The Role of Technology in Epidemic Management of Covid-19

Muyi Guo[1], Yuqi Liu[2, *], Zhijia Luo[3], Mo Zhou[4]

[1]School of Jinan University, Guang Zhou, China

[2]High School Affiliated To Nanjing Normal University, Nanjing, China

[3]School of Nankai Secondary School, Chong Qing, China

[4]The Masters School, New York, USA

*Corresponding author: 15020440116@xs.hnit.edu.cn

Abstract. The worldwide repercussions of the Covid-19 pandemic have compelled nations to seek innovative solutions. Concurrently, the evolution of technology has unveiled a host of emerging solutions that hold the potential to revolutionize infectious disease management. This study offers a comprehensive overview of pandemic control, encompassing prevention, contact tracing, detection, and treatment. Particularly in the context of the Covid-19 era, the paper retrospectively evaluates technological applications in these domains. Synthesizing insights, it provides a nuanced understanding of technology's interplay with disease management. Drawing from the collective wisdom of the Covid-19 epoch, this study informs the development of effective measures intertwined with technological advancements. Furthermore, the paper forecasts and recommends paths for technology-driven infectious disease management, establishing a basis for informed decisions amid global challenges.

Keywords: digital technology; Covid-19.

1. Introduction

Humanity's record of fighting against pandemics cannot be without technology. Like the famous SARS, Ebola, and most recently Covid-19. The Covid-19 pandemic caused widespread social instability and medical pressure, increasing unemployment and societal burden because of closing in schools and corporations. Due to this widespread trauma, technology, as a part of the fabric of modern life, has been used far more frequently. Throughout the pandemic, technology plays a big and crucial part in preventing the spread and better control the disease. It accelerated the process of ending the COVID-19 pandemic and saved many lives. Overall, the technology can be used in monitoring epidemic, performing diagnosis, assistant treatment and tracing prognosis. This review will present various technology instances, with a particular focus on the COVID-19 era, examining their relevance and future advancements across four key dimensions: prevention, detection, treatment, and contact tracing. Finally, it reflect on the fight against epidemics in the future.

2. Technology in Prevention

The 2019 coronavirus disease pandemic (Covid-19) can be prevented in large part by using big data, data science, the internet, and intelligent terminals like artificial intelligence (AI) and the internet of things (IoT). IoT devices can gather patient data continuously and aid in drawing conclusions about the disease and its course. AI can track and collect the information that heighten or lessen its symptoms on people [1]. Using of the data will help people to know how the condition is impacting the patients and how to stop the disease spread.Utilizing advanced machine learning techniques and models with the extensive data collected from IoT devices can aid in evaluating and predicting the scenarios of Covid-19 transmission [2]. Besides, people in quarantine centers and areas under lockdown can be monitored with the aid of IoT and AI. The information obtained by IoT devices, including as wearables, closed-circuit television (CCTV) cameras, cellphones with or without a global positioning system (GPS), and a range of sensors, can reveal whether or not people are abiding by the norms when uploaded to the cloud and provided to artificial intelligence models [2].The following are the more specific points of how AI and IoT can help the prevention of the pandemic.

2.1. Telemedicine

The term "telemedicine" describes the use of telecommunications technology for patient diagnosis and treatment at a distance. It allows patients to communicate with their healthcare practitioner virtually, minimizing in-person interactions with vulnerable individuals and healthcare professionals during COVID-19 [3].

2.2. Robotics

Robots that are autonomous or controlled remotely are used in sanitization of public locations to reduce contact infection, such as hospitals, airports, train stations, factories, shopping centers, movie theaters, hotels, offices, and borders. In order to clean surfaces, corners, crevices, and the air, ultraviolet type C (UVC) lights are attached on autonomous or remote-controlled mobile robots [2]. The UV robots can be done anytime and anywhere and effectively and largely disinfect areas. Robots in quarantine and lockdown areas serve food and administer meds to contaminated patients. To reduce face-to-face contact and stop the spread of illness, robots can also be employed to transfer or dispense goods [1].

