committee? Which are the benefits, difficulties, and criteria adopted for allocating patients to hospitals? The interviews lasted 1 h on average and all of them were audio-recorded and fully transcribed. Table 2 summarizes the profile of the interviewees.

[2]According to data automatically recorded on the Survey Monkey platform, respondents took on average 12 min to answer the questionnaire, and all of them answered 100% of the questions.

Another source of data involved 20 h of non-participant observations (December 2020 to February 2021) in 10 virtual meetings of the municipal ICU bed management committee. Since April 2020, meetings have been held every week on Mondays, Wednesdays, and Fridays. The meeting involves 15 technicians from the municipal health department and focuses on the monitoring of a number of indicators, such as bed occupancy rates of ICUs, number of performed COVID diagnosis tests in the local health care services, and main outbreaks under way. Each meeting lasted on average 2 h and the researchers took notes in real-time when they detected comments related to the use of the complexity guidelines.

Interviews and non-participant observations were continued until data saturation criteria were met, which means that findings started being repetitive and the data produced was regarded by the researchers as sufficient for the purpose of answering the research questions (Ritchie et al., 2003).

A thematic analysis of the qualitative data (i.e., transcripts of interviews, notes from observations, and comments of the survey respondents on the open field for describing examples of resilience), corresponding to approximately 63,000 words, followed the stages proposed by Pope et al. (2000), namely, familiarization, identifying themes, coding, charting, and mapping and interpretation. Familiarization involved reading the texts several times to gain an understanding of the recurring themes. Next, the themes that had been defined upfront by the researchers were imposed on the data as a heuristic device. The main themes corresponded to:

(i) *Resilience practices associated with the complexity guidelines*. These practices represent adaptive performance to cope with the pandemic, and therefore they were not part of everyday work (at least not at the same frequency) before that. It is worth noting that the main theme for analyzing the guideline on monitoring unintended consequences was not related to resilience practices. This occurred as the familiarization stage of data analysis made it clear that there were no relevant practices for implementing the guideline. By contrast, it was clear that there were several unintended consequences of using (or choosing not to use) the other guidelines. Therefore, we opted for defining the examples of unintended consequences themselves as the main theme for analyzing that guideline.
(ii) *The system level in which the practice played out*. The coding criteria were as follows: micro, corresponding to practices that played out within the ICU premises and did not have any strong dependence on other hospital units and/or hospital top management; meso, when there was strong dependence on other hospital units and/or top management; and macro, when there was a direct interaction or dependence on the environment external to the hospital.

The thematic analysis followed with the coding stage, in which excerpts of text were tagged according to the themes. Three researchers carried out a preliminary coding based on these criteria, separately. Then,

TABLE 2 Profile of the interviewees

Interviewee	Background/position	Workplace—all in COVID ICUs	ICU experience (years)
1	Intensive care physician	95 beds, public hospital	12
2	Nurse	9 beds, public hospital	2.5
3	Chief-nurse	18 beds, public hospital	8
4	Chief-physician	20 beds, public–private partnership	38
5	Intensive care physician/hospital director	42 beds, public hospital	20
6	ICU chief-nurse	20 beds, public hospital	14
7[a]	Intensive care physician/public health official	Municipal health department	20
8[a]	Physician/public health official	Municipal health department	22
9	Physiotherapist	25 beds, private hospital	4

Abbreviation: ICU, intensive care unit.

[a]Joint interview—thus, there were nine interviewees and eight interviews.

TABLE 3 Main characteristics of the surveyed ICUs

Criteria	ICU characteristics
Type of ICU	26 ICUs were general. The others were specialized—for example, infectious diseases and cardiac diseases
Number of beds	22.8 beds on average, ranging from 7 to 140 beds
Configuration of ICU bays	In 12 ICUs patient bays were arranged as individual rooms
Administration and funding	10 public, 16 private, 7 public–private partnerships
COVID-19 patients	29 ICUs had COVID patients
Decision-making model	4 open: attending physician makes decisions on admission, care, and discharge 10 closed: ICU team makes decisions on admission, care, and discharge 19 shared decision-making
Accreditation	21 ICUs have an accredited quality and safety management system
Teaching hospital	21 ICUs are in a teaching hospital
Palliative care team	13 ICUs have a palliative care team
Multidisciplinary rounds	29 ICUs have multidisciplinary rounds
Average occupancy rate in the last 3 months before filling out the questionnaire	83.7%, ranging from 45% to 100%

Abbreviation: ICU, intensive care unit.

codifications were compared in a joint meeting, inconsistencies were detected and a discussion followed until a consensus was obtained. This coding was still further reviewed by another researcher who read all transcripts and was a co-author of all of the earlier studies related to the five complexity guidelines, resulting in additional adjustments. The thematic analysis continued with the charting phase, which synthesized findings from the previous stages. For each complexity guideline, tables were developed (see Section 4), presenting the corresponding resilience practices. An overall analysis of the findings occurred at the mapping and interpretation stage.

4 | RESULTS

4.1 | Main characteristics of the ICUs

Table 3 presents the main characteristics of the 33 surveyed ICUs. They were mostly general ICUs (79%), small-sized (76% had no more than 20 beds), with interdisciplinary rounds (88%), organized as open-plan environments instead of single rooms (64%), part of teaching hospitals (64%), and with accredited quality and safety management systems (64%).

4.2 | Provision of slack resources

Table 4 presents the results for the guideline on slack resources. The high incidence of the meso level (18 out of the 30 practices) reflects the fact that ICU slack resources were often borrowed from other hospital units.

