Information and communication technologies in emergency care services for patients with COVID-19: a multi-national study

Leandro M. Tonetto (ltonetto@unisinos.br)
Associate Professor, Graduate Program in Design, Universidade do Vale do Rio do Sinos, Av. Nilo Pecanha 1600, Porto Alegre, RS, Brazil 91330-002

Tarcísio Abreu Saurin (saurin@ufrgs.br)
Associate Professor, Graduate Program in Industrial Engineering (PPGEP/UFRGS), Universidade Federal do Rio Grande do Sul

Flavio Sanson Fogliatto* (ffogliatto@producao.ufrgs.br)
Full Professor, Graduate Program in Industrial Engineering (PPGEP/UFRGS), Universidade Federal do Rio Grande do Sul

Guilherme Luz Tortorella (gtortorella@bol.com.br)
Associate Professor, The University of Melbourne, Parkville VIC 3010, Melbourne, Australia

Gopalakrishnan Narayanamurthy (g.narayanamurthy@liverpool.ac.uk)
Senior Lecturer, Operations and Supply Chain Management, University of Liverpool, UK

Valentina M. Rosa (valentina.rosa@hotmail.com)
PhD Candidate, Graduate Program in Industrial Engineering (PPGEP/UFRGS), Universidade Federal do Rio Grande do Sul

Jeslyn Tengkawan (jeslynmd@gmail.com)
Capella Project Foundation, Jakarta, Indonesia
Mataram University Academic Hospital, West Nusa Tenggara, Indonesia

***Corresponding Author**

Competing Interest Statement: Nothing to declare

Accepted for Publication in

International Journal of Production Research

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Abstract

Information and communication technologies (ICTs) are known for supporting healthcare services in dealing with adverse situations. However, little is known on the contribution of ICTs in a prolonged catastrophic crisis involving a new disease, such as the COVID-19 pandemic. In this study, we carry out an exploratory investigation of which ICTs contribute the most to the emergency care of patients diagnosed with COVID-19 according to healthcare technology experts and how physicians perceive these contributions. Initially, we applied an online survey to 109 healthcare technology experts. Then, we conducted 16 in-depth follow-up interviews with emergency medicine professionals from 10 countries to identify the ICTs contributing the most to treat COVID-19 patients. Results from the survey indicated four ICTs as the most useful to support the treatment of COVID-19 patients; they are remote consultations, digital platforms for data sharing, digital non-invasive care, and interconnected medical decision support. The interviews provided insight into the applicability of those ICTs for the studied context. The four main ICTs were also found to be logically compatible with the complexity of the pandemic, reducing undesirable complexity attributes (e.g., physical proximity between caregivers and infected patients) and amplifying desirable complexity attributes (e.g., interactions that support collaborative work and knowledge sharing).

Keywords: COVID-19, Emergency care, Complexity, Healthcare 4.0, Information and communication technologies.

1. Introduction

The Fourth Industrial Revolution (Industry 4.0; I4.0) brought digitalization and automation to many sectors (Lasi et al., 2014; Xu et al., 2018). When applied to healthcare, such a trend is known as Healthcare 4.0 (H4.0), which is characterized by real-time customization of care delivery (Thuemmeler and Bai, 2017; Chen et al., 2018).

This paper presents an exploratory investigation of the role of information and communication technologies (ICTs) associated with H4.0 during the COVID-19 pandemic, which has challenged the resilience of healthcare services in many countries. From a theoretical perspective, the pandemic offers an opportunity to understand which and how ICTs play a role in a high-complexity and novel scenario. Indeed, the pandemic rise, its evolving nature, and its hopeful end might all be described as complex phenomena (Saurin, 2021). It has stretched the use of existing resources to their limit, evolving in partly unpredictable ways and forcing the development of adaptive capacity on the fly (Ivanov and Dolgui, 2020).

Healthcare services are widely acknowledged as complex adaptive systems, which means that their performance changes over time and that the understanding of interactions between system elements (e.g., people, technologies, procedures) must be given priority over the modelling of individual elements (Braithwaite, 2018). The perspective of complexity has been frequently adopted in healthcare services research to the point of giving rise to literature reviews on the topic. Davies et al. (2016) conducted a scoping review of complexity theory in health services research, concluding that most studies were exploratory and focused on relationships between healthcare workers. Churruca et al. (2019) carried out a bibliometric review and found that there has been a recent shift from conceptual work to the application of concrete improvement strategies based on the complexity perspective. Braithwaite (2018) argues that complexity represents a promising perspective for quality improvement in healthcare, which challenges existing practices that overemphasize more regulations and stringency – such practices are partly conflicting with the dynamic and, to some extent, unpredictable nature of healthcare services. Bueno et al. (2019) used the complexity perspective in a literature review in which 91 quality improvement interventions in intensive care units were analyzed. The authors found that the interventions accounted for the premises of complexity at a low level, especially regarding the monitoring of unintended consequences of improvements and changes. Tortorella et al. (2021) found that I4.0 technologies positively impact hospitals' resilience, which is relevant for this study as resilience is an attribute of complex adaptive systems. Against this backdrop, it is clear that the analysis of healthcare services from the complexity perspective is relevant, although it has not yet been used to investigate H4.0 technologies. The pandemic scenario makes the complexity perspective even more relevant. The complexity of services at the front-line has undoubtedly been amplified due to the rise in demand (i.e., more elements interacting) and scarcity of human and material resources, making processes coupled and prone to quick error propagation.

In turn, ICTs may help flatten the virus epidemic curve and keep mortality rates low. According to Whitelaw et al. (2020, pp. e438-e439), "countries that have quickly deployed digital technologies to facilitate planning, surveillance, testing, contact tracing, quarantine, and clinical management have remained front-runners in managing disease burden." Thus, the role of ICTs, such as telemedicine and mobile health, is being reviewed and expanded to respond to this global health emergency (Ferrara and Albano, 2020). However, knowledge of the nature and implications of ICTs during the pandemic is incipient from a scientific viewpoint, which is understandable since the pandemic is still unfolding and several different mitigation strategies have been deployed across the world.

Considering the need for limitations of scope, we focus on ICTs applied to emergency care services which, together with intensive care units (ICUs), have been the most visible public facets of healthcare services during the pandemic. Both services are inextricably linked since many patients admitted to emergency departments (EDs) are later transferred to ICUs. The emergency care context has strong complexity characteristics, such as variable demand, time pressure, and need for multidisciplinary care teams, which jointly imply tightly coupled processes and the consequent non-linear fast propagation of errors (Yee et al., 2020; Mathew et al., 2020). The prolonged nature of the crisis and the fact of being a new disease amplifies those complexity attributes. Thus, it is unclear the extent to which ICTs remain useful in that extreme scenario. To help to bridge this gap in the literature, we propose the following research questions:

RQ_1: Which ICTs have the potential to contribute to the treatment of patients diagnosed with COVID-19 during the pandemic?

RQ_2: How physicians perceive the contributions of such ICTs to the emergency care of patients infected with SARS-CoV-2?

To answer these questions, we carried a two-stage study. In the first stage, an online survey with experts in healthcare technology was employed to answer RQ_1. It was composed of open questions in which participants were asked to report the contributions of several ICTs to the treatment of COVID-19 patients (if any) and rank services most impacted by them. Results indicated the Emergency Department as the most impacted service, leading to RQ_2. In the second stage, in-depth interviews were carried out with emergency physicians from several countries to investigate how these technologies contribute to treating such patients in everyday practice around the globe. A multicultural approach was necessary for our study, as "some countries may not have the technological infrastructure to support DH [digital health]. Furthermore, there will be a significant proportion of the population who will not have access to technology or internet connectivity" (Alwashmi, 2020, p. 4).