2.3. Drones

A drone is defined as any airborne apparatus capable of autonomous flight through software guidance or remote piloting. Drones serve as 'aerial observers' during quarantine periods, effectively assisting in the enforcement of lockdown measures. It can assist in keeping an eye on the individuals under quarantine and determining if they are adhering to protocol or not [2]. Similar to robots, drones that are autonomous or operated remotely can assist in sanitizing wide-open spaces like roads and places of worship. It can become autonomous by adding more complex features, which will enable it to go around obstacles, adapt to the proper height and location, automatically replenish and recharge itself, return to the base station, as well as cooperate and communicate with other robots for effective sanitization [2]. To reduce contact between people, drones can transport both medical equipment and patient samples [1].

2.4. Blockchain

Blockchain is a system in which transaction records are preserved across a network of interconnected computers in a peer-to-peer fashion. It has the capacity to store substantial volumes of data, such as test results. The healthcare records related to Covid-19, when implemented on a blockchain, can be adapted to securely store comprehensive test data. The information will be immutable once it has been recorded following the consensus and only authenticated entities will be able to access it. These records can be used by concerned authorized agencies for additional investigation and action [2]. Blockchain technology may be used to record the whole sanitization process and make it accessible to citizens via a smartphone application in a safe, geotagged, immutable, and transparent way. This will help restrict the spread by educating people about safe and unsafe areas [2]. Blockchain, however, is still in the research stage and is not a full Covid-19 prevention approach. Prior to its adoption for Covid-19 preventive phases, there are certain technological obstacles that must be considered, such as privacy concerns, authentication, authorization, accessibility control, inefficient performance, and energy consumption [2].

3. The Technology in Detection

As the new coronavirus spreads swiftly and the number of associated cases continues to rise, the swift and precise identification of viruses and illnesses becomes progressively crucial in controlling the origin of infection and aiding patients in preventing disease advancement.

3.1. Clinical Testing Technology

3.1.1 Nucleic Acid Detection

The polymerase chain reaction (PCR) technique is widely acknowledged as the "benchmark" for discerning individual viruses within nucleic acids because of its swift detection pace, heightened sensitivity, and distinctive attributes. Real-time reverse transcription PCR (RT-PCR) offers ample sensitivity to facilitate early infection diagnosis. Given its utility as a precise and straightforward qualitative assay, the identification of the SARS-CoV-2 coronavirus is presently of considerable interest. Nevertheless, real-time RT-PCR examinations carry the risk of generating erroneous negative and positive outcomes, constituting a drawback of this methodology. As per the guidelines of the World Health Organization (WHO), several factors may contribute to inaccurate results in the RT-PCR analysis process due to inherent technical limitations in detection, viral mutations, or PCR inhibition [4].

3.1.2 Imaging Technology

For the diagnosis of Covid-19 infection, chest computed tomography (CT) and chest X-rays are the two frequently used imaging alternatives to RT-PCR. The chest CT is similar to RT-PCR and has high sensitivity. But it still has shortcomings, such as hospital access to sexually transmitted infections, radiation safety, and low availability of CT equipment. The cost of chest X-rays is lower, the dose of radiation is lower than the CT, and the likelihood of a false negative is higher [5].

3.1.3 Blood tests

Comparatively speaking to RT-PCR and imaging, blood testing is more affordable and popular. As the Covid-19 infection progresses, the biochemical markers seen in routine blood tests, such as lactic acid dehydrogenase (LDH), C-reactive protein (CRP), etc., alter, providing information regarding the diagnosis of Covid-19. Therefore, blood tests are valuable for rapid screening of infected patients, while providing initial detection steps to compensate for the shortcomings of imaging and RT-PCR .

3.2. Digital Technology

In order to respond effectively to an infectious disease public health emergency, it is important to determine the cause, the distribution, and the timing of the disease across populations. In order to improve and analyze crucial epidemiological data on Covid-19 gathered by public health organizations, researchers are now employing a variety of digital information. This aids in swiftly diagnosing Covid-19.

3.2.1 Symptoms diagnosis of Covid-19

According to data from 10,172 cases of Covid-19 that were confirmed in the lab during the outbreak, coughing was a factor in 54.08 percent of cases [6].Thus, effectively monitoring and promptly identifying suspected patients through the swift and accurate assessment of the common pneumonia symptom, cough, holds significant importance in managing potential infection sources. Enhancing audio data and blending voice in a variety of intricate situations is the initial stage in cough identification techniques based on mel spectrum charts and the convoluted neural network (CNN) [7]. The data are pre-processed to ensure consistency of data lengths and are then transformed into mel spectrum charts in the second stage [7]. Finally, build a CNN-based model that uses mel spectrum charts to classify cough.In a difficult scenario, this method can effectively discern and spot coughing associated with Covid-19 [7].