Statement (4), which is related to the availability of human resources, obtained the lowest score in the whole questionnaire (42.8). Indeed, the shortage of clinical professionals has been widely recognized as a major problem during the pandemic and this was also pointed out by all interviewees. For example, interviewee #1 (intensive care physician) reported that

> the number of ICU beds more than doubled while the number of physicians increased by 50% or 60%…let's say that before the pandemic I cared for six patients and now there are ten…it may look like a small difference but the implications are large because I spend much time with each patient.

Lack of staff was compounded by the stressful working conditions as reported by interviewee #9 (physiotherapist):

> professionals are tired of working with uncomfortable PPE for long hours and coping with so many deaths.

Insufficient staff also implied that professionals had to share their time across hospital units and ICUs. Interviewee #9 illustrates this point:

> I was working at the ICU and then I was requested to provide immediate support at the emergency department…I was unable to quickly return to the ICU and had to make an arrangement with the ICU staff so as they could care for the patients I could not see.

The higher score (60.1) obtained by statement (5), which is related to the availability of material resources, might reflect the timing of the survey application, which occurred several months after the start of the pandemic and before the major rise in March/April 2021. All interviewees mentioned that the lack of supplies was more common during the early stages of the pandemic, when there were notorious problems of lack of PPE and drugs such as those necessary for the sedation of patients. Resilience practices that addressed these shortages included the replacement of the standard drugs by others with similar purpose and the development of new protocols for the sterilization and reuse of PPE, such as face masks.

Interviewee #5 (hospital director) reported that lack of supplies was a particularly serious issue in public hospitals as these used to maintain low inventories due to scarce financial resources. The report as follows illustrates his viewpoint:

> I doubt that there is a healthcare setting that demands more resilience than a public hospital in which you work with very little financial slack…you need to live one day at a time.

In turn, the highest score related to this guideline (74.0) was obtained by statement (2), which was related to the dynamic management of material resources. The key dimension of this statement, across the micro, meso, and macro levels, was clearly related to the management of ICU capacity. The evolution of the pandemic, with highs and lows in the number of infected people, implied cycles of closing and opening ICU beds. At the micro and meso levels, common resilience practices involved the repurposing of facilities such as recovery rooms and the suspension of elective surgeries, which released not only material supplies but also staff. At the macro level, COVID hubs were created in some hospitals and patients with comorbidities (e.g., obesity) were directed to specialized hospitals. The two interviewed officials (#7 and #8) perceived that the public health system could effectively be managed as a network and make the best use of the overall capacity due to the centralized governance of the municipal bed management system, in contrast to the capacity management of private hospitals, which was fragmented.

Overall, the guideline on slack lies at the core of the pandemic response, which from the viewpoint of the provision of health care services might be framed as a misalignment between capacity and demand. Both capacity and demand changed frequently over the course of the pandemic, which posed the challenge of capacity being always ahead of demand, which in turn rose sharply at short notice. For instance, in 3 weeks during February/March 2021, the number of ICU beds occupied by COVID patients in the studied capital city rose from 282 to 866.[3] A substantial portion of this addition of beds was only possible through the improvisation of non-ICU beds and the opening of ICU beds without full-time intensive care physicians.

4.3 | Diversity of perspectives in decision-making

Table 5 presents the results related to the guideline on diverse perspectives, for which 15 practices were identified. The scores obtained by statements (9) and (10) were clearly lower than those of statements (7) and (8). As for statement (9), concerned with the consideration of the opinions of patients and their next-of-kin, the relatively low score (56.1) reflects the limitations of ICU patients in their ability to play an active role. Despite this, an example of consultation mentioned by three interviewees (#3, #4, and #6) refers to the decision of intubating patients, which is usually a last resort and associated with high mortality rates. Another factor that may have made the consultation of patients and their families difficult was the low number of ICUs that had a palliative care team—13 out of 31. However, the formal existence of such a team is not exclusive to providing palliative care as highlighted by the following remark of interviewee #5:

[3] https://infografico-covid.procempa.com.br/

TABLE 4 Results for the guideline "provide slack resources"

Statement	Survey (mean)	Resilience practices	Level
(1) The allocation of people changes as needed and in an agile way, such as reallocating staff from one area of the ICU to another	66.0	Willingness to collaborate with colleagues and offer help regardless of being tired	Micro
		Mixed care teams with at least one experienced staff member to counterbalance and support the high number of junior staff	Micro
		Reallocation of staff to COVID units as well as to replace professionals on leave	Meso
		Suspension of elective surgeries to free up staff to COVID patients	Meso
		Leadership support to newly hired employees	Micro
(2) The allocation of material resources changes as needed and in an agile way, such as reallocating dialysis equipment and supplies from one area of the ICU to another	74.0	Transformation of regular wards and other areas into ICUs for COVID patients—scaling up capacity several times during the pandemic	Meso
		Adaptation of existing ICUs to the needs of COVID patients—for example, changes in the air-conditioning and air-filtering system, installation of negative pressure systems in patient rooms	Micro
		Repurposing of drugs, tools, and equipment	Micro
		New protocols for donning and doffing personal protective equipment (PPE)	Micro
		Borrowing equipment and supplies from other ICU and non-ICU units	Meso
		Use of kits with supplies for intubation	Meso
		Acquisition of modern technologies for monitoring vital signs	Meso
		Location of COVID-ICU physically distant from non-COVID units	Meso
(3) Caregivers have adequate time availability to carry out their activities, without excessive haste or too many simultaneous tasks	58.2		
(4) There are extra or standby human resources that can be quickly deployed, and these are available in sufficient quantity to cope with unforeseen events	42.8	Overtime work	Micro
		Hiring of new professionals, offering attractive salaries	Meso
		Cancellation of holidays	Meso
		Acceleration of capacity expansion projects under way	Meso
		Patients over 70 or mentally/physically impaired are allowed to have a full-time caregiver companion at the ICU	Micro
(5) There are extra or standby material resources that can be quickly deployed, and these are available in sufficient quantity to cope with unforeseen events	60.1	Sterilization and reuse of face masks for caregivers	Meso
		Acquisition of extra supplies	Meso
		Construction of makeshift hospitals	Meso
		Transfer of COVID patients from overcrowded ICUs in some Brazilian states to other states	Macro
		Donations of equipment and supplies (e.g., ventilators and PPE) from private companies and nongovernmental organizations	Meso
		Hospital set up its own lab for the processing of COVID tests, to reduce reliance on external agents	Meso

