How the COVID-19 pandemic is favoring the adoption of digital technologies in healthcare: a rapid literature review

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Keywords: COVID-19; SARS-CoV-2; pandemic; digital; review.

Word count (excluding title page, abstract, references and tables): 3928
Abstract.

Background. Healthcare is responding to the COVID-19 pandemic through the fast adoption of digital solutions and advanced technology tools. Many of the solutions implemented now could consolidate in the near future, contributing to the definition of new digital-based models of care. The aim of this study is to describe which digital solutions have been reported in the early scientific literature to respond and fight the COVID-19 pandemic.

Methods. We conducted a rapid literature review searching PubMed and MedrXiv with terms considered adequate to find relevant literature on the use of digital technologies in response to COVID-19.

Results. The search identified 52 articles, of which 38 full-text articles were assessed and 29 included in the review after screening. Of selected articles, most of them addressed the use of digital technologies for diagnosis, surveillance and prevention. We report that digital solutions and innovative technologies have mainly been proposed for the diagnosis of COVID-19. In particular, within the reviewed articles we identified numerous suggestions on the use of artificial intelligence-powered tools for the diagnosis and screening of COVID-19. Digital technologies are useful also for prevention and surveillance measures, for example through contact-tracing apps or monitoring of internet searches and social media usage.

Discussion. It is worth taking advantage of the push given by the crisis, and mandatory to keep track of the digital solutions proposed today to implement tomorrow's best practices and models of care, and to be ready for any new moments of emergency.
1. BACKGROUND

On January 9, 2020, the World Health Organization (WHO) stated that Chinese health authorities have identified a new strain of Coronavirus that has never been identified in humans before, subsequently classified under the name of Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2). The virus causes a respiratory disease called Coronavirus Disease 2019 (COVID-19). On 11 March 2020, the WHO itself formalized the COVID-19 as a pandemic.

The COVID-19 pandemic, like all “serious disruptions” in human history, is causing an unprecedented health and economic crisis. At the same time though, this new situation is favoring the digital transition in many industries and in the society as a whole. This is the case, for example, of education [1]. The entire sector, from primary schools to Universities, has developed new strategies for teaching remotely, shifting from lectures in classrooms to live conferencing or online courses [2].

Similarly, now - and perhaps more prominently in the forthcoming months - healthcare is responding to the COVID-19 pandemic through the fast adoption of digital solutions and advanced technology tools. In times of pandemic, digital technology can mitigate or even solve many challenges, thus improving health care delivery. This is currently being done to address acute needs that are a direct or indirect consequence of the pandemic (e.g. apps for patient tracing, remote triage emergency services, etc.). Nevertheless, many of the solutions that are created and implemented at the moment of the current emergency could consolidate in the near future, contributing to the definition and adoption of new digital-based models of care.

Although with a certain degree of digital divide, the list of new digital solutions is rapidly growing. Beyond video-visits, these options include email, and mobile-phone applications and can expand to include uses of wearable devices, “chatbots”, artificial-intelligence (AI) powered diagnostic tools, voice-interface systems, or mobile sensors such as smartwatches, oxygen monitors, or thermometers. A new category of service is oversight of persons under investigation in home quarantine and/or large-scale population surveillance. Telemedicine and remote consultation have already proven to be effective at a time when access to health services for non-COVID-19 or non-acute patients is prevented, impeded or postponed. In fact, as Keesara et al. say [3], instead of a model “structured on the historically necessary model of in-person interactions between patients and their clinicians” through a face-to-face model of care, today healthcare services and patient assistance can be guaranteed remotely through digital technologies.

Before the COVID-19 pandemic, it was expected that digital transformation in health care would have been as disruptive as that seen in other industries. However, as stated by Hermann et al. [4], “despite new technologies being constantly introduced, this change had yet to materialize” [5]. It appears that now, the spread of SARS-CoV-2 has finally provided an ineludible sound reason to fully embrace the digital transformation. Moreover, simulations show that many countries will probably face several waves of contagions and new lockdowns will probably occur [6]. Therefore it becomes necessary to map which digital technologies have been used during the emergency period and possibly consider them for continued use over time or cyclically in the event of recurring outbreaks.