This research contributes to the state-of-the-art by shedding light on the types and applicability of innovative ICTs that might be used in emergency departments during a pandemic, which is a disruptive event that is expected to reoccur from time to time. Considering that the latest pandemic of a similar scale occurred around 100 years ago (Spanish flu), this is the first major pandemic of the digital age. Therefore, the role played by ICTs in this type of disruption needs investigation as their importance in future pandemics is expected to grow as H4.0 implementation gathers pace. From a theoretical viewpoint, our contribution is grounded on the theory of complex adaptive systems, which suggests that the studied ICTs are an effective means of balancing complexity attributes (i.e., reducing undesired attributes and strengthening desirable attributes) amid the COVID-19 pandemic. From a practical perspective, our contribution is grounded on the perceptions of experts and real-life practice of physicians from several countries.

2. Background

2.1. Healthcare 4.0

H4.0 environments comprise interconnected digital applications, electronics, and microstructure technologies that foster therapeutic models, internal and external services with improved performance (Sultan, 2014; Yang et al., 2015). The use of ICTs and applications in healthcare systems have a positive impact on treatments, administrative and supporting processes (Das et al., 2011), and the sustainability of healthcare supply chains (Bai et al., 2020).

The literature on ICTs in Emergency Departments (EDs) (e.g., Reddy et al., 2019) investigates their use in coordinating communications between emergency medical services and emergency department teams. Literature reviews on H4.0 also report some applications of ICTs in EDs. For example, Jayaraman et al. (2020) mention the use of Electronic Medical Records (EMRs) and Virtual Assistants in EDs, while Tortorella et al. (2020) report the use of Augmented Reality in Emergency medicine.

An extensive number of H4.0 ICTs and applications are reported in the literature by Jayaraman et al. (2020) and Tortorella et al. (2020). Table 1 summarizes the most frequently cited groups of independent H4.0 ICTs, labeled g_1 to g_{10}, and described them according to their main baseline technologies (e.g., Internet-of-Things – IoT, big data, and cloud computing), as Frank et al. (2019) suggested. We focused on ICTs rather than their applications, although we use the latter to illustrate the former. We now provide a brief presentation of each group of ICTs.

Table 1 – Most frequently cited H4.0 ICTs

Groups of H4.0 ICTs		References
g_1	Augmented reality as clinical decision support	Demirkan (2013); Sakr and Elgammal (2016); Chen et al. (2018); Rajan and Rajan (2018); Wang et al. (2018); Munzer et al. (2019)
g_2	Remote consultations and the development of a plan of care in real-time	Demirkan (2013); Sakr and Elgammal (2016); Munzer et al. (2019)
g_3	Remotely assisted surgical and clinical procedures	Demirkan (2013); Sakr and Elgammal (2016); Rajan and Rajan (2018); Munzer et al. (2019)
g_4	Remote nutrition and infusion management	Demirkan (2013); Yang et al. (2016); Rajan and Rajan (2018); Rizwan et al. (2018); Munzer et al. (2019)
g_5	Digital non-invasive medical techniques	Rajan and Rajan (2018); Rizwan et al. (2018); Munzer et al. (2019)
g_6	Interconnected medical emergency support	Demirkan (2013); Sakr and Elgammal (2016); Yang et al. (2016); Rizwan et al. (2018);
g_7	Medical devices traceability system	Demirkan (2013); Azzawi et al. (2016); Rizwan et al. (2018); Rajan and Rajan (2018); Wang et al. (2018)
g_8	Digital platforms for collaborative sharing of patient data and information	Sakr and Elgammal (2016); Rajan and Rajan (2018); Wang et al. (2018)
g_9	Synthetic medical information generation through cloud computing	Azzawi et al. (2016); Yang et al. (2016); Rizwan et al. (2018)
g_{10}	Computer-assisted design of customized and modular medical devices	Demirkan (2013); Azzawi et al. (2016); Wang et al. (2018)

ICTs in the group g_1 – "augmented reality for clinical decision support" – allow virtual-reality reconstructions laid on top of a patient's images in real-time using augmented reality, supporting the clinical decision and digital screening of patients' symptoms and enhancing the quality of care through improved access and reduced errors (Chen et al., 2018; Munzer et al., 2019). *Augmented reality* is the baseline technology applied to layer information from physical and virtual domains, augmenting or supplementing the reality with computer-generated content (Farshid et al., 2018). Group g_2 – "remote consultations and the development of a plan of care in real-time" – allows remote doctor-patient interaction using artificial intelligence (Demirkan, 2013; Sakr and Elgammal, 2016). The objective is to support decision-making in real-time, enabling screening, diagnosis, and treatment of patients in remote settings. Some applications in this group include interconnected and real-time electronic medical records of patients, IoT-based health prescription assistants, remote diagnosis via mobile applications, and virtual doctor-patient interaction and examination. Baseline technologies supporting this group are *IoT* (i.e., the connection of objects and physical devices to the internet, enabling communication and interaction – Alhamid, 2019; Onasanya and Elshakankiri, 2019), and *remote control or monitoring* (i.e., remote monitoring of users' physical condition and physiological parameters; Rodrigues et al., 2020).

Group g_3 – "remotely assisted surgical and clinical procedures" – encompasses applications such as virtually aided clinical procedures, collaborative robots for complex medical procedures, and measurement of vital parameters in real-time (Rajan and Rajan, 2018; Munzer et al., 2019). Three baseline technologies support this group: *IoT, remote control or monitoring*, and *collaborative robots* (i.e., robots that work alongside humans; Paxton et al., 2017). Group g_4 – "remote nutrition and infusion management" – is comprised of server-connected pumps that remotely deliver and monitor nutrition and infusion to patients, using mobile cloud computing applications, virtual customization of drug management, and digital nutrition management and data record (Yang et al., 2016; Rizwan et al., 2018). The main baseline technologies of g_4 are *cloud computing* (i.e., clusters of computers serving as data centers to provide on-demand resources and services over a network; Sultan, 2010), *remote control or monitoring*, and *IoT*.

Group g_5 – "digital non-invasive care" – allows health monitoring by sampling, processing, and communicating vital signs or environmental factors through non-invasive sensors (Otto et al., 2006; Rizwan et al., 2018). Its baseline technology is *Biomedical/digital sensors* (i.e., a group of wireless networked low-power devices; Ren et al., 2005). Group g_6 – "interconnected medical emergency support" – comprises technologies that promote the connection of pre-emergency support, ambulances, and onsite services through shared information systems (Landman et al., 2011; Catarinucci et al., 2015; Sakr and Elgammal, 2016; Yang et al., 2016). Baseline technologies are *IoT*, *cloud computing*, and *big data* (i.e., computational power and algorithmic accuracy maximized to collect, analyze, associate, and compare large datasets, visualizing patterns; McCarthy et al., 2004).

Group g_7 – "medical devices' traceability system" – relates to systems that mark and identify medical devices, such as equipment and surgical instruments, within the healthcare supply chain, reducing the number of medical accidents and counterfeit or unqualified devices (Azzawi et al., 2016; Wang et al., 2018; Xia et al., 2019). *IoT*, *big data*, *cloud computing*, and *remote control or monitoring* are the baseline technology supporting g_7. Group g_8 – "digital platforms for collaborative sharing of patient data and information" – promotes secure storage and retrieval of patient data shared by organizations, physicians, and patients, including a medical encyclopedia with real-time user collaboration. *Cloud computing* and *big data* are the supporting baseline technologies.