(Continues)

TABLE 4 (Continued)

Statement	Survey (mean)	Resilience practices	Level
(6) There are protocols, training, or technological support for the early detection of the need for changing the care plan (e.g., early detection of the need for palliative care, of sepsis, of mobilizing the patient to facilitate rehabilitation)	55.9		
Others		Own financial slack to pay higher prices for scarce supplies	Meso
		Financial support from governments	Macro
		Staggered times for using the staff room to prevent gatherings	Micro
		Changes in the routes of access of employees to the hospital to prevent contagion	Meso
		Reduction in the demand for other diseases, like, flu and trauma accidents; this released capacity	Macro
		In the hospital processes and areas related to the admission of external patients, all protocols are based on the worst-case scenario—that is, patient is assumed to be infected by COVID-19	Meso
Overall mean	59.5		

Abbreviation: ICU, intensive care unit.

> regardless of not having a palliative care team we follow the principles of palliative care when appropriate.

On the other hand, the fairly high score of statement (8), which was concerned with multidisciplinary decision-making for the plan of care (67.3), might have benefited from the existence of daily interdisciplinary rounds in 28 out of the 33 ICUs. The importance of statement (8) was acknowledged by interviewee #5:

> it is unacceptable an ICU physician who does not know that a (e.g.,) physiotherapist is as important as any other professional.

Despite this recognition, the score obtained by statement (10) suggests that diverse perspectives are considered less when it comes to decisions related to the overall ICU management and development of care protocols (52.6). The novelty of COVID helps explain why an expanded participatory decision-making process has been difficult during the pandemic. Interviewee #5 (hospital director) shed light on that difficulty when saying that

> everyone has an opinion, everybody turned into an expert overnight because of the information available on the media…and I need to make hard decisions amid all sorts of opinions…furthermore, caregivers did not easily accept working with substandard number of staff…it was very hard to be a manager during the pandemic because in addition to new problems, existing ones quickly came to the surface.

For similar reasons, interviewee #2 (chief-physician) remarked that, although there was a committee that canvassed the opinions of professionals, he would make the final decisions because he would be legally responsible for the outcomes.

Another dimension of the guideline on diverse perspectives is related to the individual reactions to the pandemic. According to interviewee #2,

> there was a wide variety of reactions of staff, some of them were desperate thinking that they would die… others did not take the situation as seriously as they should. I needed to reassure the staff every day that we were doing our best.

This report acknowledges the importance of professional psychological support to staff – 12 out of the 33 ICUs had a dedicated psychologist—as well as to the role of leaders as moderators of the diverse perspectives.

Threats to the consideration of diverse perspectives were also identified from the qualitative data. One of these stemmed from the large number of inexperienced professionals hired to cope with the surge in demand. According to interviewee #3 (chief-nurse) "*although nurse technicians attended a 2-week induction training, it was not uncommon that they were unable to perform simple procedures…furthermore, they were very insecure and frightened, asking for our help quite often; this took our time.*" Interviewee #2 (nurse) made a similar remark: *"many professionals were on their first job, no experience with critically ill patients, and of course no experience with COVID…then you can imagine, it was chaotic, terrible…experienced professionals* (who

TABLE 5 Results for the guideline "diversity of perspectives in decision-making"

Statement	Survey (mean)	Resilience practices	Level
(7) Decision-making about the plan of care takes into account the impacts on other units of the hospital (e.g., implications of discharge for the wards, implications for the sectors that perform medical exams)	68.0	Caregivers in overcrowded emergency departments and primary care units need to make hard decisions on the priority patients to be sent to overcrowded ICUs	Macro
(8) Decision-making about the plan of care is multidisciplinary	67.3	Frequent meetings between ICU management and leaders to build a shared understanding of the care protocols and prevent the spread of misinformation	Micro
		Interdisciplinary rounds at the bedside	Micro
		Palliative care team at the ICU	Micro
(9) Opinions of patients and family members are accounted for in health care decision-making	56.1	Patient and family members are consulted for critical decisions such as whether or not resort to intubation	Micro
		Patients are given the opportunity to make video calls to family	Micro
(10) Interventions to improve ICU management and patient care protocols are developed by multiprofessional teams and, if relevant, involving representatives from other units of the hospital	52.6	Participation of representatives from several professional categories in the design of the clinical pathway of COVID patients	Micro
		Daily meetings between ICU management and staff in charge of managing supplies	Micro
		Weekly meeting involving the municipal department of health and hospital representatives to discuss the status of bed occupancy and the need for resources	Macro
Others		ICU management committee requested opinions from hospital units when necessary	Meso
		Hospital top management frequently present at the front-line, listening to the opinions of caregivers and showing that they can trust them for support	Meso
		Open environment and good communication between professionals from different specialties	Micro
		Counseling services to ICU staff	Meso
		Rotation of some employees across COVID and non-COVID areas to reduce the stress of those primarily allocated to COVID areas	Meso
		Quick setup of training program for new hires, using both on-site and distance learning	Meso
Overall mean	61.0		

Abbreviation: ICU, intensive care unit.

worked in these areas full of new employees) *did not want to return after seeing the chaos."* These reports indicate a downside of diverse perspectives; namely, when there is a wide knowledge gap between team members the benefits of the exchange of opinions and information is mostly unidirectional, from the most to the least competent people.