In Covid-19 outbreaks, detection of asymptomatic infections is important to control the outbreak. The parameters of the blood that have been discussed above are important in identifying cases of Covid-19, when the one-dimensional data above is converted after pre-treatment into two-dimensional imaging data and is processed using CNN, the final success rate of the Covid-19 detection is 19.94%[8]. This study is more convenient and cheaper than imaging technology.

3.2.2 Internet of Medical Things (IoMT)

IoMT includes internal, domestic, and physical applications and addresses the Internet connectivity of medical devices, hardware, and software [8]. Recent progress in sensor technology, information technology, and software engineering, when applied to detection methods within the healthcare field, is increasingly revealing the unmistakable potential for the evolution of remote monitoring, instantaneous diagnosis, analysis, and data sharing. An online medical tool known as a "chat bot" might assist patients in identifying early symptoms and directing individuals toward medical care should symptoms deteriorate [9]. Moreover, there is smartphone software that recognizes and saves medical data, including daily temperature and symptoms [9]. While it doesn't sound like it's particularly eye-catching, it's more accessible and seems to do more. Because almost everyone can use it.

The technology is clearly safer in terms of diagnosis, lessening the workload of medical workers and improving diagnostic efficiency. Nevertheless, it exposes many shortcomings. IoMT’s connection to the Internet poses security risks, and patients’ privacy rights are not guaranteed [10]. Of course, companies are working on encryption to prevent fraudulent attacks and privacy violations, but there is room for improvement [10].

3.2.3Telemedicine and Robots

Telemedicine also enhances physicians' clinical judgment and performance skills and teaches other healthcare providers who have never dealt with Covid-19 patients or are unfamiliar with the clinical and radiological manifestations of the disease [1], help them to diagonosis Covid-19 correctly and quickly. Robots can be used for sample preparation and collection.Autonomous robots perform various tasks using robot arms and specialized end-effectors. A vision system plays a crucial role in guiding the robot by identifying specific areas within the patient's nasal and throat passages for swabbing. Subsequently, the robot arm retrieves the swab, carefully deposits it into a container, securely seals the lid, and then transports the sample to a laboratory for analysis. One noteworthy example of such automation is the Danish pipetting robot known as flowbot ONE, which is employed to streamline the Covid-19 testing procedures. This robot takes charge of the process following the initial inoculation, automating the entire sample preparation, including the mixing of liquids and chemicals required for Covid-19 analysis [2].

4. Technology in Treatment

The Covid-19 virus has ravaged the globe and infected billions of people. Those who are unfortunate enough to be infected with Covid-19 will suffer greatly, like high fever, difficult breathing, and pneumonia. Health workers around the world rushed to research and conduct clinical trials on treatments. Technology has played an important role to makes these treatment plans efficient and feasible.

4.1. Telerobotic Surgery

The Telerobotic surgery is a surgical operation remotely by manipulating surgical robots. To complete a telesurgery, some conditions are indispensable. For patients, they must have some unmet needs. For hospital, it must own surgical robots which can be used to do the surgery. And there must some robotic surgeons who are experienced and superior and they will operate the surgical robots. For network engineers, they must check the telecommunication network and equipment are intact.

This technique can more likely save one's life in time [11] under the Covid-19 infection, because it can prevent contacting with patients who are infective. However, there are still some technical deficiencies. For example, the delays, which is a unsolved difficulty, may cause some problems like resulting in less precise surgery [11]. The expensive fees are also problems. Most people can't afford such a high cost and they will lose their fortune.

4.2. Telerobotic Intelligent Nursing Assistant (TRINA)

It is a system that can help look after and monitor the patients [12]. Staff can monitor the condition of many patients at the same time and give timely care to those who need it. It can reduce the workload of the staff a lot. It has a body like human, and these two big arms are mainly used to finish something. Staff can command TRINA to do everything in its power through its control system. Also, he can observe the patient's condition conveniently through the camera on the head of TRINA.

This technology can prevent contacting with patients who are infective Covid-19. Besides, it can observe patients more conveniently. But there are still some human performances which can not be copied.According to recent studies, the robot effectively completes around 60% of nursing chores on average 20 times slower than a person [12]. Eventually, it lacks some human care, which can not notice the emotion and feeling of patients so that it can not give patients care timely.