2. AIM OF THE STUDY

According to Hermann et al. [4] digital technologies can be categorized based on the healthcare needs they address: diagnosis, prevention, treatment, adherence, lifestyle, and patient engagement. We argue
that it is necessary to understand which digital technologies have been adopted to face the COVID-19 crisis, and whether and how they can still be of any use after the emergency phase. The aim of this study is therefore to describe which digital solutions have been reported in the early scientific literature to respond and fight the COVID-19 pandemic.

3. METHODS

We conducted a rapid review of the scientific literature to include quantitative and qualitative studies using diverse designs to describe which digital solutions have been reported to respond and fight the COVID-19 pandemic. The initial search was implemented on April 10th, 2020. The search query consisted of terms considered by the authors to review the literature on the use of digital technologies in response to COVID-19. Therefore, we searched PubMed/MEDLINE using the following search terms and database-appropriate syntax:

("COVID-19"[All Fields] OR "COVID-2019"[All Fields] OR "severe acute respiratory syndrome coronavirus 2"[Supplementary Concept] OR "severe acute respiratory syndrome coronavirus 2"[All Fields] OR "2019-nCoV"[All Fields] OR "SARS-CoV-2"[All Fields] OR "2019nCoV"[All Fields] OR (("Wuhan"[All Fields] AND ("coronavirus"[MeSH Terms] OR "coronavirus"[All Fields]))) AND (2019/12[PDAT] OR 2020[PDAT]))) AND (digital[Title/Abstract] OR technology[Title/Abstract])

We also manually searched MedRxiv/BiorXiv¹ (a preprint server for health science paper) section COVID-19/SARS-CoV-2 for digital technologies-related studies.

We placed a language restriction for English, without other limits. A two-stage screening process was used to assess the relevance of identified studies. For the first level of screening, only the title and abstract were reviewed to preclude waste of resources in procuring articles that did not meet the minimum inclusion criteria. Titles and abstracts of studies initially identified were checked by two independent investigators (D.G. and E.B.).

For the second level of screening, all citations deemed relevant after title and abstract screening were procured for subsequent review of the full-text article. A form was developed to extract study characteristics such as publication date, authors' nationality, title, aim of the study, technology/ies, main findings/results, actual and potential use of the technology.

In particular we categorized the retrieved papers according to the healthcare needs addressed (diagnosis, prevention, treatment, adherence, lifestyle, and patient engagement). The definition of each healthcare need is reported in Table 1. We added “surveillance” as an additional healthcare need to those identified by Hermann et al. [4], given the importance of early identification and confinement of COVID-19 patients to preserve population health. Two of us (D.G. and E.B.) independently classified all identified articles in the predefined categories. Any disagreements were resolved through discussion and consensus between the two reviewers. If disagreement persisted, another reviewer (G.C.) was called as a tie-breaker.

¹ https://www.medrxiv.org/
Table 1. Definition of the healthcare needs addressed by digital technologies.

| Use of technology | Definition |
|-------------------|------------|
| Diagnosis         | The process of determining which disease or condition explains a person's symptoms and signs. |
| Surveillance      | The continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice |
| Prevention        | Preventing the occurrence of a disease (e.g. by reducing risk factors) or by halting a disease and averting resulting complications after its onset. |
| Adherence         | The degree to which a patient correctly follows medical advice. |
| Treatment         | The use of an agent, procedure, or regimen, such as a drug, surgery, or exercise, in an attempt to cure or mitigate a disease |
| Lifestyle         | Adoption and sustaining behaviors that can improve health and quality of life |
| Patient engagement| To actively involve people in their health and health care |