4.4 | Visibility of processes and outcomes

Table 6 presents the results for the guideline on the visibility of processes and outcomes. The prominence of the micro level (12 out of the 14 practices) reflects the operational character of most visibility practices, which are directly targeted at the ICU staff. The two highest scoring statements of the whole questionnaire were related to this guideline. Statement (13) scored 89.2, which suggests that accessibility to information about the treatment and condition of each patient was not seriously compromised by the high number of patients. Similarly, workplaces remained clean and tidy in general as indicated by statement (11), which scored 80.5. These positive results might reflect practices that were solidly implemented before the pandemic (e.g., electronic medical records and housekeeping) and that resisted the scenario of scarce resources. In addition, 21 out of the 33 ICUs had accredited quality and safety management systems.

TABLE 6 Results for the guideline "visibility of processes and outcomes"

Statement	Survey (mean)	Resilience practices	Level
(11) Workplaces are clean and tidy, without unnecessary items, such as used syringes, empty medicine bottles, used gloves, among others	80.5	Housekeeping practices	Micro
		Dedicated teams for cleaning beds	Micro
(12) The results of performance indicators (e.g., occupancy rate, mortality rate, etc.) are widely disseminated, through means, such as posters, electronic panels, whiteboards, brochures, and meetings	51.0	Boards and monitors in circulation areas with results of indicators	Micro
		Computerized system for recording and supporting the analysis of a number of metrics associated with the pandemic evolution at the city level	Macro
(13) Information about the treatment and condition of each patient (e.g., exams, vital signs, medical records, prescriptions, care plan) are easily accessed by caregivers	89.2	User-friendly electronic charts	Micro
		ICU layout that facilitates visualization of all beds from the nursing station	Micro
		Use of digital technologies for the remote monitoring of vital signs of patients—for example, charts directly connected with monitors of vital signs can be updated with little delay	Micro
		Whiteboard that displays handwritten information on the health condition and acuity of each patient—it is filled out by physicians, physiotherapists, and other professionals	Micro
		Visual devices at the bedside to identify patients under mechanical ventilation	Micro
(14) Real-time information on the ICU status as a whole (e.g., number of hospitalized patients, number of patients waiting for beds, professionals on duty) is easily accessed by caregivers	63.0	WhatsApp groups for the exchange of information between caregivers. These groups are usually divided by professional category	Micro
		Web cameras for telemonitoring patients beds	Micro
		Updated information on the ICU status available at the hospital intranet	Micro
Others		FM/AM radio brought by nurses to the ICU. It plays music and news to patients who accept this offer	Micro
		Separate and signaled flows for COVID-19 patients since the hospital reception	Meso
Overall mean	70.9		

Abbreviation: ICU, intensive care unit.

Practices associated with housekeeping were probably in place partly due to accreditation requirements.

The low cost and ease of use of some practices related to visibility might also explain their use. Interviewee #9 (physiotherapist) illustrated this point when commenting on the whiteboard displaying information on the patient health condition:

> it is a reliable means of communication…let's say that a nurse has just arrived to start their shift, they can have a look at the board and then they know what to do, they know whether the patient had any obstruction, if they have secretion, and so on.

On the other hand, statement (12) had a fairly low score (51.0) suggesting that the results of performance indicators related to the overall ICU performance are not effectively disseminated. It is possible that this type of information, if available, is accessible mostly to managers. This is a drawback for resilience as the ability of the front-line professionals to anticipate threats and opportunities is hindered. Also, the rationale of decisions made by leaders may be unclear to other professionals as they do not have the whole picture of the ICU performance.

The role of digital technologies for the implementation of this guideline is also worth highlighting. In particular, despite the utility of electronic dashboards for displaying performance indicators, a drawback came to light during the observations of the meetings of the municipal bed management committee. Amid contrasting views regarding the extent of the mobility restrictions to be applied, some committee participants who were in daily contact with the front-line of care felt that some of the top health officials did not fully grasp the extent of the dramatic situation experienced at the front—one of the meeting participants reported that it was necessary "*to see with their*

own eyes" in addition to looking at the dashboards that guided the meetings.

4.5 | Monitoring and understanding work-as-done

Table 7 presents the results for the guideline on work-as-done. There were 11 practices or conditions, all of them related to the micro level. This is expected as the work-as-done of interest to this study occurred within the ICU premises. Statement (17) obtained the highest score (67.1), which may reflect the use of voluntary incident reporting systems as a relatively common practice in health care services.

By contrast, statement (18), concerned with learning from what goes well and normal everyday variability, had the second lowest score (44.5) of the whole questionnaire. This is unsurprising as health care services are known for their reactive safety management approach, which focuses on learning from failure (Braithwaite et al., 2020). Furthermore, this drawback is possibly part of a broader lack of emphasis on understanding work-as-done as indicated by the low score of statement (19)—46.2, which is concerned with studying work-as-done before making changes in management and care protocols.

However, statements (18) and (19) are limiting to some extent as they refer to "routines" and "study," which convey a structured learning approach. In fact, the pandemic has certainly been a period in which caregivers have learned from what goes well, particularly in terms of clinical practice—for example, not rush to intubate patients and use prone positioning. Interviewee #2 (nurse) exemplified this point when saying that

> nowadays we recommend that patients hospitalized in the wards self-prone, that is, that they sleep lying on their stomach to improve ventilation.

Interviewee #9 (physiotherapist) provided another learning example related to prone positioning: according to her, the time taken to prone a patient reduced from 40 to 15 min during the pandemic.