Group g_9 – "synthetic medical information generation through cloud computing" – allows the combination of accurate health information from patients to create realistic virtual data which can be made available publicly without compromising patients' privacy (Azzawi et al., 2016; Goncalves et al., 2020). Three baseline technologies support g_9: *IoT*, *big data*, and *cloud computing*. Finally, group g_{10} – "computer-assisted design of customized and modular medical devices" – promotes the design of products custom-made for each patient (e.g., prosthetics), which may also be 3D-printed (Angelini et al., 2019; Colpani et al., 2018; Wang et al., 2018). *Big data*, *remote monitoring and control*, and *cloud computing* enable baseline technologies of g_{10}.

2.2.Complex adaptive systems

Complex adaptive systems (CAS) are living systems of any type (e.g., a company, an ecosystem, a cell) that have the capability of adapting to a changing environment, surviving and thriving even in the face of adverse conditions, such as scarcity of resources and uncertainty (Braithwaite et al., 2018). That capability is commonly referred to as resilience, which emerges from the interactions between many diverse elements (e.g., people, equipment, materials, software) that form a CAS (Hollnagel, 2017). CAS display non-linear interactions, which means that small changes might produce disproportionate consequences (Dekker, 2011). Such interactions are also invisible and unplanned (Perrow, 1984). The characteristics above make the behavior of CAS impossible to be wholly understood and predicted (Cilliers, 2005).

From this background, it is easy to realize that ICTs, particularly their software portion, influence the complexity of CAS (Dekker, 2011). This influence may have mixed implications.

On the one hand, ICTs allow for an extension of human adaptive performance, supporting anticipation, monitoring, learning, and responding abilities (Tortorella et al., 2021). On the other hand, downsides are related to technological glitches and accidents that baffle investigators due to the lack of easily identifiable causes (Favaro et al., 2013; Leveson and Turner, 1993). However, it is worth noting that ICTs by themselves are only complicated artifacts since they can be fully described and understood based on the decomposition of their parts. When interacting with their socio-technical environment in the real world, ICTs become an inseparable part of a broader CAS, influencing and being influenced by other system elements (Dekker et al., 2013).

3. Methods

The proposed method is comprised of four steps: (*i*) development of the data collection instrument, (*ii*) data collection and determination of sample characteristics, (*iii*) semi-structured follow-up interviews, and (*iv*) data analysis and discussion. The first three steps are detailed next; step (*iv*) is presented in sections 4 and 5.

3.1. Development of the data collection instrument

A list of 24 ICTs and applications compiled from the literature by Tortorella et al. (2019) was used as a departing point. We grouped technologies by similarity and generated a list of 10 non-redundant groups of H4.0 ICTs (see section 2.1) after four rounds of discussion with six experts knowledgeable on H4.0 technologies and applications. Such experts were academics from Brazil (2), Australia (1), Chile (1), Argentina (1), and the UK (1), who have been investigating healthcare digitalization for at least five years. In total, they have published over 40 articles on the topic in highly ranked, peer-reviewed journals. In addition to their academic backgrounds, they also have consultancy experience in healthcare operations management, which complements their knowledge from a practical standpoint. The ten groups of H4.0 ICTs were organized in a 10-question survey implemented in the online platform SurveyMonkey (See Appendix A).

The survey's cover page collected general information about respondents (country of residence and years of experience working with healthcare). Ten pages followed, each related to a group of ICTs. In part (i), respondents were asked to evaluate the impact level of the group of ICTs on the resilience abilities of healthcare systems using a six-point scale (no impact, very weak impact, weak impact, moderate impact, strong impact, and very strong impact). In part (ii), respondents were asked to rank the contribution of the group of ICTs to six healthcare services (primary care units, outpatient wards – consultation and follow-up, emergency care, surgical theater, inpatient wards, and intensive care units). In part (iii), respondents were asked whether the group of ICTs was usable for treating patients with COVID-19 (yes or no) and why if the answer was positive (open questions). In what follows, we use responses from part (iii).

3.2. Data collection and determination of sample characteristics

E-mail invitations to respond to the survey were sent to professionals from two networks; they are the Health Technology Assessment International (HTAi – htai.org), through the mailing list of participants in their 2019 Annual Meeting, and the participants of the 2019 Resilient Healthcare Network meeting (resilienthealthcare.net). We also invited authors reviewed in Tortorella et al. (2019) and Ellis et al. (2019). Our inclusion criteria were knowledge about healthcare technologies and resilience in healthcare environments. A total of 658 e-mail invitations were sent from May 29, 2020, to Aug 04, 2020. We received 49 complete responses resulting from the first invitations. We issued follow-up e-mails in June and July 2020, which resulted in 60 additional responses. The final sample comprised 109 respondents (response rate of 16.6%). Non-response bias was verified through Levene's test for equality of variances and a *t*-test for the equality of means (Armstrong and Overton, 1977), yielding significance levels higher than 0.05 and indicating no significant differences in means and variances from the two sets of responses. The final sample has the characteristics shown in Table 2.

Table 2 – Sample characteristics.

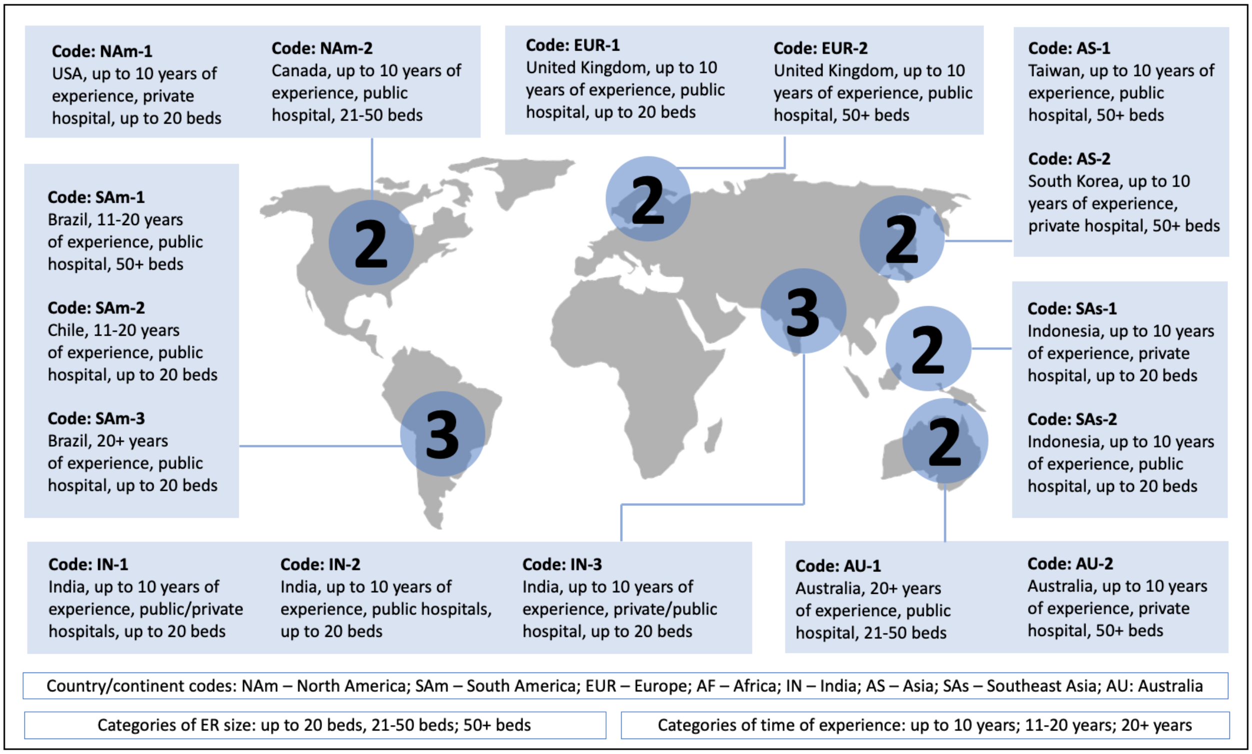
Socioeconomic context		
Emerging	60	55.0%
Developed	49	45.0%
Healthcare experience		
Less than 5 years	29	26.6%
Between 5 and 10 years	23	21.1%
More than 10 years	57	52.3%