4.3. Artificial Intelligence (AI)

AI could be used to develop drugs to treat Covid-19 [13]. It may be used by researchers to forecast the Covid-19 virus's protein structure, and they can create molecular models of the virus using algorithms like generative autoencoders, genetic algorithms, and language models [13]. This technology can avoid the troublesome and time-consuming process of artificially constructing molecular models of viruses, saving economic expenditure and time.

Although these structures require verification, this is indeed a promising and highly practical approach [13]. With these molecular models of the Covid-19 virus, AI can automatically extract useful information benefit scientist to create or improve drugs in clinical trials [13]. It is also likely to play a key role in vaccine development, big data statistics, and risk assessment.

5. Contact Tracing Technologies

Amidst the ongoing global battle against the Covid-19 pandemic, the importance of proficient epidemic control measures has become increasingly evident [14].

In a scenario where vaccines are not yet universally available, drugs for treatment are not fully developed, and testing remains limited, the need for strategies to reduce transmission and contain diseases like Covid-19 is paramount. Contact tracing, a fundamental tool in epidemic control, has gained renewed attention due to its potential to identify and isolate infected individuals, thereby curbing the spread of the virus [9].

Contact is defined as close proximity (within one meter) to a confirmed Covid-19 case for more than 15 minutes, engaging in direct physical contact with an infected individual, or providing care to Covid-19 patients without sufficient protection within the timeframe spanning from two days prior to symptom onset to a duration of fourteen days thereafter. People who have been recognized as confirmed contacts in cases containing Covid-19 are required to undergo a 14-day quarantine beginning with their most recent exposure and are under the control of health officials [15].

5.1. Traditional Contact Tracing

Traditional manual contact tracing relies on telephone or face-to-face interviews, which are known for their sluggishness and inefficiency [9]. The worldwide public health crisis triggered by the SARS-CoV-2 virus, known as the Covid-19 pandemic, has swiftly evolved into a crisis of unprecedented proportions, marked by millions of confirmed cases and fatalities across the globe [14]. Conventional contact tracing encounters significant hurdles in light of the sheer volume of cases. Moreover, these procedures struggle to match the swift transmission of Covid-19, rendering it arduous for health authorities and disease control teams to amass thorough contact details.

A significant proportion, approximately 84%, of Covid-19 infections are attributed to asymptomatic and mildly symptomatic individuals [9]. Traditional manual contact tracing is ill-equipped to identify and manage these cases, limiting its ability to control the disease's transmission effectively. Experts speculate that Covid-19 might follow a seasonal epidemic pattern, akin to influenza [9]. This anticipated shift presents significant hurdles for traditional manual contact tracing, further stressing its limitations in managing a virus with changing dynamics.

The complexity of tracking displaced migrants using traditional manual methods poses practical challenges [9]. Displaced populations often lack stable residence and may be difficult to reach, making traditional contact tracing unlikely to be successfully implemented.

5.2. Digital Contact Tracing

Digital contact tracing utilizes electronic data to detect instances of potential exposure to infections, offering the prospect of overcoming limitations associated with conventional approaches [9]. By harnessing contemporary technologies such as mobile devices, GPS-based, Wi-Fi-based, and Bluetooth-based, it can consistently monitor individuals' mobility and whereabouts, thereby aiding in the identification of potential contacts [9]. Empirical research has illustrated that widespread adoption of Digital contact tracing holds the capability to mitigate the spread of epidemics and decrease the necessity for extensive isolation measures [9].

5.2.1 Bluetooth-based solutions

The Bluetooth-based solution utilizes wireless technology for the identification of nearby mobile phones that have Bluetooth enabled and have tested positive for infection. This technology operates by emitting Bluetooth Low Energy (BLE) signals, commonly referred to as 'chirps,' and establishing a database exchange system to record the pseudo-random bit sequences emitted by the infected mobile phone, along with an estimate of the audio transmission power.

Due to the widespread inclusion of Bluetooth capabilities in smartphones, identifying proximity with other Bluetooth-enabled mobile devices is uncomplicated and economically efficient. The low power consumption of Bluetooth enhances accuracy, as it focuses on recording instances of 'contact' between smartphones rather than continuous location tracking. Moreover, the use of bit sequences instead of personal user data safeguards user privacy, and individuals receive real-time notifications when they share the same vicinity as an infected user.

