Transforming healthcare through a digital revolution: A review of digital healthcare technologies and solutions

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The COVID-19 pandemic has put a strain on the entire global healthcare infrastructure. The pandemic has necessitated the re-invention, re-organization, and transformation of the healthcare system. The resurgence of new COVID-19 virus variants in several countries and the infection of a larger group of communities necessitate a rapid strategic shift. Governments, non-profit, and other healthcare organizations have all proposed various digital solutions. It’s not clear whether these digital solutions are adaptable, functional, effective, or reliable. With the disease becoming more and more prevalent, many countries are looking for assistance and implementation of digital technologies to combat COVID-19. Digital health technologies for COVID-19 pandemic management, surveillance, contact tracing, diagnosis, treatment, and prevention will be discussed in this paper to ensure that healthcare is delivered effectively. Artificial Intelligence (AI), big data, teledmedicine, robotic solutions, Internet of Things (IoT), digital platforms for communication (DC), computer vision, computer audition (CA), digital data...
management solutions (blockchain), digital imaging are premiering to assist healthcare workers (HCW’s) with solutions that include case base surveillance, information dissemination, disinfection, and remote consultations, along with many other such interventions.

**KEYWORDS**
healthcare, telemedicine, digital healthcare, artificial intelligence, blockchain

**Introduction**

The recent outbreak of the COVID-19 pandemic has had a significant impact on socio-economic, sustainability, and healthcare systems across the world. The disease is highly contagious and causes a range of symptoms (1) including dry cough, diarrhea, headache, fever, sore throat, and conjunctivitis, amongst others. At the end of May 2021, digital data repositories have claimed around 3,565,021 mortalities, and more than 171 million morbidities globally (2). The number of critically ill patients in developed countries is exceeding the critical care capacity (3, 4) and low-income and middle-income countries (LMICs) are even more at risk due to the lack of medical infrastructure (5) to manage the surge of the disease. The availability of intensive critical care (ICU) for severely ill patients is also a major deciding factor in mortality rates in underdeveloped and developing countries. Preventive measures and precautions should be taken in developing countries before it exceeds their healthcare capacity. The need for suitable preventive measures to mitigate the impact of the pandemic is in the spotlight. The conventional preventive methods including social distancing, quarantine, lockdowns, and safety gear are all under practice. However, the lockdowns and quarantines have led to psychological distress in individuals (6–9) and economic recession (6, 7, 10, 11).

Information Technology (IT) sector is primarily gaining attention because digital health technologies can provide effective measures to tackle the ongoing challenge (12–14). Artificial intelligence (AI), cloud data solutions, real-time tracking and monitoring systems, telemedicine powered by 5G, and robotic technologies can provide innovative solutions for front-line protection, accelerated detection, infectious risk management to reduce morbidity and mortality rates, and their consequences. World Health Organization (WHO) has developed a practical guide that is to be used by national authorities to develop and update their COVID-19 responses (15). Following these guidelines, various national health ministries have advocated the promotion and prevention of disease spread while embracing a cascade of healthcare measures (16). This review discusses the related healthcare models presently practiced in developing countries, and advances that can be potentially deployed in LMICs. The substantial exposure to the current advancements in digital health technologies could incentivize new beginnings in technological ventures and encourage the adoption of the latest healthcare models. The review synthesizes global trends in digital healthcare with a siloed system approach to replicate the process within individual countries.

**The necessity of digital healthcare**

The healthcare systems in LMICs are suffering from a lack of cutting-edge technologies that are available in developed countries. The private healthcare service providers often play a competitive role at par with the government sector in providing state-of-the-art medical facilities (17). The long wait for these consultations and advanced procedures in government healthcare facilities creates a space for private sector healthcare setups to provide quicker and often better services with higher payments. The low-income group, especially in villages are suffering to afford timely medical care and quality healthcare services. However, several factors that govern the overall performance of the health sector in a country are vividly discussed in Figure 1. While the current pandemic is de-normalizing healthcare management globally, LMICs are facing a severe threat. Improvement in world-class training, deployment of skillful practitioners, external inbound investment, broadening mindset of inland naive users, demands of high moral values in the country, ability to possess digital devices, willingness to adopt changes, improved educational facilities and strengthened inter-country fraternity against invisible enemy creates a thrust for LMICs to adopt and adapt the digital health care models.