We used descriptive statistics for the yes/no questions (usability of each group of ICTs for treating patients with COVID-19). Two of the authors grouped the answers given to the open questions (reasons listed by the respondents to support the answers given to the yes/no questions) by similarity of content (e.g., support medical decisions and facilitate patient follow-up) to determine the frequency of each contribution. The grouping was concluded when the two researchers agreed on the final list of contributions.

3.3.Semi-structured follow-up interviews

In-depth interviews were carried out to strengthen our understanding of the different groups of ICTs' contributions to treating patients with COVID-19. They focused on the four groups of ICTs most frequently indicated as valuable by the professionals described in Table 2 and their use in emergency care. We conducted 16 interviews with physicians from 10 different countries. The sample characteristics are presented in Figure 1. All interviewees are emergency physicians currently working in the area and experienced in diagnosing and treating COVID-19 patients. Information about the physicians and respective hospitals is presented in broad categories to preserve anonymity, following directives from the Ethics Committee that approved the interview protocol.

Interviewees were recruited through the professional networks of the authors. They were contacted by phone or e-mail. Ethical and practical procedures were explained, and the aims of the research were discussed. After they agreed with and signed an informed consent form on an online platform, video-recorded interviews were appointed. In three cases, interviews based on e-mail exchange were carried out due to the participants' high workload.



Code: NAm-1
USA, up to 10 years of experience, private hospital, up to 20 beds

Code: NAm-2
Canada, up to 10 years of experience, public hospital, 21-50 beds

Code: EUR-1
United Kingdom, up to 10 years of experience, public hospital, up to 20 beds

Code: EUR-2
United Kingdom, up to 10 years of experience, public hospital, 50+ beds

Code: AS-1
Taiwan, up to 10 years of experience, public hospital, 50+ beds

Code: AS-2
South Korea, up to 10 years of experience, private hospital, 50+ beds

Code: SAm-1
Brazil, 11-20 years of experience, public hospital, 50+ beds

Code: SAm-2
Chile, 11-20 years of experience, public hospital, up to 20 beds

Code: SAm-3
Brazil, 20+ years of experience, public hospital, up to 20 beds

Code: SAs-1
Indonesia, up to 10 years of experience, private hospital, up to 20 beds

Code: SAs-2
Indonesia, up to 10 years of experience, public hospital, up to 20 beds

Code: IN-1
India, up to 10 years of experience, public/private hospitals, up to 20 beds

Code: IN-2
India, up to 10 years of experience, public hospitals, up to 20 beds

Code: IN-3
India, up to 10 years of experience, private/public hospital, up to 20 beds

Code: AU-1
Australia, 20+ years of experience, public hospital, 21-50 beds

Code: AU-2
Australia, up to 10 years of experience, private hospital, 50+ beds

Country/continent codes: NAm – North America; SAm – South America; EUR – Europe; AF – Africa; IN – India; AS – Asia; SAs – Southeast Asia; AU: Australia

Categories of ER size: up to 20 beds, 21-50 beds; 50+ beds

Categories of time of experience: up to 10 years; 11-20 years; 20+ years

Figure 1 – Sample characteristics.

The interview followed a semi-structured guide that focused on four groups of ICTs; therefore, it was organized into four parts. Each part started with the description of the group of

ICTs under analysis, based on the content presented in section 2.1. In case the interviewees had experience using it, the following questions were asked:

i) Can you explain why this technology is (or isn't) useful to treat patients with COVID-19 in emergency care?

ii) Please, share an example if you can recall one; and

iii) Are there any difficulties or barriers to implement or use this technology in your institution?

In cases in which participants had never used the technology, they were asked: "Do you believe this technology could be useful to treat patients with COVID-19 in emergency care? Why?".

The interviews were transcribed and analyzed through Content Analysis (Neuendorf, 2002). Verbalizations were grouped by similarity. Four categories were defined *a priori*, corresponding to the four groups of ICTs. Literal fragments of the interviews were grouped according to such categories. Answers from physicians who have experience using each group of ICTs were separated from those given by interviewees who have not yet used them. We then formulated subcategories of responses corresponding to the contributions of such ICTs for diagnosing and treating COVID-19 patients. Data collection was carried out until data saturation was reached (i.e., new physicians were recruited and interviewed until their answers became repetitive and clear reasons for their perceptions on the contributions of the four groups of ICTs were identifiable). Two researchers carried out the analysis in parallel. All transcriptions were categorized, generating a first draft of the categories, which was discussed by the two researchers to obtain the final set of categories.

4. Results

4.1. Survey with experts in H4.0

The most relevant groups of ICTs to diagnose and treat COVID-19 in the assessment of H4.0 and Resilience Engineering experts were remote consultations and development of plan of care in real-time, digital platforms for collaborative sharing of patient data and information, digital non-invasive care, and interconnected medical emergency support. They correspond to ICT groups with a percentage of positive responses in the survey higher than 70% (see Figure 2) and presenting standard deviations from the average larger than +0.5.

