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DIGITAL TOOLS FOR THE RESILIENCE OF THE HEALTHCARE SECTOR DURING THE COVID-19 PANDEMIC: OVERVIEW

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ABSTRACT
In times of crisis, organizations need to quickly adapt to unexpected disruptions and prevent the halt of their ongoing workflows. The COVID-19 pandemic had wracked havoc across economies worldwide, and the associated toll of lost lives, together with the incommensurable financial losses on the global markets will always be remembered as the defining grim consequences of this crisis that humanity faced. As a side effect, the pressure that it exerted over businesses worldwide has given rise to new ways on how digital tools and can be leveraged to combat intrinsic pandemic effects, such as limited mobility of people and goods, or various types of supply chain inconsistencies. As a result, in the context of medicine, the COVID-19 pandemic has accelerated the transition to the concept of "digital health" in health care systems worldwide. In this work we provide an overview of various digital tools and solutions reported in the frame of public and private health care sectors, which have been successfully used during the COVID-19 pandemic as solutions for the resilience of healthcare sectors worldwide.

Keywords*: digital health; business resilience; COVID-19; digital tools; healthcare sector*

1. INTRODUCTION

The first COVID-19 case was reported in December 2019 in the city of Wuhan, China, and in the years after, the highly aggressive and transmissive SARS-COV-2 virus had spread in all corners of the world, resulting in nearly 700 million reported cases, and nearly 7 million deaths, by the time of writing this article. The typical hallmarks of COVID-19 are flu- or pneumonia-like symptoms such as fever, cough or difficulty breathing. In most severe cases the cytokine storm effect severely impairs breathing. Inflammation and malfunction of the pulmonary alveoli leads to depriving blood and organs of oxygen, finally leading to the latter stopping their function. However, growing number of data suggest that this coronavirus directly attacks organs, resulting in important consequences such as hear inflammations, degradation of kidney tissues, brain disfunctions, or liver and gastrointestinal problems[1-6]. Noteworthy, a very large segment of individuals infected with coronavirus were asymptomatic. However, even for them, many risks are still present, given important evidence reported to date showing that potential damage to their organs may silently develop in the future without them being aware of it (same as in patients infected with the hepatitis viruses develop fibrosis, finally leading to liver failure).

Given the wide palette of health hazards linked to the SARS-COV-2 virus, from acute to chronic ones, governments and global authorities worldwide, such as the World Health Organization, have implemented diverse measures to protect the population, such as lockdowns, quarantine for infected patients, or for people at risk, travel restrictions, closed borders, etc. While all these measures have definitely alleviated the spread rate of the virus, at the same time they were inevitably associated with dire consequences on the economies worldwide, which were wildly disturbed. Thus, the COVID-19 pandemic, the most important one since the Influenza pandemic in 1918, will always be remembered not only because of the toll of lost lives, but also for the incommensurable financial losses it has caused on the global markets, and by the many ways in which it has disrupted various businesses. As a side effect, the pressure that it exerted over businesses worldwide has given rise to new ways on how digital tools can be leveraged to combat intrinsic pandemic effects, such as limited mobility of people and goods, or various types of supply chain inconsistencies. As a result, in the context of medicine, the COVID-19 pandemic has accelerated the transition to the concept of "digital health" in health care systems worldwide.

In this work we provide an overview of various digital tools and solutions reported in the frame of public and private health care sectors, which have been successfully used during the COVID-19 pandemic to ensure the resilience of health care sectors worldwide.

2. Overview of Digital Health tools and trends implemented during the COVID 19 pandemic

The concept of "Digital Health" was first introduced in the year 2000 by Seth Frank[7], who envisioned internet-based applications and media to improve medical content, commerce, and connectivity. In the years elapsed since then, making up nearly quarter of a century, the realm of digital health has grown to encompass a much broader palette of concepts and technologies, including genomics, artificial intelligence, analytics, wearables, mobile applications, and telemedicine[8]. In 2018, the World Health Organization issued a detailed taxonomy of Digital Health, nominating a wide range of domains now linked to this concept, which is becoming a key priority for many countries, due to the many associated advantages. In the next we provide an overview of some of the most important Digital Health tools and trends that were successfully implemented during the COVID-19 pandemic as solutions for the resilience of world-wide health care sectors.