In turn, the low score obtained by statement (15)—52.7, suggests that the gap between work-as-imagined and work-as-done may have

TABLE 7 Results for the guideline "monitoring and understanding work-as-done"

Statements	Survey (mean)	Resilience practices	Level
(15) Professionals know when, why, and how to adapt or fill in gaps in standardized operating procedures	52.7	Training of newly hired professionals	Micro
(16) There are routines to check reality against what is prescribed in care plans, protocols, and policies. Examples of possible routines: quality audits, meetings to compare expected versus actual performance	53.4	Audits	Micro
		Daily meetings of staff	Micro
(17) There are systems for voluntary reporting of incidents, abnormalities, or other relevant situations, such as unprofessional behavior of co-workers	67.1	Anonymous reporting system that electronically sends the report directly to the supervisor of the worker observed in an unsafe behavior/condition	Micro
(18) There are routines to learn from what goes well or from normal everyday variability. Possible examples: short meetings at the end of the working day (i.e., after action reviews), reporting systems for the dissemination of good practices	44.5	Learning from experience on what works or not as the pandemic evolves and experience accumulates	Micro
		Constant monitoring of changes in the profile of patients, which changed during the pandemic	Micro
		Realistic simulation	Micro
(19) Changes in ICU management and patient care protocols are preceded by a study of how work actually occurs in practice, knowing its variability, constraints, and difficulties	46.2		
Others		Training and simulation of donning and doffing PPE	Micro
		Active search for patients with multiresistant germs (to cope with an outbreak) and daily dissemination of results to teams	Micro
		Physiotherapy team provides theoretical and practical training to the nursing team in clinical procedures	Micro
		Revision of existing protocols, making them closer to work-as-done	Micro
Overall mean	52.8		

Abbreviations: ICU, intensive care unit; PPE, personal protective equipment.

grown wider during the pandemic. This is hypothesized to have occurred for reasons such as:

(i) The prolonged period working under restrictive rules, which tends to produce fatigue. Interviewee #5 (hospital director) remarked that "*there is a limit to human resilience*" and that it was hard to convince the staff that "*we would continue working under restrictions and strict procedures for a long time*"; and
(i) Lack of knowledge and doubts of professionals regarding the clarity and applicability of the new work-as-imagined. For example, interviewee #1 (physician) reported that, despite protocols that established separate pathways for COVID patients, there were doubts because sometimes the patient did not know whether they were infected.

4.6 | Monitoring and understanding unintended consequences

Table 8 presents the results for the guideline on unintended consequences. The survey scores were in general low and the overall mean was the lowest (45.4) among the five guidelines. To some extent, these low scores reflect the difficulties of the pandemic period, in which overloaded professionals had little time for the analysis of barriers and risks of changes (statement 21, score 46.1) as well as for collecting data on performance indicators (statements 22, score 46.8 and 23, score 44.5). In turn, the low score of statement (20)—44.1—is particularly worrying as rapid cycles of small-scale experimentation would be even more relevant in face of changing pandemic demands.

Unintended consequences were frequently a result of using the guideline "provide slack resources." This makes sense as slack changes the nature of the interactions between the system elements (Perrow, 1984). For instance, staggered times for using the ICU staff room prevented gatherings (i.e., it created slack) but hindered informal social interactions between caregivers, which could be useful for resilience.

In addition, there were unintended consequences stemming from the adaptation of facilities to provide slack. To increase capacity, ICU beds were created in areas not originally designed for that purpose. Interviewee #1 (physician) offered an example of this situation: *"in those areas not designed for ICUs, the work organization is much more difficult…the space to do the daily activities is more restricted…it was possible to provide care, but it was certainly worse."* A similar point was made by interviewee #2 (nurse):

> the ICU format is not straight, it is an 'L'…some beds are distant and not visible from the nursing station…. how can we see these patients on the other side?

Slack also implied unintended consequences when resources were transferred from one part of the system to another. This is

TABLE 8 Results for the guideline "monitoring and understanding unintended consequences"

Quantitative findings: Statement	**Mean**
(20) Changes in ICU management and patient care protocols are made firstly on a small scale and rapid cycles, before large-scale implementation.	44.1
(21) As part of planning changes in ICU management and patient care protocols, there is a formal analysis of barriers and risks.	46.1
(22) When there are changes in ICU management and patient care protocols, multiple performance indicators are gathered for assessing the outcomes, contributing to the identification of unintended consequences.	46.8
(23) When there are changes in ICU management and patient care protocols, the outcomes are monitored over the medium (months) and long term (years), rather than just in the immediate post-intervention period.	44.5
Overall mean	**45.4**
Qualitative findings: Examples of unintended consequences	**Level**
Fatigue from chronic high workload and prolonged period of vigilance and discipline for complying with new procedures	Micro
Frustration and anxiety of caregivers as they are unable to provide care to all those who need it, having to prioritize certain patients	Micro
Facilities transformed into ICUs posed constraints that could not be overcome—for example, L-shaped room that hindered visibility, lack of space for the installation of utilities, little space in-between beds	Meso
Patient companions at the ICU were not collaborative with caregivers—for example, giving unauthorized food to the patient	Micro
Patients resist to seek for emergency services and medical care as they fear being infected—this further deteriorates their health condition	Macro
Staggered times for using the staff room and discouragement of gatherings could hinder informal social interactions that could be useful for resilient performance	Micro
Extra ICU capacity, facilities, and workforce after the end of the pandemic—this is a positive potential unintended consequence	Macro
Backlog of patients with untreated diseases due to suspended elective procedures	Macro
Patients transferred from other states could spread new variants of the virus	Macro

Abbreviation: ICU, intensive care unit.

exemplified by the suspension of elective surgeries and outpatient consultations during the most critical moments of the pandemic; this freed up staff and facilities to treat COVID patients. Interviewees #7 and #8 (public health officials) stressed that the health condition of many non-COVID patients deteriorated due to the postponement of clinical care, which led to a demand surge after the regular procedures were reinstated, adding to the high workload from COVID patients. Overall, it seems that the observed unintended consequences were not necessarily unexpected but accepted as a price to be paid for short-term goals. Decision-makers either implicitly or explicitly opted for the course of action judged as most effective and morally acceptable in face of the circumstances.