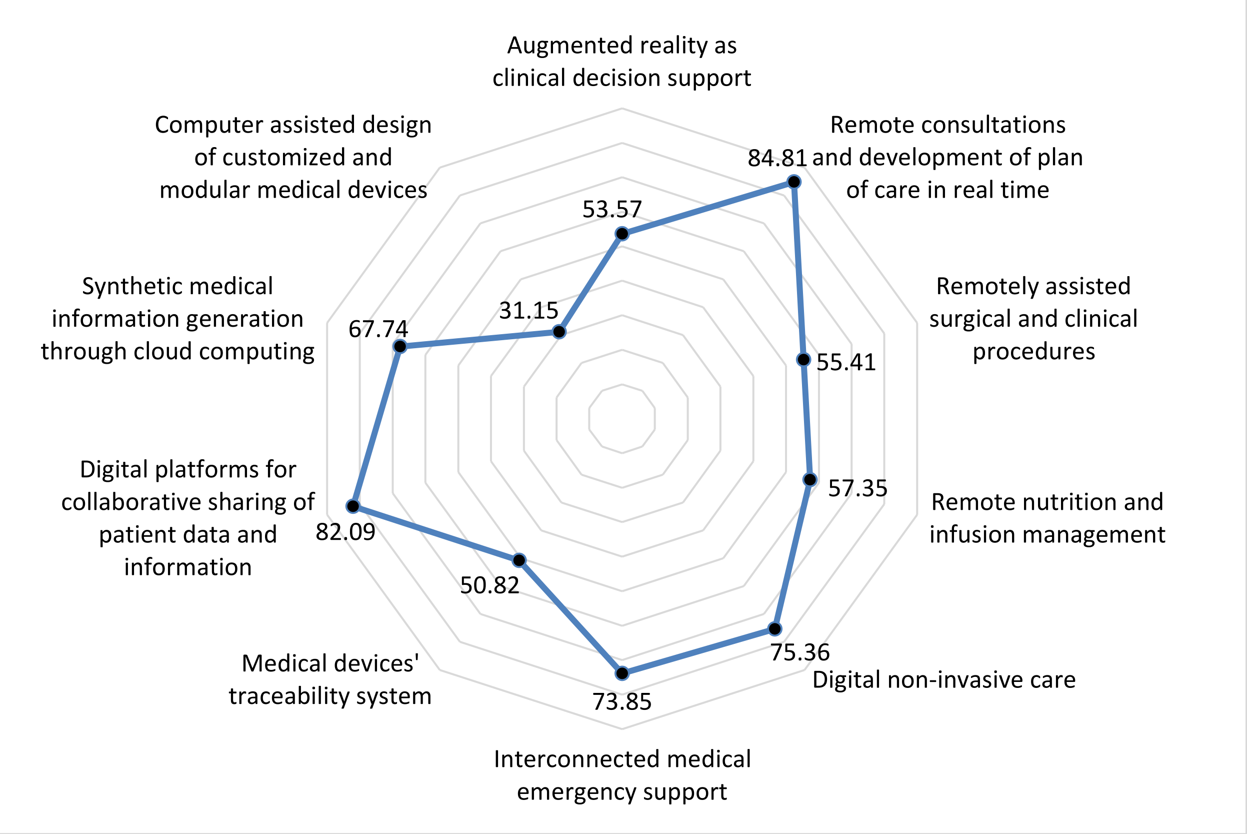


Figure 2 – Contribution of each ICT group to diagnose and treat patients with COVID-19 (percentage of valid responses).

Table 3 indicates the contributions offered by the top four ICTs for diagnosing and treating COVID-19, as perceived by the survey's respondents (contributions of the bottom six ICTs are available in Appendix B).

The main contributions for treating patients diagnosed with COVID-19 reported in the survey and displayed in Table 3 may be summarized as follows:

- Several ways of promoting social distancing and isolation, safely monitoring patients and anticipating actions and/or facilitating diagnosis were listed as contributions from the four groups of ICTs;
- Supporting medical decisions was a contribution related to all groups of ICTs, except for "digital non-invasive care";
- Contributions to the management of healthcare services during the COVID-19 pandemic were associated with ICT groups "remote consultations and development of plan of care in real-time", and "interconnected medical emergency support" (e.g., facilitate better allocation of resources, coordinate different levels of healthcare, manage emergencies, avoid low severity patients going to hospitals, overcome distances, and support hospitals with limited capacity); and
- Learning about the pandemic and epidemiologic data contributed to "digital platforms for collaborative sharing of patient data and information" and "digital non-invasive care".

Table 3 – Contributions of the top four ICT groups to diagnose and treat patients with COVID-19

ICT group	**Contributions**	**Freq.**	**%**
Remote consultations and development of plan of care in real-time (N=67)	Promote social distancing and isolation	23	34.33
	Safely check symptoms and patient follow-up and monitoring	14	20.90
	Analyze tests and perform diagnosis	10	14.93
	Increase the safety of healthcare professionals	8	11.94
	Support medical decisions	7	10.45
	Avoid low severity patients going to hospitals	7	10.45
	Understand the stage of the disease the patient is in	6	8.96
	Plan the treatment	6	8.96
	Overcome distance between patients and hospitals	5	7.46
	Enable remote contact between physicians and experts	2	2.99
	Support hospitals with limited capacity	2	2.99
Digital platforms for collaborative sharing of patient data and information (N=55)	Monitor the diffusion of COVID-19, comparing patients' evolution	21	38.18
	Advance knowledge by sharing information on other cases	20	36.36
	Share the patient's history to elaborate better treatment plan	18	32.73
	Support medical decisions	13	23.64
	Map possible action plans	13	23.64
	Follow statistics and tends in treatment planning	5	9.09
	Promote social distancing and reduce risk of infection	4	7.27
Digital non-invasive care (N=52)	Monitor patient's evolution and vital signs	30	57.69
	Promote social distancing and reduce risk of infection	15	28.85
	Facilitate homecare	13	25.00
	Anticipate actions	7	13.46
	Facilitate patient follow-up	5	9.62
	Reduce the risk of infection of healthcare workers	2	3.85
	Learn COVID-19 epidemiologic data	2	3.85
Interconnected medical emergency support (N=48)	Anticipate courses of action	14	29.17
	Enhance responses	12	25.00
	Coordinate the different levels of healthcare	12	25.00
	Facilitate better allocation of resources	10	20.83
	Support medical decisions	9	18.75
	Manage emergencies	8	16.67
	Promote social distancing and reduce risk of infection	6	12.50
	Enhance patient monitoring and treatment	6	12.50
	Assist in diagnosis and triaging	4	8.33

4.2.Follow-up interviews

- Technology 1: Remote consultation

Physicians with experience in using remote consultations (RC) considered such technology useful to diagnose and treat patients with COVID-19 in EDs (NAM2; SAM1; SAM3; EUR1; IN1; IN3; SAS2). Advantages of using RCs are remote access of patients' medical histories (SAM1), minimize the time taken to diagnose them (IN1), avoid physical contact with patients (SAM3, EUR1), and allow consultations with specialists unavailable in loco, using video calls (SAS2).

> *There are a lot of remote diagnostic tools which are being used, primarily telemedicine. Some of them provide immediate results, but some are being interpreted by specialist doctors working remotely.* […] [Diagnosing COVID-19] *requires multiple parameters which are analyzed and kind of categorize the patient based on these inputs and their history* […]. *This process will help a clinician to make their decision at the point of care. That will be very helpful because there are chances that the patient will deteriorate his condition.* […] *The longer you take to diagnose, the more the patient can infect others. So, it should be minimum contact with the doctor and minimum time to get the diagnosis done so that you know their health care needs are immediately catered to.* (IN1).

RCs were considered particularly useful in isolated areas: "It is a support [to the healthcare system] […], for example, to reduce the pressure on hospitals and at the same time to monitor the patients who are quarantining, self-isolating." (IN3). However, RCs were not assessed as inclusive tools, as "not everyone has a phone [in such areas] and it can only reach out for younger generations." (SAS1).

Contrasting the positive perspective on using RCs, **interviewees with no experience using such technology** (NAM1, SAM2; EUR2; IN2; AS1; AS2; SAS1; AUS1; AUS2) reported three concerns regarding their use. The first is that RCs may only be adequate to use before diagnosing patients with COVID-19. This kind of consultation "can be useful for decision making to urge patients to directly go the ER" (SAS1) and explain to them "what to do and what not to do" (AS1). Thus, RC was not considered a proper means to diagnose COVID-19, as physicians "usually need to have visual and audible data, so it is necessary to see the patient up close." (AS2). Also, after diagnosing the patients, "if they are stable, they can be treated from home, but in unstable cases, you cannot do that." (IN2).

The second concern is the lack of safety and accessibility issues where RCs are held, as well as the inability of patients and service providers working remotely to handle medical materials and environments: "You are relying on people to have this structure at home [e.g., monitors and appropriate lighting], or to have access to it. I don't know if there is somewhere where they can use it, but then who is there to manage it? Who is making sure it is working? Who is cleaning everything up after each patient?" (NAM1).