At the same time bluetooth has some limitations as it requires the device to have enough power to run. Also, bluetooth signals may be less accurate in areas where there are many walls and obstacles to heart good. Bluetooth locates where electronic devices are located and is likely to give false alarms to non-infected people, leading to unnecessary concerns.

5.2.2 Wi-Fi-based solutions

Solutions based on Wi-Fi technology rely on Wi-Fi networks and the related data, including system logs, to collect pertinent information for contact tracing. When a user gets tested for Covid-19 and inputs their phone's IP address into the contact-tracing system, Wi-Fi logs from the network are examined to ascertain the locations the user has visited. By monitoring the user's connectivity to various access points as they change locations, these solutions can establish their movements over the preceding 14 days.

Wi-Fi-based solutions is faster than bluetooth, enabling quicker data transmission. Additionally, Wi-Fi has a wider coverage range, reaching up to a hundred meters from the base station, facilitating comprehensive contact tracing efforts. Properly configured Wi-Fi can also offer enhanced security measures, safeguarding user information. The greater bandwidth capacity of Wi-Fi ensures a smooth and reliable flow of information.

However, Wi-Fi-based solutions have limitations. Accurate distance measurement is a challenge, particularly outside the range of access points, resulting in less precise location determination. Wi-Fi-based solutions are primarily designed for indoor environments and may have limited effectiveness outdoors due to traffic and interference. Privacy concerns arise as contact-tracing tools require user data, potentially risking personal information exposure. When various devices are linked to the same wireless network access point, it is possible to identify multiple instances in a single area, even if only one individual is infected.

5.2.3 GPS solutions

Individuals who have been introduced to or sick with Covid-19 were tracked down utilizing location-based technologies, particularly GPS. User motions are captured and saved as locations and date and time stamps in GPS-based contact tracking. A user's device transmits where it's located via the system, and the information is stored and encrypted on a server. GPS technology finds extensive application in monitoring and enforcing quarantine restrictions for Covid-19 patients by identifying areas with a heightened concentration of cases. Due to the widespread availability of GPS-enabled cellphones and their inexpensive cost, GPS location is a benefit. However, security intrusions like spoofing and jamming can compromise GPS position tracking. While jamming uses radio waves on the same frequencies to interfere with the GPS signal, spoofing includes transmitting bogus GPS signals to produce inaccurate position and time information. Additionally, GPS has a range of only around 5 to 10 meters and has poor performance indoors and during bad weather, such as thunderstorms. GPS tracking also requires users to keep their phones charged and location tracking enabled. Similar to previous contact monitoring methods, GPS-based contact tracing raises privacy issues because user location, identity, and associated data are stored in a database without encryption. Moreover, GPS-based applications consume more power compared to bluetooth, as location services need to be constantly enabled.

5.2.4 Quick Response (QR)-based solutions

The use of quick response codes in contact monitoring apps has been shown to be a successful means of containing and slowing the spreading of the Covid-19 epidemic. QR codes play a significant role in countering Covid-19 because they provide trustworthiness, trackability and interoperability. The automatic screening and analyzing of code information offered by Quick Response (QR) codes has the advantage of eliminating errors and increasing data reliability. This method considerably speeds up processing as compared to manual processes. Additionally, integrating various features on a centralized platform helps overcome delays in data sharing, which ensures efficient control of highly infectious diseases. Furthermore, QR codes allow people to self-triage and organizations to self-schedule, relieving pressure on overworked healthcare systems. They accurately identify people who have had close touch with someone who has been infected while protecting user privacy by not retrieving location data.

However, there are certain limitations to consider. Privacy issues may make it more difficult for the general public to accept QR code-based applications, which would reduce the number of people who download them. Risks associated with unauthorized and unlawful use of healthcare data include monetary losses and harm to service providers' reputations. Furthermore, QR code data may not be as accurate as GPS data in identifying all contacts. GPS data provides more precise location information, whereas QR codes rely on individuals scanning codes when entering public places. Notwithstanding this limitation, the utilization of QR code technology has proven to be remarkably effective in managing and decelerating the pandemic's propagation, as evidenced by the minimal count of confirmed Covid-19 cases in China [15].