5 | DISCUSSION

5.1 | What resilience looks like in ICUs during the pandemic

This study shed light on what resilience looks like in ICUs during the pandemic. Although 70 resilience practices were identified, several of these are not applicable to everyday complexity (e.g., addition of several new beds at short notice). This point reinforces the need for understanding what resilience looks like in a pandemic as the corresponding adaptive strategies differ when compared to other types of disasters—for example, contagion by infectious diseases may not be a serious concern when coping with victims from mass casualty accidents.

Nine unintended consequences surfaced, meaning that the resilience practices were at best approximate adjustments (Hollnagel, 2012) due to the high interconnectivity and trade-offs that characterize health services (Braithwaite et al., 2020). Figure 1 presents the total number of practices and unintended consequences according to the micro/meso/macro levels and the corresponding guidelines. Although the data in Figure 1 is not generalizable, it illustrates the potential utility of this type of analysis in larger data sets, provided any patterns are identified from them—for example, slack resources are more likely to be found in other hospital units (i.e., meso).

Some of the unintended consequences played out at the macro level as a result of practices deployed at the micro and meso levels. Similarly, some practices at the macro level certainly influenced the two other levels. This makes clear that the performance of the three levels is intertwined and their isolated optimization is likely to be ineffective in the long term, which is consistent with the proposal of Berg et al. (2018).

However, despite all efforts, results (and knowledge publicly available on the pandemic) suggest that ICU resilience was not enough to support desirable performance and that running out of resilience was part of everyday work during a prolonged period. These features are not self-evident in earlier descriptions of resilience that mostly focus on either everyday work under "normal" times or short-lived crises (Patriarca et al., 2018).

The concept of running out of resilience was evidenced by: (i) the lack of effective treatments and the consequent high mortality rates compromised the production of the required outputs (i.e., healed patients), which is a key dimension of resilience (Hollnagel et al., 2013); (ii) professionals who could not cope with the stressful working conditions—Azoulay et al. (2020) reinforce this point as they found that the pandemic had an overwhelming psychological impact on intensivists, who experienced distress due to suboptimal decision-making and provision of substandard care; and (iii) mismatches between capacity and demand, which highlighted the finite nature of slack resources—this had also been noted by Anderson et al. (2016) as a key for resilient health care.

Thus, running out of resilience can be framed as instantiations that play out in the form of unwanted events such as an adverse event or a professional that resigns. Furthermore, resilience in disasters such as the pandemic tends to degrade slowly (Woods, 2015) as margins get smaller and smaller over the course of hours, days, and weeks, rather than following a step function. This proposition is supported by the model of critical care surge capacity planning proposed by Hick et al. (2014), which places pandemics at the extreme of operating conditions, requiring ICUs to expand at least three times (200%) their usual capacity for a prolonged period.

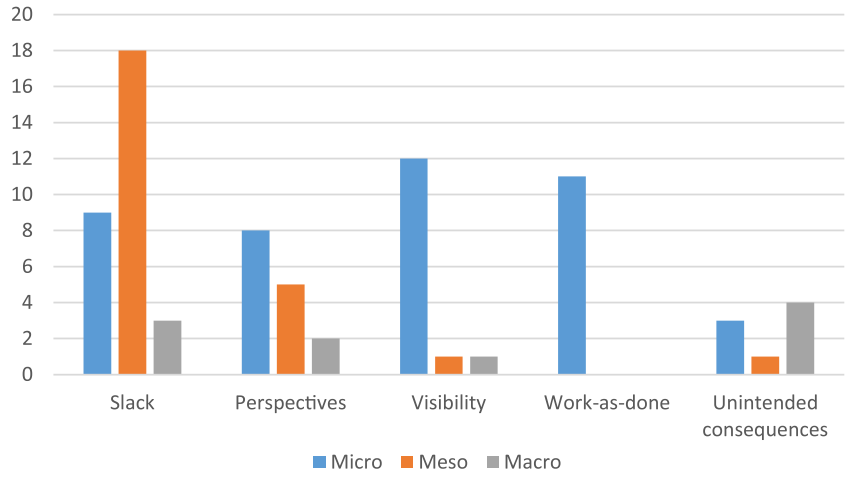

FIGURE 1 Number of practices and unintended consequences according to the complexity guidelines

The reliance of health services on human performance, which is arguably more adaptive than technological artifacts, is likely to be a reason for the graceful degradation during the pandemic. A more general implication of this insight is that, similarly to what occurs with technical infrastructures (e.g., Dunn et al., 2018 on electricity networks, and Zobel & Khansa, 2012, on cyberinfrastructures), there might be patterns of resilience curves for different sectors and disasters types. The identification of these patterns might guide the prioritization of resilience practices (e.g., slow degradation offers more opportunities for learning while the events are still unfolding, while brittle step functions call for preplanned responses) as well as the identification of benchmarks for intra- and intersector learning.

5.2 | Lessons learned in light of the complexity guidelines

The prominent role of the guideline on *slack* resources was clearly related to the mismatch between ICU capacity and demand. All sources of data indicated that qualified caregivers were the key slack resource as it was harder to obtain in comparison to other resources. ICU staffing shortages have also been a major problem in the US during the pandemic, in which contingency plans include the use of ICU telemedicine (Harris et al., 2020). Furthermore, slack resources were commonly found beyond the ICU boundaries such as staff from other hospital units and beds in other hospitals. In fact, the pandemic led to the creation of units and teams practicing intermediary assistance between ICU and non-ICU wards—for example, in non-ICU wards dedicated to the care of COVID patients, noninvasive ventilation devices and high-flow nasal catheters have been used in an unprecedented way (interviewee # 1). This situation corresponds to the concept of "ICU without walls," which is based on two premises: (i) the collaboration of all staff involved in patient care during hospitalization; and (ii) technological support for the early detection of patients at risk of deterioration throughout the hospital, based on the assessment of vital signs and/or laboratory test values (Gordo & Abella, 2014).