4. RESULTS
The PubMed and MedrXiv search identified 52 articles, of which 38 full-text articles were assessed and 29 included in the review after screening. Of selected articles (Table 2 and Table 3), 41.4% addressed the use of digital technologies for diagnosis [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18], 37.9% for surveillance [15, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27], 34.5% for prevention [12, 15, 19, 20, 26, 28, 29, 30, 31, 32], 10.3% for treatment [28, 33, 34] and 6.9% and 3.5% for adherence [16, 28] and lifestyle [28]. No articles included in the review addressed the use of digital technologies specifically for patient engagement. In Table 3 (Supplementary materials) we resume the results of the literature review. Below we provide a summary of the existing digital solutions for the fight against COVID-19 reported in the scientific literature available to date. In order to do this, we discuss the retrieved articles for each of the healthcare needs/domains.

Table 2. Categories of healthcare needs addressed by digital technologies in the articles selected. N: absolute number of times healthcare needs are addressed.

| Healthcare need       | N  | %* |
|-----------------------|----|----|
| Diagnosis             | 12 | 41.4 |
| Surveillance          | 11 | 37.9 |
| Prevention            | 10 | 34.5 |
| Treatment             | 3  | 10.3 |
| Adherence             | 2  | 6.9 |
| Lifestyle             | 1  | 3.5 |
| Patient engagement    | 0  | 0  |

*the total is higher than 100% because some articles may include technologies used to address more than one healthcare need.
4.1 Diagnosis
We report that digital solutions and innovative technologies have mainly been proposed for the diagnosis of COVID-19. In particular, within the reviewed articles we identified numerous suggestions on the use of AI-powered tools for the diagnosis and screening of SARS-CoV-2 or COVID-19. Most studies propose the adoption of AI tools based on the use of CTs’ data [7, 8, 10, 11, 13, 14]. For example, Zhou et al. [7] developed and validated an integrated deep learning framework on chest CT images for auto-detection of novel coronavirus pneumonia (NCP), particularly focusing on differentiating NCP from influenza pneumonia (IP), ensuring prompt implementation of isolation. Their AI model potentially provides an accurate early diagnostic tool for NCP. Therefore, a diagnostic tool like this can be useful during the pandemic, especially when others such as nucleic acid test kits are short of supply, which is a common problem during outbreaks. Nonetheless, performing CT scans as a screening method presents significant limits, both considering the risk of radiation exposure, and operator or machine-type dependence [11].

Aside from these studies, many Authors propose COVID-19 AI-powered diagnostic tools not based on CT scans data [9, 12, 15, 18]. Feng et al. [9] developed and validated a diagnosis aid model without CT images for early identification of suspected COVID-19 pneumonia on admission in adult fever patients and made the validated model available via an online triage calculator that needs clinical and serological data (e.g. age, %monocytes, IL-6, etc.). Similarly, Martin et al. [12] proposed a chatbot and a symptom-to-disease digital health assistant that can differentiate more than 20,000 diseases with an accuracy of more than 90%. The authors tested the accuracy of the digital health assistant to identify COVID-19 using a set of diverse clinical cases combined with case reports of COVID-19, and reported that the digital health assistant can accurately distinguish COVID-19 in 96% of clinical cases. However, the article declares several limitations of the analysis, such as the low number of control clinical cases, and it is currently published as pre-print, therefore has yet to be peer reviewed.

A further innovative digital technology proposed to support the diagnosis of COVID-19 is the blockchain (or distributed ledger) technology. In one study [15] Authors recommend a low cost blockchain and AI-coupled self-testing and tracking systems for COVID-19 and other emerging infectious diseases in low middle income countries (LMIC). They developed and deployed a low cost blockchain and AI-coupled digital application (app) suggesting it as a potential tool against COVID-19. The app requests a user’s personal identifier before opening pre-testing instructions. Following testing, the user uploads results into the app and the blockchain and AI system enable the transfer of the test result to alert the outbreak surveillance. These types of solutions can also be of interest in high income countries.