**Digital healthcare models**

**Tracking suspected subset of individuals via open-source web solutions**

Studies showed that the number of new infectious cases are doomed by a single infectious person (18, 19) and the infected person could either be symptomatic or asymptomatic...
(20, 21). Hence, identifying the infected patient, tracing their contact, to contain the transmission, is crucial. A centralized tracking technology, i.e., the Pan-European Privacy-Preserving Proximity Tracing (PEPP-PT) (22), is facilitating the creation of a social graph of individuals and their interactions. This centralized approach traces geological locations, whereabouts, and close contacts, and stores them in central repositories for the concerned authorities to access and monitor the sensitive information. However, civil rights authorities stand against this centralized approach (23), as law enforcement entities and government departments can access the information for future surveillance. Therefore, they are emphasizing de-centralized data tracing, i.e., Decentralized privacy-preserving proximity tracing (DP-3T) (22). On the other hand, many European countries are interested in short range tracking technologies such as Bluetooth technology (Bluetooth tracking) to fit this model. Generally, contact tracers with sensitive details including CCTV footage, location tracking, credit card transactions are more likely incompatible with privacy-minded protocols. Thus, Bluetooth tracking is apparently made alluring. Bluetooth’s “Handshaking” is enough to identify close contacts and contact duration. Meanwhile, Google and Apple have announced that they will provide technological support for de-centralized contact tracing solutions (24).

**District health information software (DHIS2) digital toolkit**

District Health Information Software 2 (DHIS2) has released digital data management and analytics package that engaged in a variety of applications all around the world, with countries mainly in Africa and Asia. This data aggregation and management tool equipped with advanced charts, geographic information system (GIS), pivots, and dashboards make it easy for the software to dynamic data visualization. It facilitates diverse applications (25, 26). Including (a) Health Information systems; (b) COVID-19 surveillance; (c) COVID-19 vaccine; (d) Education management systems; and (e) Tracking.

It records individual identities, and other socio-demographic details for accelerated case detection, case situation reporting, active surveillance, and the response to COVID-19. This model enables tracking techniques to trace out the suspected subsets.
Dynamic dashboard models

The dashboard platforms are online dependant models which are exposed to substantial data processing in real-time. The integrated information from WHO, the Center for Disease Control and Prevention (CDC), the European Center for Disease Control and Prevention (ECDC), NXC, DXY, BNO are broadly used to track the COVID-19 statistics in real-time by International dashboards providers such as Johns Hopkins University dashboard, Microsoft Bing COVID-19, CDC, WHO The New York Times and worldometer.info (27, 28). GitHub avails the raw data to the general public (29) which ensures the access of COVID-19 statistics to the researchers. Data analyzing dashboards in LMICs like Sri Lanka which are facilitated by many domains such as HPB (Health promotion bureau) (30), Arimac Digital (31), Presidential secretariat (32) are giving real-time case dynamics, death rate comparison, disease growth rate compared with other countries and district wise case distribution. These dashboards enable citizens to escape fake updates and causeless panic while receiving confidential updates from legal authorities.

AI-enabled big data analysis and computer vision

Technology can provide an innovative solution even in the medical field from assisting in diagnosis, screening, and individual risk assessment. The AI-based big data analysis can either be used to assist risk assessment through case tracking and modeling or to improve the prognosis. Successful forecasting AI tools and algorithms (33) requires a bulk of data for training and validation to eliminate biases. Therefore, AI has not yet been impactful enough to solely provide robust solutions for forecasting outbreaks (34). Due to lack of raw data, noisy social media data, outliers, and big data hubs, most forecasting models used established epidemiological models, being called the SIR model (Susceptible, Infectious, and/or Recovered) (33) for disease forecasting. In addition, AI would potentially contribute to finding suitable vaccines (35–37). Few vaccines have been discovered in the recent past and quite a few of them are approved by WHO for COVID-19 usage. WHO has approved to use of Pfizer/BioNTech, AstraZeneca-SK Bio, Serum Institute of India, Janssen, Sinopharm COVID-19, and Moderna vaccines for emergency use (38). However, clinical trials for these vaccines have finished and mass vaccinations and booster programs have started.