The third concern is that remote consultations do not substitute the expertise and promptness of human physicians:

> [Remote consultations] *may be helpful to support protocol-driven and guideline-based management. However, the beauty of clinician assessment is that you can adjust care to the nuances specific for a patient; i.e., if they*

> *have diabetes, do they need a different blood sugar level or, if they are usually hypertensive, a systolic blood pressure of 110 is actually 'hypotension' for the number being truly below the categorical 90 systolic. So, they* [i.e., RCs] *may be helpful if hospitals were overwhelmed to triage or preliminary assess patients at risk to support clinicians, but I do not think it will ever be able to replace the adjustments a clinician makes to care on a case-by-case basis.* (AUS2)

The interviewees mentioned four **difficulties and risks in implementing RCs at their institutions**:

i) Privacy and reliability: sharing patients' confidential information among different institutions (SAM1) and reliability of background data (IN1);

ii) Hospital structure: poor infrastructure (SAM3); limited space, logistics, and financial resources (NAM2), and insufficient staff to handle unexpected demands (NAM2; IN2);

iii) Systems: incompatible hospital systems and software (EUR1); and

iv) Patients' familiarity with and availability of technologies: limited or no access to modern technologies at home (SAM1, IN2), and communication barriers (all systems should be suitable for staff and patients; IN1).

- <u>Technology 2: Digital platform for collaborative sharing of patient data and information</u>

Physicians with experience in using digital platforms for collaborative sharing of patient data and information (DP) considered such technology useful to diagnose and treat patients with COVID-19 in ERs (NAM2; SAM1; SAM3; EUR1; EUR2; AS1; SAS1; SAS2; AUS1; AUS2). According to them, DPs offer two main contributions.

The first contribution is the ability to access medical records easily (SAM1; EUR1; EUR2; AUS1; AUS2), ensuring information integrity (SAM1). At some hospitals, different types of information are made available depending on the role of the professional within the organization, e.g., physicians and receptionists (AUS1). Patients benefit from knowing and recording their medical information (SAM1; AS1), but they are secretive in some instances, e.g., travel history (AS1). Thus, having access to their history may be crucial: "I know what has happened in the past, what medications to change, and what the diagnosis can be. So, I believe that with the help of past medical history, past letters, or past medications of that person, it will be easier [to deliver emergency care]." (EUR1).

The second contribution of DPs to the emergency care of patients with COVID-19 is convenience; namely: (i) access information anytime (SAM1; EUR2) and anywhere at the hospital through artifacts such as wristbands containing QR codes (AUS1; EUR2); (ii) ask opinions from other experts (SAS2); (iii) facilitated diagnose and treatment plan (AS1); (iv) no need to "read confusing handwriting or pull charts" (NAM2).

Likewise, some **interviewees with no experience in using DPs** (NAM1; SAM2; IN1; IN2; IN3; AS2) recognize the benefits of adopting such technology to treat and/or diagnose COVID-19 in EDs. They consider that DPs facilitate recording data about the patients to learn from current practices to provide better care in the future (IN2; IN3). "COVID-19 is still new and not really understood, and colleagues' experiences would be beneficial to update the knowledge [about the disease]" (SAS1). They also highlighted that when a country has multiple languages, physicians can access data that patients could have difficulties explaining (e.g., having diabetes) (IN3).

Some other interviewees without experience in using DPs do not think that they are beneficial, as "most people who have COVID-19 do not even feel sick […]. If they are sick enough to be in the hospital, then you are not really concerned about what their previous medical record is." (NAM1). DPs may facilitate access to medical data (SAM2) and even diagnosing COVID-19, but there is no integration into the treatment in some developing countries (IN1).

Three **barriers to implement DPs** at hospitals were emphasized during the interviews: (i) DPs may be hard to use (AS1), taking time and effort to learn how to use them safely and adequately (AUS2; IN1); (ii) the lack of unified national platforms to integrate data in some countries (NAM1; IN1; IN2; AUS2), leading to concerns with privacy violations (IN1; AS2); and (iii) restrictions to integrate different systems (NAM1; EUR1; AUS2) and register information (EUR1; AUS1).

- <u>Technology 3: Digital non-invasive care</u>

Physicians with experience in using digital non-invasive care (DNIC) assessed such technology as useful to diagnose and treat patients with COVID-19 in EDs (NAM2; SAM1; AS1; AS2). DNIC's main contribution is to improve the safety of healthcare staff and patients: "It is very useful because we can know the patients' condition 24 hours and rapidly respond when something goes wrong, and we can minimize contact between patients [to have] a lower infection rate in the hospital." (AS1). Also, DNIC facilitates the decision whether patients will be hospitalized or not, "especially children [that] usually get treated at home so that we can monitor them." (NAM2).

The majority of **interviewees have not used DNIC** (NAM1; SAM2; SAM3; EUR1; EUR2; SAS1; SAS2; IN1; IN2; IN3; AUS1; AUS2), but they also indicated that it would help to monitor patients' vital signs with minimum human contact (NAM1; SAM2; SAM3; SAS1; IN1;

IN2; IN3), particularly when physicians need to follow up a patient daily (IN3) or remotely (NAM1; EUR2). "I think body sensors will make a lot of sense, especially for COVID-19, considering non-invasive SPO2 and respiratory rate." (IN1). On the other hand, some interviewees do not think DNIC offers any unique benefits to these patients (AUS1; AUS2). "Such sensors would be helpful in improving the ability to assess a patient remotely; however, I do not think this would be unique to COVID-19 patients, but rather all ED patients." (AUS2).

Some **barriers to implementing DNIC** were mentioned during the interviews: (i) patient engagement with DNIC due to continuous wearing of uncomfortable sensors (AS1; IN1); (ii) high cost to implement such technology (IN1); and (iii) reliability, as "it has to be proven in large groups, and trials must be done, so that it could be relied on even on emergency (IN2).

- Technology 4: Interconnected medical emergency support

Physicians who have used interconnected medical emergency support (IMES) assessed such technology as useful to diagnose and treat patients with COVID-19 in ERs (SAM1; IN1; AUS2; AS2). The main reason for this assessment is that there are information control centers in certain countries and regions (e.g., SAM1; IN1; AUS2). Ambulance services, availability of hospital beds and physicians, estimated times of arrival, and severity categories are all being constantly and remotely assessed by those control centers. However, this assessment does not necessarily happen in real-time, which can be risky:

> *In the case of an urgent patient or when the emergency room is overcrowded,* [sometimes] *the patient's information is not transmitted properly. There are cases in which it is lost or transferred incorrectly. In addition, even if you receive medical guidance, there may be cases where*

> *the best treatment required in time is not achieved because it is only made with information on the wire. Therefore,* [it is important] *not only relying on wired calls but utilizing wireless networks in real-time and exchanging patient information using visual information* […]. *Even in the case of COVID-19 patients, this information-sharing system will be of great help to patients in situations where vital signs are unstable and rapid decision-making is required.* (AS2)

Some **interviewees who have not yet used IMES** (NAM1; NAM2; SAM2; SAM3; EUR1; EUR2; IN2; IN3; SAS1; SAS2; AS1; AUS1) assessed it as relevant to diagnose and treat patients with COVID-19 in ERs, for two main reasons. First, hospitals can prepare to quickly assist a patient with a condition that needs immediate intervention and "make use of the golden hour of emergency state and treat it as soon as possible" (SAS1). Ideally, the hospital would have a system that can "automatically transfer the patient's vital signs to a computer" (EUR1), preserving patient confidentiality (EUR2). However, there are many more fundamental difficulties in practice, such as "information forgotten in the ambulance" (NAM2). Second, IMES would allow having people more focused on core medical activities and less in simpler tasks, such as transferring patients (IN2; SAS2). However, there is a concern with the front-end personnel's qualification (e.g., ambulance drivers) to be involved in more complex tasks (EUR1).