4.2 Prevention and surveillance
Our literature review suggests that digital technologies can be useful for COVID-19 diagnosis as well as for implementing prevention and surveillance measures.

In Judson et al. [19], Authors deploy a Coronavirus Symptom Checker that is a digital patient-facing self-triage and self-scheduling tool in a large academic health system to address the COVID-19 pandemic. The purpose of this tool was to provide patients with 24-hour access to personalized recommendations and information regarding COVID-19, and to improve ambulatory surge capacity through self-triage, self-scheduling and avoidance of unnecessary in-person care. The majority of patients involved in the use of the app did not make any further contact with the health system during the subsequent days. Therefore, such tools may help in preventing unnecessary face-to-face appointments and access to healthcare facilities.
Another topic of paramount importance in the context of healthcare digitalization is epidemiological surveillance. Our review highlights that prevention and surveillance are often considered together in the scientific literature, given that "prevention of COVID-19" can be intended as "prevention of further spread", which is mainly done through surveillance. For COVID-19 pandemic, surveillance definitely overlaps with prevention, since by applying a successful surveillance plan and controlling the interactions between infected subjects and the healthy population the risk of infection can be reduced.

A study by Ferretti et al. [25] analyzes the key parameters of the COVID-19 epidemic spread to estimate the contribution of different transmission routes and determine requirements for successful case isolation and contact-tracing. The authors concluded that viral spread is too fast to be contained by manual contact tracing, but could be controlled if this process is faster, more efficient and happens at scale. The solution is the implementation of a contact-tracing app which creates a temporary record of proximity events between individuals, and immediately alerts recent close contacts of diagnosed cases and prompts them to self-isolate. An important limitation of this kind of tracing technology is that, in order to achieve its goal, it must be used by a significant portion of the population.

An example of successful use of a mobile application for contact tracing is the one that the Chinese Government has implemented in Wuhan, as described by Hua et al. [23]. A QR code-screening of people was implemented in the city of Wuhan and, later, in the whole Hubei province. This QR code was used to monitor people’s movement, especially on public transportation entering public areas. Using big data and mobile phones, three colors coding were attributed to each citizen: green (safe), yellow (need to be cautious), and red (cannot enter).

A similar tool was implemented in Taiwan [20]. In fact, through the Taiwan citizens’ household registration system and the foreigners’ entry card, it was possible to track individuals at high risk of COVID-19 infection because of their recent travel history in affected areas. If identified as high risk when in quarantine, the subjects were monitored electronically through their mobile phones. Then, the Entry Quarantine System was launched: through the completion of an health declaration form (requiring the scan of a QR code that leads to an online form, either prior to departure from or upon arrival at a Taiwan airport) travelers could receive a fast immigration clearance.

Our literature review suggests that another meaningful way to control the spread of an epidemic is through monitoring/surveillance of internet searches and social media usage. Wang et al. [19] used WeChat, a Chinese social media, to plot daily data on the frequencies of keywords related to SARS-CoV-2. The authors found that the frequencies of several keywords related to COVID-19 behaved abnormally during a period ahead of the outbreak in China and stated that social media can offer a new approach to early detect disease outbreaks. Similarly, the italian words for “cough” and “fever” have been searched in Google Trends to find useful insights to predict the COVID-19 outbreak in Italy, showing a significant association with hospital admissions or deaths in the two following weeks [35]. These two papers show that tracking public health information from online search engines might have a role in the prediction of future COVID-19 waves, complementarily to traditional public health surveillance systems.