Healthcare workers (HCWs) and authorities are using AI-powered tools to adjunctively identify the target groups using AI computed tomography (CT) scanners and Temperature scanners [iThermo] after a standard test for diagnosis. RT-PCR (reverse transcriptase-polymerase chain reaction) fails to identify the asymptomatic cases by 39–61% (39, 40) and PCR tests consume days to identify the infection. Li et al. observed that the accuracy of CT imaging (98%) could be significantly higher than PCR (71%) (41). Hence, artificial intelligence-based CT scanning was established in Shanghai, China. A start-up called “Infervision” based in Beijing created software using artificial intelligence in CT Images. Ping smart healthcare unveiled a smart image reading system that reads CT images in 10s with more than 90% confidential rate whereas manual CT diagnostics can take up to 15 min (42). However, both RT-PCR and AI-enabled CT scan does not pose a serious impact on identifying infected patients. But rather it helps the health staff to diagnose and isolate patients from the crowd without major spread.

Wearable data analytics and IoT

Wearable and implantable medical devices (IWMDs) use micro or nanosensors or implantable microchips for continuous health monitoring and treatments. These burgeoning wearable technologies hold significant potential to provide savings in terms of monetary cost and lives. However, externally wearable sensors are easy to use and can be worn flexibly. If any sensor detects abnormalities in physiological metrics, the device automatically alerts the patient through Bluetooth/Wi-fi to the mobile app and simultaneously communicates with the cloud through data fusion. It enables health professionals and caretakers to monitor remotely and take care of the patients in real-time. “Scripps research translational institute” in partnership with “CareEvaluation” released the app-based solution, DETECT, which analyses wearable data shared by users to identify the spread of viral illness. These solutions are more desirable for in-home quarantine, to transfer the physiological parameters using electronic health records (EHR) without crowding test centers. “Apple health Check-up Siri”, “Give me guidance”, and “Alexa daily check” are a few examples that are providing the required functionality.

Telehealth during the pandemic

Telehealth uses two-way media interactions to connect health professionals and patients from different geospatial locations who are often distant. Dr. Ceasar Dhavaherian, the chief medical officer of Telehealth company, Carbon health, says that telemedicine is an implication of healthcare services into virtual interactions assisted with devices whether using storing information in “Apple watch” or remote stethoscope like “EKO Health” or some of the other at-home pressure cuffs and connected scales. So, telehealth solutions are ahead of general health care systems, providing health care services from a safer distance. In a way, the best outcome of telehealth during the pandemic is that a doctor/physician can triage the suspects using physical symptoms without incurring patient...
in-hospital clustering. Hence, the telehealth solutions evolved during the pandemic crisis. However, several factors accompany the interventions in telehealth systems implementation.

Robots in healthcare

Autonomous robots are using cutting-edge telepresence technology to help to combat the spread of the COVID-19 virus. Robots have been used to deliver medicines, and foods, disinfect rooms, examine, treat suspected patients, and prevent staff from overexposing to the virus.

Delivery

The need for delivery robots is largely in demand for hospitals and food deliveries as the world has been confined to their homes without any means of supply. So, the demand for delivery robots is now on a spike. Beijing-based Zhen robotics is used to deliver foods, patrolling around the malls for those who are not wearing masks. Ezhou hospital has incorporated a robot chef in the kitchen for food preparation and serving. University of Michigan’s start-up, Refraction AI, developed “REV-1” in food delivery as a pilot deployment for approximately 500 customers in corona use-cases. In another instance, the autonomous mobile robot “Phollower 100” by the company Photoneo was used for the safe distribution of medicines or auxiliary medicaments in the hospital quarantine zone.

Screening and treatment

The first COVID-19 patient who was treated with a robot equipped with a stethoscope and the virtual screen was in Seattle, USA. The robot was used for a man in isolation, used to take his vitals and communicate with the doctor on the console. China used hand sanitizer dispensing robots in their cities, refilled with disinfectants. A patrol robot in Shenyang, China, checks the body temperature and disinfects people and spaces. The operators on the mobile scooters control the robot. Tunisian police deployed a robot equipped with infrared, thermal imaging cameras, and an alarming system.

Awareness

A start-up company “Asimov Robotics” in India has launched two robots for the sake of spreading awareness, and distributing hand sanitizers and facemasks.

Interactive

“Zorobots” from Belgium designed a robot intended for elderly people to communicate with loved ones from the comfort of their home in a safe environment that keeps the most vulnerable groups from infection (43).