Other interviewees who have not yet used IMES are skeptical about the contributions of such technology to treat COVID-19 in ERs:

> *It is like you are giving the information, and the patients are there 10 minutes later, so you could call me over the radio* […]. *I think that it is quicker to do it that way than to have them put in all the vital signs*. […]

> *But long term, or knowing like, having access to their previous medical records, I think it is like the biggest thing, that is the most revolutionary thing that electronic medical records have done*. [...] *So, it has changed things a bit, but I do not think it does a lot for COVID-19 emergency or acute settings*. (NAM1)

Some **barriers to implementing IMES** were mentioned: (i) the quality of the information is questionable, as the staff often does not have the qualification to deal with information (SAM1); and (ii) there is a high cost to implement IMES and train people to use it (IN1; IN3), and organizations would probably have to prioritize other investments to treat COVID-19, making the implementation of IMES less urgent due to the lack of financial resources (IN2).

5. Discussion

Results from the survey and interviews indicated the applicability of selected ICTs in providing care to COVID-19 patients, even though some of the interviewees noted drawbacks. Four ICTs stood out: remote consultations, digital non-invasive care, digital platforms for data sharing, and interconnected medical decision support. In this section, a discussion is made on whether the selected ICTs are conceptually consistent with the complexity of this unprecedented scenario.

As for remote consultations and telemedicine in general, they provide a buffer of space, physically separating caregivers from patients. That implies complexity reduction as physical proximity is a catalyzer of unintended interactions (Perrow, 1984). Indeed, several interactions are eliminated through remote consultations, such as those related to donning and doffing PPE (Grelot et al., 2016), triage, assessment, screening, and patient evaluation (Hamm et al., 2020). In fact, the use of buffers is a usual approach for coping with complexity (Perrow, 1984), making processes loosely coupled and dampening the propagation of undesired variability (i.e., the virus, in this case). Buffering has been a key for coping with the COVID-19 pandemic in healthcare services in general due to the surge in demand for human and material resources (Saurin, 2021).

Digital non-invasive care represents a similar complexity-coping-mechanism, as it also works as a buffer between patients and caregivers. Furthermore, digital non-invasive care reduces the frequency of physical interactions between patients and caregivers (e.g., for monitoring vital signs), thus also contributing to complexity reduction. Despite these strengths, this technology's complexity reduction potential seems to be lower compared to remote consultations. Indeed, the size of the space buffer created by digital non-invasive care is smaller than that of remote consultations. In the former, both patients and caregivers are located in the same hospital facility. Similarly, the number and variety of interactions eliminated by digital non-invasive care is certainly not as large as that made possible by remote consultations.

Digital non-invasive care also fits the highly dynamic nature of complex systems, which are continuously evolving (Perrow, 1984). In this case, the patient can be seen as a complex system whose health condition is constantly changing. The monitoring of this evolution in complex systems is important for the anticipation of tipping points, which is a complexity attribute that refers to specific performance levels that, once achieved, imply abrupt changes of system properties (Dekker, 2011). For example, precise measurements of vital signs provided by ICTs allow for the quick detection of tipping points (e.g., too high or too low respiration rate) that put the patient in imminent danger. Furthermore, digital non-invasive care plays a role in reducing perceived complexity as it gives visibility to otherwise invisible attributes of a patient's health (e.g., heart rate).

As for digital platforms for collaborative sharing of patient data and information, they increase desired interactions between people, which is a beneficial dimension of complexity. As such, digital platforms for collaborative sharing allow for the exploitation of the diverse perspectives that exist in complex systems. No single actor has complete knowledge of complex systems, and different people hold partly overlapping and partly complementary viewpoints (Page, 2010). Such fragmentation tends to be compounded by the novelty of COVID-19, which has been investigated from several medical perspectives, both in the laboratory and at the front line of care. Furthermore, the large number of patients treated during a short time frame implies massive production of data, which benefits from computerized processing and sharing. Therefore, more than in normal times, digital collaborative sharing of information tends to be a strong asset during the pandemic. It may also play a role in accelerating the learning curve of healthcare professionals regarding their understanding of the disease and deployment of treatments. This backdrop, involving learning benefits and sense-making of large amounts of data, suggests that digital platforms for collaborative sharing of data reduce the perceived complexity.

Regarding interconnected medical emergency support systems, they facilitate the anticipation of short-term demand, which is a critical ability for complex systems' resilience (Hollnagel, 2017). Such anticipation reduces, to some extent, the unpredictability of those systems, in addition to creating a buffer of time for the setup of resources for care. In this case, the buffers are created as a result of interactions between teams physically separate. Therefore, the amplification of one complexity attribute (i.e., interactions) allows for reducing another complexity attribute (i.e., tightly coupled processes). Such trade-off between complexity attributes contributes to the effective use of scarce human and material resources, which has been a significant concern during the pandemic (Bielicki et al., 2020).

Finally, it is worth exploring the relationship between the selected ICTs and the complexity attribute known as unintended consequences of changes. In fact, the use of ICTs in general, and not only in healthcare settings, is known for its unintended consequences (Dekker, 2011). That occurs since ICTs' implementation triggers interactions with other technical and human elements of the healthcare system. While the survey respondents emphasized desirable unintended consequences (e.g., production of COVID-19 epidemiological data from digital non-invasive care ICTs), the interviewees provided a more holistic view by mentioning undesired and unintended consequences as well (e.g., higher costs and patients discomfort due to body sensors). To some extent, their concern with undesired, unintended consequences can be due to contextual conditions. Examples are lack of familiarity with the technologies, past dissatisfactory experiences, and the perception that patient care at the front-line often implies quick decision-making and professional expertise, which do not significantly benefit from automation. That is also a reminder that context matters, and there are no universally effective solutions in complex systems (Wilson, 2014).

Overall, the discussion above suggests that the four selected ICTs have played a mixed role in the complexity of healthcare systems during the COVID-19 pandemic, as follows:

i) The introduction of buffers, real-time monitoring of patients, and anticipation of demand contribute to the reduction of complexity by making processes more loosely coupled, understandable, and predictable;

ii) Support for collaborative work is expected to increase the frequency and richness of interactions between caregivers, which is a form of increasing desirable complexity; and

iii) The introduction of the ICTs adds complexity to healthcare services *per se*, as it implies the inclusion of new elements and consequently new, and possibly more,

> (unintended) interactions. However, the complexity brought by the ICTs remains hidden from their end-users, which are likely to perceive the system functioning as less complex. This point may be illustrated using an analogy that compares manual and automatic transmission in cars. Although the latter is significantly more complex as it involves more components and more interactions, automatic transmission looks simpler from the driver's viewpoint (Ramasesh and Browning, 2014).

In summary, the selected ICTs seem to be an effective means of balancing complexity attributes amid the COVID-19 pandemic. This finding resembles the conclusion of Soliman et al. (2018) in their analysis of the influence of lean production on the complexity of socio-technical systems. I.e., lean was found to amplify some complexity attributes (e.g., social interactions) while reducing others (e.g., waste in terms of unnecessary process steps). As such, it is possible that innovative ICTs and lean principles can work in synergy in healthcare services, similar to what was proposed by Tortorella et al. (2021) regarding that synergy in manufacturing industries.