Although its potential is irrefutable, the technology behind surveillance and contact tracing apps raises many concerns, as discussed by Calvo et al. [27], the most obvious one being “surveillance creep”, that is when a surveillance tool developed for a precise goal (in the case of China and Taiwan, an app to monitor people’s movement) sticks around even when the crisis is solved. Privacy must be a primary concern for the policy makers and a key challenge for designers and engineers that design the digital tools for epidemic control. As already outlined in a previous work by Carullo [36], in the EU applications to combat COVID-19 should not process personal data whenever possible. The General Data Protection
Regulation (GDPR) dictates the principle of privacy by default, that is "by default, only personal data which are necessary for each specific purpose of the processing are processed". In this regard, it should be reminded that according to the GDPR, data is "personal" only when and insofar it allows the identification of a natural person. Therefore, the processing of data, including clinical data, which cannot in any way identify a natural person, is not personal data. Which therefore completely rules out any privacy concerns. To be compliant with this principle, a preferable approach is therefore to trace the spread of the virus, and therefore alert users, without collecting any personal data. A promising example that goes in this direction is brought by Yasake et al. [22], with their open source proof-of-concept app for contact tracing that does not require registration or the divulgation of any private data, such as location. Instead, this tool utilizes an ingenious “checkpoint” system, that allows the users to create a peer-to-peer network of interactions and to know if they have been exposed to any risk of infection; diagnosis of infection can be logged into the app, the data is transferred to a central server but stays anonymous.

While the aforementioned articles addressed surveillance and prevention in outpatients and the general population, an interesting point-of-view on inpatients surveillance comes from the study by Lin et al. [24]. This paper describes a prospective active surveillance system with Information Technology Services (i.e. using a surveillance algorithm based on data from electronic medical records) to identify hospital inpatients whose pneumonia did not show marked improvement with antibiotic treatment and to alert the primary care medical teams on a daily basis.

In regard to the field of prevention, other important digital technologies proposed in the literature are telemedicine and telehealth [3, 12, 28, 30, 31, 33]. Nonetheless, telemedicine does not always cover emergencies, and, differently from the article by Lin et al. [24], many COVID-19 patients may need to go to the hospital for higher level care. For this purpose, Turer et al. [30] propose using electronic Personal Protective Equipment (ePPE) to protect staff and conserve PPE while providing rapid access to emergency care and fulfilling Emergency Medical Treatment and Active Labor Act (EMTALA) obligations for low risk patients during the COVID-19 pandemic. ePPE has potential applicability to settings such as emergency medical services, medical wards, and intensive care units.

4.3 Treatment and adherence

Telemedicine and telehealth technologies are also used to increase patient adherence and for treatment purposes. An article that considers using telemedicine/telehealth is the one by Tourous et al. [28]. In it, the Authors describe the potential of digital health to increase access and quality of mental health care. They make examples of digital health innovations and explore the success of telehealth during the present crisis and how technologies like Apps can soon play a larger role. Telehealth is seen as a useful solution to deliver mental health care commonly [37], and during social distancing and quarantine periods. In addition, digital therapy programs can also be offered through courses of evidence-based therapies, or using augmented and virtual reality systems.

As another example, Calton et al. [33] deliver some useful tips on the implementation of telemedicine to deliver specialty-palliative care into the homes of seriously ill patients and their families. The authors state that digital divide must be taken into account. Patients need access to a digital device suited for video conference and to an internet connection. For the elderly or the less prone to technology, it may be necessary to identify a caregiver as a “technological liaison” for the patient. The appointment must be well coordinated and there must be a contingency plan if the meeting does not start at the scheduled time. Hence, to create a successful treatment telemedicine environment, many critical factors are needed:
workforce training, high-quality evidence, digital equity, and patient adherence.

5. DISCUSSION
While SARS-CoV-2 is causing a pandemic worldwide, it is also favoring the rapid adoption of digital solutions and advanced technology tools in healthcare practice. On the one hand, physicians and health systems may need to track large populations of patients on a daily basis for surveillance purposes [3]. On the other hand, they may need fast diagnostic tests for COVID-19 screening, in order to reduce the workload and enable patients to get early diagnoses and timely treatments.