Disinfecting spaces

The health-threatening COVID-19 virus highlights the potential for finding solutions to disinfect transmission surfaces and bio-contaminated air. Hospital-acquired infection (HAIs) is a new threat in hospitals as the transmissions happen during hospital visits. The UV disinfection robotics systems are emerging to implement disinfection in hospitals, healthcare facilities, airports, and shopping malls. Robotics firms such as “blue ocean robotics”, “UVD Robots” and “Kenex” are at their peak to deploy UV-Light-based virus-fighting robots in hospital facilities all around the world. These robots are controlled using remote technology and refilled with sanitizers.

Blockchain in healthcare

States and hospitals across many countries still have conflicting data on the number of ventilators, PPE, medications, and hospital/ICU beds in the supply chain, their locations, who is allowed to share them, and who is in the greatest need (44, 45). The information flow is fragmented and disorganized, making it extremely difficult for government agencies to respond to the needs during the pandemic efficiently. It is critical to have a single consolidated and accurate picture of real-time supply and demand information for these critical equipments in order to coordinate and effectively handle this issue. The combined capabilities of digital technologies like as Blockchain, Cloud, and AI may be leveraged to build a unified, trustworthy, and transparent view of supply and demand data across numerous stakeholders, locations, and legal organizations (46). Following that, local governments could collaborate to rapidly and effectively distribute supplies as demand varied from state to state. Blockchain is a type of decentralized ledger technology that allows for the safe storing and transport of data (47). Because each transaction is recorded across each node on the network, no record can be changed retrospectively without affecting any following blocks in the chain. Decentralizing data recording improves security and stability in data ownership and administration, as well as financial and logistical traceability in complicated healthcare supply chains (48).

Role of social media in publicizing government safety measures

Education, public engagement, and technological literacy are the crucial elements that the general public considers while responding to the pandemic outbreak. Constituent public awareness was influenced through the press and
### TABLE 1 List of digital solutions for countries to combat COVID-19.

| Usage       | Function                                                                                                                                                                                                 | Solution name                                                                                     | Company name                                      | Reference |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------|-----------|
| Surveillance | Cloud-based solution for monitoring people during self-isolation with suspected or confirmed COVID-19 infection                                                                                           | COVID-19 Self-Isolation Monitoring and Notification                                              | HN Consultants Ltd                                | (53)      |
|             | Cross border tracing tool enables to access personal records through the international borders                                                                                                           | Journey solution                                                                                | Inter-Governmental Agency for Development         | (54)      |
|             | Hyperlocal heat map for the spatial dynamics of the at-risk population who are much more vulnerable to COVID-19 complications                                                                             | Spatial dynamics of at-risk populations (Risk Profiles)                                          | Fraym                                             | (55)      |
|             | A field data collection tool during public health emergencies can be used for case detection, contact tracing, and visualization of transmission chains | Go. Data                                                                                        | Pan American Health Organization /World Health Organization | (56–58)  |
|             | 'Web-based & mobile app real-time traveler’s data reporting at airport entry points. The data is then used for real-time evidence-based decision making | Traveler’s Surveillance MIS (TSMIS)                                                              | USAID—GHSC PSM                                   | (59)      |
|             | A platform that ensures active surveillance and tracing isolation. It groups the patients based on the geographical location of pathology and assigns health care staff to each patient | ADILIFE PLATFORM                                                                                | ADITECH SRL                                       | (60)      |
| Prevention  | A web-based learning platform to engage, train the healthcare workers, families about the prevention measures                                                                                            | Special Olympics                                                                                | Special Olympics International                    | (61)      |
|             | Mobilizing tablet equipped female health workers in the villages of Punjab and Sind                                                                                                                     | LifesavHERs: how tech-enabled frontline health workers are combating COVID-19                     | docHERs                                           | (62)      |
|             | Maximize the usage of ICT enabled radio to disseminate knowledge, share health practices, and change the attitudes of rural sub-Saharan communities       | Farm Radio                                                                                       | Farm radio international                          | (63)      |
|             | Crisis response platform that continually updates COVID-19 info on any mobiles and provides live, automated health coach, remote assessment & triage | Cell-Med COVID-19                                                                               | Cell-Ed                                           | (64)      |
|             | An end user-focused app platform designed to share information, sending reminders for timely uptake of health services during COVID-19.                                                               | HERA App                                                                                        | HERA Inc.                                         | (65)      |
| Diagnosis   | Highly configurable software application platform to capture diagnosis results, trigger and manage referrals, communicate with patients and health workers, and share data with other systems including DHIS2 | Mango for diagnosis support                                                                      | Greenmash                                         | (66)      |
|             | Using the web, app, and messaging platforms, people can use diagnosis to assess risk, a guide to decision making, subscribe to alerts, find nearby testing sites and health services | COVIDcheck                                                                                      | The Commons Project                               | (67)      |
|             | Decision supporting and telemedicine app to train, assist frontline health workers, and for data analytics. Frontline Health workers may use it for risk assessment, decision support & provider-to-provider teleconsultation. | Intelehealth                                                                                    | Intelehealth                                      | (68)      |
|             | An open-source mobile e-health system designed for case detection, contact tracing and follow up, laboratory data management, case management, and data analytics | Surveillance Outbreak Response Management and Analysis System (SORMAS)                            | Helmholtz Center for Infection Research (HZI)     | (58)      |