Thus, the guideline on slack deals with a tangible dimension of complexity management that involves decision-making on the right amount and mix of resources (Spearman & Hopp, 2021). Additionally, slack can be either designed (i.e., a resource is planned ahead of time to cope with predefined variabilities) or opportunistic (i.e., a resource plays a role as slack even though that was not their original purpose) (Saurin & Werle, 2017). This backdrop sets the stage for the following lesson learned.

Lessons learned related to slack: Capacity addition to health care services such as ICUs must encompass a wide mix of designed and opportunistic slack resources, which are likely to be out of the boundaries of the service focused on. Caregivers are likely to be the major slack resource as they enable the use of other resources and cannot be easily made available at short notice with the required competence level.

Regarding the guideline on *diverse perspectives*, it best represents the constructivist side of the adopted philosophical view of complexity. Both the advantages and disadvantages of diverse perspectives were probably amplified during the pandemic (Saurin, 2021) as the disease was new and there were many stakeholders (e.g., health care providers and businesses owners) with partly conflicting objectives. On the one hand, the use of diverse perspectives was exemplified by creative problem-solving and multidisciplinary care not only to patients but also to providers (e.g., counseling services and closer support from leaders). On the other hand, drawbacks of diverse perspectives were highlighted such as the creation of new meetings for the exchange of information and the effort spent to fight the spread of misinformation originated from the external environment (e.g., unproven treatments)—these drawbacks are costs of collaborative work (Goorden et al., 2014).

The analysis of this guideline can also be conducted in light of the law of requisite variety that applies to complex systems. This law states that a system can only be stable if the number of states of its control mechanisms is equal to or greater than the number of possible states of the system (Ashby, 1991). The possible system states, in this case, might be represented by the profile of the patients, which were cared for in ICUs dedicated to a single disease (i.e., COVID). It is hypothesized that this relatively low variety of patient profiles demanded a disproportional variety in terms of medical viewpoints, tentative treatments, and support from other health care services. Thus, it seems that the law of requisite variety misses the novelty of the system state—that is, if variety is low, but novelty is high, the control mechanisms should be both varied and novel. The lessons learned on this guideline are presented below.

Lessons learned related to diversity of perspectives: the benefits of diverse perspectives apply not only to patient care but also to the well-being and safety of providers. Furthermore, novel situations make the diversity of perspectives even more important, despite the possible low diversity of the process to be controlled. Also, a portion of the coordination costs stemming from this guideline involves the resources spent to fight against perspectives that add unnecessary complexity.

In turn, the guideline on *visibility* took advantage of both digital technologies (e.g., WhatsApp groups) and work organization measures (e.g., housekeeping). However, the role of the former approach was not strongly emphasized by the interviewees, which is to some extent contrasting with the potential of digital technologies for supporting resilience (Borsci et al., 2018; Tortorella et al., 2021).

The statements related to the visibility guideline obtained the highest average overall score in the survey, which may be due to reasons such as: (i) the importance of visibility under conditions of high uncertainty (Beynon-Davies & Lederman, 2017); (ii) the invisible nature of the main hazard (i.e., the virus) which makes the visibility of proxy indicators (e.g., patient with symptoms, number of COVID tests) even more important than in normal times (Saurin, 2021); (iii) the pre-existence of solid visibility practices as a result of past improvement initiatives; and (iv) the large number of inexperienced employees, who can benefit even more from easy access to reliable information. As a drawback, visibility can be a source of additional stress (Bernstein, 2017) to caregivers as they are aware of the

deteriorating condition of patients and systems and can do little about it. On the basis of this context, the lessons learned on visibility are summarized below.

Lessons learned related to visibility: Reliable, real-time, accessible, and easily interpretable information on the status of health care services are realistic goals during crises such as the pandemic. Digital technologies and quality and safety management systems help make those goals achievable. However, a large number of inexperienced professionals demand visual management strategies tailored to their needs. Furthermore, the availability of information must be accompanied by action-taking; otherwise visibility practices can be discredited and become a source of frustration.

As for the guideline on *work-as-done*, the novelty, resource scarcity, and time pressure posed by the pandemic were catalyzed for learning by doing (e.g., prone positioning and intubation timing). Similar situations occur in other sectors such as in aviation (Carim et al., 2016), even though the corresponding crises are acute rather than chronic. As a result, work-as-imagined was probably frozen in its prepandemic form while work-as-done evolved at a fast pace. This learning experience is likely to inform the design of more realistic standardized operating procedures and training programs post-pandemic. However, the high workload and insufficient staffing were hindrances for the full exploration of the learning possibilities. Indeed, slack of time is critical for reflection and learning (Lawson, 2001)—statement (3) was related to the said slack and had a low score (58.2). The lessons learned related to this guideline are summarized below.

Lessons learned related to work-as-done: learning by doing in face of resource scarcity and novelty such as in the pandemic is to some extent inevitable and desirable. However, monitoring and learning from work-as-done might be even more important during crises, although that may require slack resources such as external consultants, staff from units not directly involved in the crisis, and spare time for reflection.

The guideline on *unintended consequences* shared commonalities with the guideline on work-as-done in terms of the low survey scores and implementation difficulties due to effort required for data collection and analysis. Despite these difficulties, major unintended consequences at the macro level stemming from the use of the other guidelines were certainly anticipated by policy-makers such as the creation of a backlog of patients with untreated diseases due to suspended elective procedures. In principle, awareness of these consequences would make it possible to mitigate their impacts when they played out. On the other hand, there were more subtle unintended consequences at the micro level—for example, lack of informal social interactions as a result of limits to gatherings in areas, such as staff rooms; inadequacies in the built environment of areas where new ICUs were installed. The corresponding lessons learned are summarized below.