2.1 Telemedicine for diagnostics

Public and private healthcare providers faced severe challenges in implementing their routine protocols for diagnostics, especially due to the high-risk of SARS-CoV2 infection spread among patients visiting the healthcare provider at the same time, or between patients and medical practitioners. Furthermore, quarantine policies implemented throughout the world kept patients from performing hospital visits at times when these were required. To mitigate this, hospitals, and medical practices in general, had to replace a large proportion of their physical protocols for diagnostics with digital technologies. Maybe the most widely adopted solution to this end had consisted in the replacement of physical meetings between the patient and the medical practitioner by online meetings. To this end, in the United States for example, the US Department of Health and Human Services (DHHS) and pharmacy boards have approved the use of videoconferencing applications that were already enlisted in the Health Insurance Portability and Accountability Act (HIPAA), such as Skype for Business, Microsoft Teams, VSee or Updox. Other non-HIPAA compliance tools such as FaceTime, Zoom, Cisco Webex, and Skype had also been temporarily approved to be used in telemedicine[9, 10]. Besides such video-conferencing applications meant for general use, many healthcare provides throughout the world, such as the AmWell and Teladoc virtual medical-care companies in the US, have enabled communication workflows between patients and physicians through secure video chats, supported by own applications[10, 11]. China, Australia, as well as all countries in Europe have adopted similar policies enabling permissions for supplying medical consultation remotely[11]. Importantly, such telemedicine workflows have also been approved in the context of telepharmacy. For example, in the US the Ryan Haight Online Pharmacy Consumer Protection Act of 2008, which required in-person assessment before issuing a prescription, had been temporarily suspended during the COVID-19 pandemic, allowing prescription of medication via telemedicine means[10].

2.2 Remote biomedical data collection for diagnostics

In the case of many pathologies, acquiring biomedical data from the patient in order to establish a diagnostic, and to identify the optimal therapeutic strategies is instrumental. However, during the first COVID-19 waves, such task become very difficult to implement due to many factors such as lack of medical staff at the healthcare provider, due to staff relocation or medical leave, or due to strict disease prevention policies. This has led to a dramatic fall in diagnostic procedures based on biomedical data collection. For example, for obstructive sleep apnoea (OSA), a high incidence disease characterised by the collapse of the upper airways during sleep, leading to breathing and sleeping disorders, and various subsequent medical problems, the number of diagnostic tests during the first COVID-19 wave, was reduced with 80%.[12] To alleviate this, physicians at the Regional Sleep Service of the Wythenshawe Hospital in UK have adopted during the first COVID-19 wave a fully remote diagnostic and treatment approach for patients referred with suspected OSA[13]. After a first consultation by telephone the patients with moderate-to-severe OSA were sent by courier an AirSense™ 10 AutoSet (ResMed UK) continuous positive airway pressure (CPAP) device accompanied by written instructions and an online video explaining the setup process. The effective pressures and residual apnoea-hypopnoea index (AHI) were monitored with the Airview software (ResMed UK)[13].

The transition of diagnostic assays for cardiovascular diseases (CVD) to the realm of digital health, has also been considerably accelerated by the COVID-19 pandemic, which has important significance considering that CVD claims over 18 million lives every year[14]. Various facets of the efforts undertaken in this direction are discussed in the thorough review works of Battineni et al.[15] and Kennel et. al [16]. Furthermore, the importance of smart and wearable sensors for remote cardiovascular screening in the post COVID-19 era is discussed in the review work of Bayoumi et al. [17]. A relevant example on the use of remote monitoring of cardiovascular signals is the clinical trial presented by Liu et al. [18]. In this trial the dose-related cardiotoxicity of hydroxychloroquine, a tentative COVID-19 drug that has been postulated to elevate the pH of acidic intracellular organelles inhibiting membrane fusion and viral entry[19], was remotely assessed. The QTc, representing the heart-rate corrected QT interval on the electrocardiogram, a measure of the efficiency of repolarization of the left ventricle, has been evaluated in absence of any physical interaction between physicians and the subjects of the study. This was achieved by using a 6-lead EKG with a smartphone application, KardiaMobile® 6L (AliveCor, Mountain View, CA). Besides this software application, a 6-lead hardware monitoring pad was shipped to all participants in the study, to be attached to their smartphones. Using this kit, the enrolees of this FDA approved trial recorded their EKGs in their own homes, remotely sending the data to the coordinator of the study.

Each year new technologies are reported. Traditionally, the transition of newly reported tools, services or concepts to the realm of medicine is slow, given the sensitive nature of this field, and the many regulations and bodies that govern it. The COVID-19 pandemic has show us however, that, while caution is obvious mandatory, the benefits that derive from exploiting new technologies are significant and can outweigh the risks. In this context, we find important to mention the work of Sicari et al.[20] who introduced in their work a set of rules and processes based on the Internet of Things (IoT) paradigm, which enable the integration of different devices, in order to remotely monitor the live statistics of home-based patient. Apart from live readings, their framework envisions the triggering of alerts when patient readings take values outside the safe intervals. The authors argue that such a system can help in lowering the heavy dependence on medical infrastructures and could deliver more efficiency in management of patients.

2.3 Transition to Artificial Intelligence-powered disease monitoring and diagnostics

Important progress reported in the realm of Artificial Intelligence over the past 10 years has taken the world by storm, with many fields benefiting from this family of technologies, including medicine[21, 22]. Although the transfer of AI tools to the clinical field, is not easy, due to the extensive permissions required, the COVID-19 pandemic highlighted the need for AI-based methods to complement or entirely replace traditional disease monitoring and diagnostic assays, facilitating efforts in this direction. To highlight this, we refer to the realm of CVD, already discussed under the previous point. The left ventricular ejection fraction (LVEF) represents the fraction of chamber volume ejected in systole (stroke volume) in relation to the volume of the blood in the ventricle at the end of diastole (end-diastolic volume). A LVEF of 50% to 70% is categorized as normal; lower values indicate the need for medical investigation, intervention or medication. Noteworthy, the US FDA issued an Emergency Use Authorization for the detection of low LVEF as a potential complication of COVID-19 using an Artificial Intelligence based electrocardiogram algorithm integrated in the digital Eko stethoscope (Eko Devices).[23, 24].