This is also done with the help of digital technologies, which were already available in different industries before the current crisis. These tools have now been implemented in healthcare due to the pandemic.

In this rapid literature review we describe numerous digital solutions and technologies addressing several healthcare needs, with particular regard to diagnosis, prevention and surveillance. The constantly updated scientific literature is a source of important ideas and suggestions for finding innovative solutions that guarantee patient care during and possibly after the COVID-19 crisis.

In the field of diagnosis, digital solutions that integrate with the traditional methods of clinical, molecular or serological diagnosis, such as AI-based diagnostic algorithms based both on imaging and/or clinical data, seem promising and widely used.

The literature shows interesting digital tools also in the field of prevention and surveillance. In the first case, the concept of electronic personal protective equipment (ePPE) seems very promising and would allow high standards of care, while ensuring the safety of patients and operators. As for surveillance, digital apps have already proven their effectiveness, but problems related to privacy and usability remain.

For other healthcare needs, various solutions have been proposed using, for example, telemedicine or telehealth tools. These have long been available, but perhaps this historical moment could actually favor their definitive large-scale adoption.

However, all of this is easier said than done. In the context of the “Health Care’s Digital Revolution” [3] brought to the USA (and worldwide) by the COVID-19 pandemic, while private corporations and education institutions have made a quick transition to remote work and videoconferencing, the healthcare system is still lagging behind in adopting digital solutions. This is mainly due to the fact that clinical workflows and economic incentives have been developed for a face-to-face model of care which, during this pandemic, contributes to the spread of the virus to uninfected patients who are seeking medical care.

Other than healthcare policies “history”, there are additional limiting factors to the implementation of tools like telemedicine, including a legal framework that is not yet fully designed to regulate the use of innovative IT systems in healthcare, as well as an inadequate ICT infrastructure and an obsolete reimbursement and payment structure.

Other countries are facing the same regulatory issues of the USA, like Italy - the first western country to experience a total lockdown due to the COVID-19 pandemic [31]. Therefore the challenges for digital health have become a global issue into the public health response to COVID-19 and future outbreaks.

Digital tools such as telemedicine should indeed be integrated into international and national guidelines for public health preparedness, alongside the definition of national regulations and funding frameworks in the context of public health emergencies. In order to switch to new digital-based models of care (e.g. using outpatient teleconsultations), increasing digital-expertise of health care professionals and educating the population are fundamental issues. Moreover, by implementing a data-sharing mechanism, digitally collected and stored data will be a precious tool also for epidemiological surveillance, that, as discussed
earlier, is fundamental in controlling the epidemic spread. Lastly, in order to describe and assess the impact of digital tools during outbreaks, scientific evaluation frameworks should be defined.

This rapid literature review presents some limitations. First, the research was conducted in a period of epidemiological emergency. This determines a large number of daily publications, which is difficult to keep up to date. As a result, we have been forced to select articles in a reduced time span, potentially missing other studies and including studies yet to be peer-reviewed. Secondly, due to the design of the rapid review, the search could not be fully comprehensive, as it was conducted exclusively on Pubmed and MedRXiv. Finally, the articles and concepts included in this preliminary review certainly need to be afterwards integrated at the end of this international emergency phase.

In conclusion, the COVID-19 crisis is favoring the implementation of digital solutions at a speed and with an impact never seen before. It is therefore mandatory to keep track of the ideas and solutions proposed today to implement tomorrow's best practices and models of care, and to be prepared in case of future national and international emergencies. We believe that it is worth taking advantage of the push given by the crisis we are experiencing today to implement at least some of the solutions proposed in the scientific literature, especially in those national health systems which in recent years proved to be particularly resistant to the digital transition.

ACKNOWLEDGMENTS:
N/A

COMPETING INTERESTS:
The authors declare that they have no competing interests.

FUNDING SOURCES:
The authors declare that they have not received any specific funding.

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