6. Conclusion

The use of ICTs for coping with COVID-19 exemplifies the need for complex responses for coping with complex problems. According to the law of requisite variety (Ashby, 1958), a system can only be stable if the number of states of its control mechanisms is equal or greater than the number of possible states. There should be a minimum variety (or diversity) of elements, skills, materials, and tools to match the variety from the external environment (e.g., demand volatility, resources availability) (Ashby, 1958). In this respect, it is worth reinforcing a conceptual strength of ICTs: they add complexity to the healthcare system (thus being a complex response to the pandemic) while mostly not looking complex from the end users' (e.g., caregivers and patients) perspectives. That is particularly important in the COVID-19 context since healthcare professionals have been submitted to highly stressful working conditions and excessive workload. Therefore, ICTs contributing to reducing mental workload and freeing up professionals from at least some data gathering and analysis activities are highly desirable.

Despite our focus on COVID-19, our findings are likely applicable in mitigating other infectious diseases and managing crises with an acute and short-term nature. However, the high volume of patients treated in a short timeframe and the massive human and economic implications of the pandemic make COVID-19 a particularly relevant case study for ICTs in healthcare. In general, it seems that the studied ICTs fit the complexity of emergency care services in the COVID-19 context.

This study presents some limitations. First, both studies – survey and in-depth interviews were based on convenience samples. Nevertheless, the follow-up interviews allowed us to explore *how* the contributions listed by the survey respondents assist in diagnosing and treating patients with COVID-19 during the pandemics. We acknowledge the exploratory nature of our study and, as such, attempted to minimize biases by using a combination of data sources. Second, we focused on the impacts of ICTs in the operation of emergency care services during the COVID-19 crisis. Although carefully selecting interviewees such that their backgrounds could provide a holistic perception of emergency care services, we acknowledge that the impact level of H4.0 digital technologies is likely to vary among hospital departments. That calls for an extension of our investigation to include other healthcare services severely affected by the pandemic, such as Intensive Care Units (Xie et al., 2020). Second, the adoption of new technologies brings changes in work processes. As previously mentioned, in complex systems such as emergency departments, changes may yield unintended consequences, desired and undesired (Dekker, 2011), which need to be further evaluated in future studies. Third, new technology adoption in medical practice may face doctors' resistance, as reported in previous research (e.g., Singh et al., 2009; Wallace, 2015; Pan et al., 2019). Further investigation on ways to mitigate the resistance, particularly in the light of complex system management, is a promising research direction. Fourth, the population we focused on in the survey is composed solely of experts who are also academics that work in healthcare technologies and resilience in healthcare services; thus, considerably limiting the availability of reliable respondents. Finally, at the moment of writing this paper, the pandemic was still raging in communities around the globe. Therefore, results on the applicability of the ICTs and physicians' perceptions should be framed as exploratory, setting a benchmark for future retrospective investigations that may offer revised and more complete perspectives.

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Appendix A – Survey

Cover Page:

- Name
- E-mail
- Country of residence
- Would you like to receive an executive summary of the collected data?

  (_) Yes (_) No
- Level of knowledge regarding healthcare digital applications

  (_) None (_) Basic (_) Moderate (_) Advanced
- How many years of experience do you have working with healthcare?

  (_) 1 - 5 years (_) 6 - 10 years (_) 11 - 15 years (_) 16 - 20 years (_) > 20 years

Ten pages followed, each related to a group of ICTs. First, a brief explanation of the group of ICTs was provided. Second, two questions were presented: (i) Is "[Group of ICTs]" useful for treating patients with COVID-19?" and (ii) If yes, "Explain why." The same two questions were repeated in each of the ten pages. Descriptions presented to describe the groups of ICTs:

- Augmented reality as clinical decision support (virtual-reality reconstructions laid on top of a patient's images, in real-time);
- Remote consultations and development of plan of care in real-time (Remote doctor-patient interaction using artificial intelligence to support decision-making in real-time);
- Remotely assisted surgical and clinical procedures (Advanced telecommuting that makes the expertise of specialized physicians available to patients without the need for traveling beyond their local hospital);

- Remote nutrition and infusion management (remote delivery and monitoring of nutrition and infusion, using server connected pumps);
- Digital non-invasive care (non-invasive digital technology used for home or onsite patient care, supported by wireless network of body sensors);
- Interconnected medical emergency support (shared information systems between pre-emergency support, ambulances, and onsite services);
- Medical devices' traceability system (mark and identify medical devices, e.g., equipment and surgical instruments, within the healthcare supply chain);
- Digital platforms for collaborative sharing of patient data and information (secure storage and retrieval of patient data shared by organizations, physicians, and patients, including a medical encyclopedia with real-time user collaboration);
- Synthetic medical information generation through cloud computing (cloud-based simulators that combine information from health records of existing patients to create realistic virtual patients);
- Computer-assisted design of customized and modular medical devices (devices intended for the sole use of a particular patient, e.g., prosthetics).

Appendix B – Contributions of the bottom six ICTs to diagnose and treat patients with COVID-19

ICTs	Contributions	Freq.	%
Synthetic medical information generation through cloud computing (N=42)	Knowledge sharing through access to patient data	21	50.00
	Anticipating situations and scenarios through simulation	10	23.81
	Help in the decision-making process	4	9.52
	Promote social distancing and reduce risk of infection	3	7.14
	Allows training	2	4.76
Remote nutrition and infusion management (N=39)	Promote social distancing and reduce risk of infection	19	48.72
	Remote management	13	33.33
	Reduce the risk of infection of healthcare workers	11	28.21
	Remote monitoring	8	20.51
	Useful for intubate patients (severe cases of COVID-19)	4	10.26
Remotely assisted surgical and clinical procedures (N=41)	Promote social distancing and reduce risk of infection	19	46.34
	Supporting other professionals with knowledge support	12	29.27
	Reduce the risk of infection of healthcare workers	8	19.51
	Promote diagnosis and treatment remotely	6	14.63
	Perform consults before procedures and follow-up after it	2	4.88
	Reallocation of personnel from other medical fields	2	4.88
Augmented reality as clinical decision support (n=45)	Source of information (e.g., Symptoms, data, developments) - monitoring	16	35.56
	Help the decision-making process and diagnosis - response	10	22.22
	Help with predictions/forecasting (threats, opportunities) - anticipating	9	20.00
	Learning and training	6	13.33
	Reading imaging exams	5	11.11
	Patient interaction (with the patient and between patients)	5	11.11
	Check condition changes	5	11.11
	Remote care	5	11.11
	Avoid contagion	3	6.67
	Overlaying information, improving visualization	2	4.44

Appendix B – Contributions of the bottom six ICTs to diagnose and treat patients with COVID-19 (*Cont.*)

Medical devices' traceability system (N=31)	Track devices and contact tracing	9	29.03
	Monitor device availability	6	19.35
	Monitor and treat patients	6	19.35
	Forecast materials and devices demand	5	16.13
	Know which equipment is infected	4	12.90
	Monitor how the devices are used	4	12.90
	Better allocation of devices	4	12.90
	Security for its users	4	12.90
	Promote social distancing and reduce risk of infection while controlling the pandemic	3	9.68
Computer-assisted design of customized and modular medical devices (N=19)	Development and testing of equipment (medical devices and gear for healthcare workers' protection)	6	31.58
	Improve care delivery	4	21.05
	Homecare	4	21.05
	Promote social distancing and reduce risk of infection	3	15.79
	Supplement supply chains	2	10.53
	Monitor patients' health	2	10.53