AI-based approaches motivated by the COVID-19 pandemic have also been proposed for addressing this exact disease. For example, in a clinical trial outlined in a protocol reported by Wong et al. [25], subjects with close COVID-19 contact under mandatory quarantine at designated facilities in Hong Kong were subjected to a remote monitoring strategy based on wearable biosensors that continuously monitored skin temperature, respiratory rate, blood pressure, pulse rate, blood oxygen saturation and daily activities, which were transferred in real time to a smartphone application called Biovitals Sentinel. The collected data was processed using a cloud-based multivariate physiology analytics engine named Biovitals to detect subtle physiological changes, in the purpose of COVID-19 diagnosis.

2.4 At the cross-roads between digital tools and nanotechnology

Besides accelerating the translation of digital concepts and tools to the realm of medicine, the COVID-19 pandemic had also played a key role in pushing nanotechnologies at the forefront of clinical practice. The key example in this regard stands obviously in the emergency use authorization provided by the US-FDA and other competent policy making bodies throughout the world for two mRNA-based vaccines: BNT162b2 (Pfizer-BioNTech) and mRNA-1273 (Moderna). These two vaccines are intensively based on nanotechnology, as carefully designed lipid nanoparticles, acting as nanocarriers, protect the encapsulated mRNA from ribonucleases and facilitate the delivery of intact mRNA to the target site, aiding in better cellular penetration.[26].

The COVID-19 pandemic also stimulated the advent of novel tools exploiting in tandem digital health concepts and nanotechnology. For example, Huang et. al[27] have reported a method mixing artificial intelligence and surface-enhanced Raman spectroscopy (SERS) enabling sensitive, rapid, and on-site detection of the SARS-CoV-2 antigen in the throat swabs. The SERS substrate consisted of gold nanoparticle (AuNP) arrays. Another relevant example mixing digital tools and nanotechnology is the recent work of Kang et al[28], who reported an artificial intelligence framework for the quantitative detection of zoonotic viruses, including SARS-COV-2 on brightfield microscopy images of virion contaminated Gires-Turnois Immunoassay Platforms, that were based on nanostructured thin films, reported earlier by the same group as valuable tools for colorimetric SARS-COV-2 detection[29].

2.5 Digital certificates for disease-spread control

The COVID-19 pandemic introduced a new concept, consisting of cross-border verifiable digital vaccination certificates. While vaccination certificates have been introduced in many parts of the world, we find important to highlight the policies of the European Union, which, in an effort to stop the spread of the disease, has allowed Member States to restrict free movement within the Union, by requiring from citizens wanting to cross borders a certificate documenting either a negative test result, a prior infection, or proof of vaccination. While the efficiency of these policies, and their ethical implications are still under debate[30], it is noteworthy to mention that this unprecedented digital tool does hold potential to contain the spread of contagious disease, and may find in the future applications in other scenarios. Further refining this concept, and its use practices, will hopefully help overcome the shortcomings and concerns associated to the first generation of digital vaccination certificates[31].

2.6 Digital tools for assessing the social opinion on novel medicines, medical tools or public health policies

The vaccination campaigns implemented during the COVID-19 pandemic were received with some scepticism by some population segments. There were many reasons to this, such as insufficient trust on vaccines based on new technologies, insufficient information on associated risk and hazards, or exposure to social media advocating against vaccination. From the social sciences perspectives it is very important to achieve a good understanding on why different population segments looked at the vaccination campaigns from different angles, some with enthusiasm, and others with reluctance or even fear. AI-based tools have been demonstrated as very helpful means to contribute to this, in light of their capacity to process vast amounts of data. For example, in the work of Nyawa et al. [32], different Deep Learning models were evaluated in terms of their ability to identify Twitter posts linked to vaccination hesitancy. Alam et al.[33] focused on a related problem, namely, on assessing the sentiments of people regarding various vaccines using a natural language processing tool, which enable the classification of Twitter posts in three vaccine perception groups (positive, negative, and neutral). Related problems were tackled by Aygun et al[34]. Such efforts pave the way for future use of artificial intelligence methods to assist in the evaluation and quantification of the population's perception of novel drugs, medical tools, medical practices, or policies.

3. CONCLUSIONS

The COVID-19 pandemic resulted in a concerted effort of many fields of sciences and technology, aimed at combating its effects. Developments in the area of digital health were instrumental in ensuring the resilience of the healthcare sector, which was put under tremendous pressure in the course of the past years. In this work we provide an overview of several important ways by which digital health tools and approaches helped in combating the wide palette of negative effects linked to the pandemic. Among others, we provide and discuss examples linked to telemedicine, remote biomedical data collection, AI-based automated diagnostics or AI-based assessment of population attitudes.

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