6. Summary

Since it was initially discovered in Wuhan, Covid-19 has spread quickly over the globe. The disease exhibits a remarkably high level of contagiousness, rapidly transmitting from person to person. The lack of an initial vaccine or effective virus treatment is linked to its elevated mortality rate. The most recent medical technologies can be quite helpful in tracing, detection, treatment, and prevention of the pandemic, such as loT, AI, Robots

Although these technologies are being used to prevent the pandemic, privacy and trust issues continue to be concerns.Several additional obstacles that affect the utilization of digital technology encompass the older population's challenges in adapting to technology, interruptions in internet connectivity, limited accessibility to technology, and inadequate training for healthcare professionals in harnessing technological tools. As a result, using technology to help pandemic is not only a promising industry but also an item with great potential and great improvement areas. The Covid-19 pandemic not only confirms the need for data sharing, but also confirms that, as the emerging field of mobile and digital medicine develops, a rigorous evaluation and community-based ethical framework is needed.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Alam Mehtab. Parveen Rizwana, Khan Ehtiram. Role of Information Technology in COVID-19 Prevention. 2020.

[2] Singh PK, Nandi S, Ghafoor KZ, et al. Preventing COVID-19 Spread Using Information and Communication Technology. IEEE Consumer Electronics Magazine, 2020, 10(4):18–27.

[3] Tilahun B, Gashu KD, Mekonnen ZA, Endehabtu BF, et al. Mapping the Role of Digital Health Technologies in Prevention and Control of COVID-19 Pandemic: Review of the Literature. Yearb Med Inform, 2021,30(1):26-37.

[4] Lv Z, Chen D, Feng H, Zhu H, Lv H. Digital Twins in Unmanned Aerial Vehicles for Rapid Medical Resource Delivery in Epidemics. IEEE trans Intell Transp Syst, 2021,23(12):25106-25114.

[5] Kalane P, Patil S, Patil BP, Sharma DP. Automatic detection of COVID-19 disease using U-Net architecture based fully convolutional network. Biomed Signal Process Control, 2021, 67:102518.

[6] Tahermanesh K, Hanjani S, Saadat Mostafavi SR, Shahriyari R, Fazel Anvari-Yazdi A, Karimi-Zarchi M, Samimi M, Karimi A, Allahqoli L, Alkatout I. Hourglass cesarean scar: A neglected external niche in association with the internal niche. Int J Gynaecol Obstet, 2022,157(2):478-480.

[7] Zhou Q, Shan J, Ding W, Wang C, Yuan S, Sun F, Li H, Fang B. Cough Recognition Based on Mel-Spectrogram and Convolutional Neural Network. Front Robot AI, 2021, 8:580080.

[8] Irkham I, Ibrahim AU, Nwekwo CW, Al-Turjman F, Hartati YW. Current Technologies for Detection of Covid-19: Biosensors, Artificial Intelligence and Internet of Medical Things (IoMT): Review. Sensors,2023, 23(1):426.

[9] Mao Z, Yao H, Zou Q, Zhang W, Dong Y. Digital Contact Tracing Based on a Graph Database Algorithm for Emergency Management During the COVID-19 Epidemic: Case Study. JMIR Mhealth Uhealth, 2021, 9(1):e26836.

[10] Ndiaye M, Oyewobi SS, Abu-Mahfouz AM, Hancke GP, Kurien AM, Djouani K. IoT in the Wake of COVID-19: A Survey on Contributions, Challenges and Evolution. IEEE Access, 2020, 8:186821-186839.

[11] Huraj L, Šimon M, Horák T. Resistance of IoT Sensors against DDoS Attack in Smart Home Environment. Sensors (Basel), 2020, 20(18):5298.

[12] Hanly, Eric J., and Timothy J. Broderick. Telerobotic surgery. Operative techniques in general surgery, 2005, 170-181.

[13] Nguyen., Thanh T. Artificial intelligence in the battle against coronavirus (COVID-19): a survey and future research directions. arXiv preprint arXiv, 2020, 2008.07343.

[14] Ferretti L, Wymant C, Kendall M, Zhao L, Nurtay A, Abeler-Dörner L, Parker M, Bonsall D, Fraser C. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. Science, 2020, 368(6491):eabb6936.

[15] Min-Allah N, Alahmed BA, Albreek EM, Alghamdi LS, Alawad DA, Alharbi AS, Al-Akkas N, Musleh D, Alrashed S. A survey of COVID-19 contact-tracing apps. Comput Biol Med, 2021, 137:104787.