Lessons learned related to unintended consequences: similar to the mitigation strategies deployed at the societal level (e.g., lockdowns), ICUs and hospitals also adopted simple measures in the sense of stopping activities such as elective surgeries, which drastically and quickly reduced complexity. Therefore, unintended consequences had a fractal nature (Song et al., 2006) as their nature was similar across scales—for example, hospitals lost revenue due to canceled surgeries similarly to businesses losing revenues due to lockdowns; caregivers suffered pandemic fatigue while there was an expected growth of mental illnesses in the population in general (Ornell et al., 2020). Public acknowledgment of this fractal nature could foster empathy in society and tackle the counterproductive perspectives of some agents. An active search for nonobvious unintended consequences stands out as another learning opportunity. That search benefits from the imagination of the work system designers and risk analysts (Adamski & Westrum, 2003), particularly in all decisions that involve the provision of slack resources. Slack has a disruptive potential by adding new elements (e.g., beds), reallocating elements (e.g., staff), or separating existing elements (e.g., social distancing). As a consequence, slack amplifies the potential for unintended consequences (Perrow, 1984).

TABLE 9 Correlations between the guidelines: $p < .01$

	G1	G2	G3	G4	G5
G1	1.00	0.65	0.44	0.59	0.58
G2		1.00	0.75	0.80	0.93
G3			1.00	0.66	0.69
G4				1.00	0.93
G5					1.00

Note: (G1) provision of slack resources, (G2) encouraging diversity of perspectives in decision-making, (G3) supporting visibility of processes and outcomes, (G4) monitoring and understanding the gap between work-as-imagined and work-as-done, and (G5) monitoring unintended consequences of improvements and changes.

Finally, as an overall lesson learned, the joint use of the guidelines seems to be desirable to resilient performance. This lesson is supported by Pearson's correlations between the guidelines, which were all positive and statistically significant at the 99% confidence level (Table 9). Righi and Saurin (2015) found similar results regarding these correlations. Moreover, these correlations make logical sense and were reinforced by data from the interviews and observations. For example, resilience practices related to visibility (e.g., whiteboards displaying information on the patient condition) can contribute to the free sharing of information across professional groups, thus facilitating decision-making based on multiple perspectives. In the same vein, resilience practices related to the monitoring of work-as-done (e.g., realistic simulation and training) can make caregivers more aware of the ICU dynamics, helping the anticipation and monitoring of unintended consequences of improvements and changes.

6 | CONCLUSIONS

This study offers an exploratory investigation of what resilience in ICUs looks like during the COVID pandemic in Brazil and presents lessons in light of guidelines for coping with complexity. As for the

nature of resilience, this paper introduced the concept of running out of resilience, which describes how a sociotechnical system can work in a crisis mode, producing substandard outcomes, for a prolonged period. The chronic mismatch between capacity and demand lies at the heart of running out of resilience. In the pandemic, dealing with that mismatch clearly requires societal resilience, which means that the ICU resilience is dependent on the resilience of the society at local, national, and international levels. The characterization of resilience set a basis for five lessons learned, each corresponding to one of the complexity guidelines. These lessons contribute to the better understanding of the guidelines, which can support their assessment and implementation in contexts other than the pandemic.

Two practical implications of this study can be highlighted: (i) the development of a list of 70 resilience practices, which can be used as a source of ideas not only for ICUs but also for other health care services; and (ii) the survey questionnaire, which is a potential new resilience assessment tool that can be applied both in individual ICUs aiming at continuous improvement and in large samples of ICUs aiming at the identification of trends and benchmarks.

Limitations of this study must be mentioned. First, the complexity of the pandemic and its evolving nature makes it impossible to fully capture its resilience manifestations even when restricted to ICUs. This limitation was compounded by the impossibility, for safety reasons, of conducting observations of work-as-done within the ICUs premises. Second, there was also a limitation to the Brazilian context and the sample size of the survey was small. These drawbacks were counterbalanced by the mixed-method research design and data gathering while events were still occurring, which provided authentic findings. Third, there was no quantitative evaluation of the correlation between the scores obtained in the survey and the quality and safety outcomes of the ICUs. Fourth, there are other relevant theoretical lenses for exploring the human factors implications of the pandemic on health care services—for example, system thinking frameworks (e.g., system dynamics, functional resonance analysis method) and naturalistic decision-making could be useful.

There are opportunities for future studies resulting from this study, such as: (i) similar investigations of how other health care services, such as emergency departments and primary care, coped with complexity during the pandemic; (ii) the use of the questionnaire as a tool to be applied on a regular basis, to support the identification of general trends, benchmarks, and cross-country comparisons; (iii) the gathering of data on the ICUs safety and quality outcomes, to assess correlations with the use of the guidelines; (iv) the development of an open-access computational platform for the voluntary upload of resilience practices from around the world; (v) a deeper study of the role of specific resilience practices during the pandemic, such as those related to bed management; (vi) the analysis of the pandemic from other relevant human factors lens; and (vii) the development of frameworks for assessing and influencing the resilience of health care services in light of societal resilience.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Tarcisio Abreu Saurin http://orcid.org/0000-0003-2929-5888
Priscila Wachs http://orcid.org/0000-0001-6580-8826
Wagner Pietrobelli Bueno https://orcid.org/0000-0003-3611-8089
Ricardo de Souza Kuchenbecker http://orcid.org/0000-0002-4707-3683
Carolina Melecardi Zani http://orcid.org/0000-0002-2649-2432

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