(Continued)
media releases regardless of the truth. However, the resource-constrained subset of the population could still not access the real-time updates on time. But on the other hand, being overexposed to social media and fake online resources may result in psychological distress in some individuals, besides infection. Social media becomes one of the main sources of news online with 2.4 billion internet users, among them 64.5% receive breaking news from the sites like Instagram, Facebook, Twitter, WhatsApp, and Snapchat among others. It’s estimated that 90.4% of millennials, 77.5% of generation Xers, and 48.2% of baby boomers are active social media users (49, 50). This international fact-checking network’s (IFCN) WhatsApp bot uses machine learning tools to deliver the information (51). WhatsApp announced a $1 million grant for IFCN fact-checking ventures to report the rumors spreading via WhatsApp and SMS (52).

COVID-19 digital responses

The sudden outbreak unleashed enormous digital solutions and potential mitigation strategies. Digital tools include the use of radio technology, television, mobile phones, blockchain, AI, unmanned aerial vehicles (UAV) drones, and geographic information systems (GIS) that enables internet and satellite technologies to provide timely solutions. Self-diagnosis, teleconsultation, information dissemination, case surveillance, reminders, laboratory data management, and track records are considerable features of digital response. Table 1 synthesizes digital health platforms that are effectively implemented in a few developing countries to help mitigate the spread. Tabulated solutions are some of the premier tools used by a few developing countries for the COVID-19 emergency response. These tools have enhanced the accessibility of healthcare to all citizens. The solutions can be re-established in other developing countries through careful assessment.

Challenges and opportunities

Digitalization brings challenges in disguise, despite being hailed as a source of development. Digitalization produces timely solutions and is important during the pandemic. However, individuals may be reluctant to the change and have several concerns. In particular, the employees in an organization may expose to severe pushbacks once the pandemic is over. Reasonably, they may have a fear of losing jobs, changes in their roles, being unable to adapt to the new environment, and taking additional responsibilities if digitalisation demands fewer human interactions. Therefore, organizations and entities should be prepared for these perceived consequences and should plan solutions to futureproof their working solutions and staffing needs.
Conclusion

The COVID-19 pandemic imposed seamless challenges on the healthcare sector globally. Digital technologies can provide an accurate and robust solution for the ongoing and upcoming outbreaks, with measures to support the healthcare sector. The technology brings in new perceptions and hope for the betterment of the community with utmost effectiveness. These digital healthcare solutions provide accelerated case detection, constant surveillance, access, advanced decision-making, and virtual consultations while improving the quality of services. The concerned authorities and decision-makers should understand the basic functionality, intrinsic capabilities, opportunities, and possibilities of these solutions in all dimensions. A rigorous and honest assessment of the suitability and reliability of how these solutions integrate with the existing infrastructure of the country is also necessary. Furthermore, digital health solutions require extensive collaboration and support from disparate entities and the public.

Author contributions

NN, BH, BS, BR, and VP contributed to the conception and design of the study. NS, SV, KS, JS, and SI organized the database and wrote the first draft of the manuscript. NS, SV, KS, SI, AS, HK, KN, DS, and VP wrote sections of the manuscript. PC, BH, BR, and BS critically reviewed and edited the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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