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Review Article

Digital contact tracing in epidemics: fast tracking the future

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ABSTRACT

The COVID pandemic has brought unprecedented changes in the current healthcare model, more as a necessity than by choice. The rapid unraveling of the pandemic has fast tracked the use of technology and artificial intelligence in healthcare systems by identifying and implementing more efficient processes to mitigate the crisis. Digital contact tracing technology (DCTT) has been hailed as the savior for opening up the community towards some semblance to the previous normal. Understanding contact tracing as both a proactive tool in the containing of an epidemics and as a reactive tool in limiting damages after spread is of utmost importance before taking a call into its effectiveness and implication on privacy of the individuals involved. The current pandemic response is like building a plane during its flight, and hence the risks involved in understanding the disease and mitigating the problems due to the novel nature of the disease needs to be done in real time. The political and social outcries on the use of DCTT are enough reasons for caution in applying previously unperfected technologies in diseases whose natural course has not yet been fully understood. The relationship between epidemics and contact tracing, conventional contact tracing, DCTT, different models of DCTT used during the current epidemic, limitations of DCTT and the future of incorporating DCTT into healthcare systems from the view of epidemiology and patient safety will be the primary focus of this article.

Keywords: Digital contact tracing technology, Epidemics, COVID-19 pandemic, Contact tracing, Artificial Intelligence, Reopening economies

INTRODUCTION

Epidemics and contact tracing

Contagious nature of epidemics makes the understanding of the disease process very important and the COVID pandemic has highlighted the consequences of diseases historically restricted to certain areas can spread globally. The easy connectivity between nations and the unrestrained movement of travellers has transformed an epidemic in Asia into a global pandemic. Contact tracing is an important step in curbing an infection from becoming an epidemic or worse into a pandemic. The next person to whom the contagion has the possibility to spread is a designated contact, not necessarily the next case of disease who happens to be the next person to whom the disease has been successfully transmitted.[1] Hence the needs to trace these contacts in epidemics can have a big say in shaping up the epidemic itself. This is a proactive response in the early stages of an epidemic whereby the possible contacts are screened, isolated and quarantined to prevent the spread of the infection. Contact tracing normally is effective in diseases with low prevalence where rapid and effective testing for the disease can result in containing an epidemic in its earliest stage.[2] The current pandemic has been an eye opener as the disease is not only highly infective but the incidence or new cases of the disease are very high compared to the earlier epidemics.

Contact tracing is the epidemiological exercise of identifying, assessing, and managing potentially infected people due to exposure to prevent onward transmission of a disease. This public health tool when used systematically helps break the chains of transmission thereby containing the disease. In case of the present pandemic, this requires identification of contacts and constant vigilance for a minimum of fourteen days from the last point of exposure through isolation or quarantine.[3] Contact tracing preparedness, readiness and action will depend on the four main transmission scenarios namely: places with no cases where the planning and training for contact tracing is initiated, sporadic case detection where exhaustive contact tracing for rapid suppression of transmission is essential, clustering of cases where contact tracing reduces transmission within clusters, and community transmission where transmission is intense and contact tracing focused on household contacts, health care workers, high-risk and vulnerable contacts needs to be done.

The present knowledge of COVID provides us with four possible ways of transmission namely: symptomatic transmission: direct transmission from a symptomatic person which is clearly remembered and identified; pre-symptomatic transmission: direct transmission from a person who appears normal due to the early stage of the disease; asymptomatic transmission: direct transmission from individuals who will never show signs of infection; and environmental transmission: transmission through no apparent significant contact between individuals, maybe due to contamination of the surroundings from the diseased person.[4]

The current model of curbing the infection depends on isolation of the symptomatic patients and then tracing their contacts that are isolated and quarantined accordingly. Thus, conventional contact tracing CCT serves as a proactive intervention which prevents the spread of the contagion by reducing the transmission from both diseased and contacts who maybe symptomatic or asymptomatic, thereby minimizing the spread to the rest of the population. In spite of previous knowledge about these facts the world stands at a point in time where the epidemic is full blown in most parts of the world as many countries chose to sit on the problem at a time when rapid testing and contact tracing would have prevented explosion of the epidemic. The current interest in contact tracing is part of the suppression of the epidemic, used as a damage control tool to open up lockdowns and economies in order to achieve something in semblance to normal.[5] Contact tracing was effectively used during lockdowns in many essential services like healthcare workers, law enforcement services and media as they were vulnerable to infections. Contact tracing is now being glorified as the new saviour to bring back normalcy to the current state of things as it provides a ray of hope into ways to combat further transmissions and second waves of this dangerous disease.[6]

Control strategies for outbreaks of the COVID infection have focused on tracing contacts of symptomatic patients with epidemiologic links and early data has proved that severe acute respiratory syndrome (SARS) corona infection is more likely to be transmitted than Middle East respiratory syndrome (MERS) corona infection because of a higher estimated reproductive number and a shorter estimated serial interval distribution.[7] The viral shedding epidemiological studies have found that forty percent of transmission within close contacts happen pre-symptomatically followed by shedding up to one week after symptoms and also through high shedding in asymptomatic individuals.[8] Most contact spread happens within households with a secondary attack rate is around ten percent and the decisive factor in effectiveness of case isolation and contact tracing is the percentage getting infected from asymptomatic and pre symptomatic individuals.[4] Successful strategies include ample testing and contact tracing, supplemented by moderate forms of social distancing can keep the transmission rate near the epidemic threshold. Successful maintenance of this epidemic threshold needs a high level of resources which can be labour intensive and imperfect if done manually.[9] There is enough evidence suggesting that at least seventy percent of the contacts need to be traced to control an epidemic of which more than eighty five percent of the positive cases are pre symptomatic which are responsible for more than half of the total number of documented cases.[2] Understanding the current methodologies and principals involved in conventional contact tracing will form the basis for understanding the need for adapting swifter and more thorough technological advances for effective management.

METHODS

Conventional contact tracing

Conventional contact tracing is an epidemic control measure quite effectively used by many systems, especially when epidemics are identified and stopped at an early stage. This methodology follows the principles of back tracing the steps of an infected individual to identify, educate and monitor people who had significant contact for potential infection. The process involves patient interview followed by interview of the identified contacts which is easy, especially if the infection is exotic and the patient had a relatively quiet time with respect to travel and socializing.[10] Plotting of space-time points occupied by patients during their infective period helps identify the contacts through construction of patient movement maps and route maps. The maps are made by plotting places of the patient with respect to time during the infective period through interview of patient. An epidemiologic investigation team visits the area and collects additional information including location history from smart phones and social media geo tagging. This map is then widely publicized through visual, print and social media through official governmental agencies to intimate people with possible contact through designated platforms to communicate with the health authorities. Once identified these contacts are screened, isolated, and quarantined

accordingly and a surveillance list containing both primary and secondary contacts is published.[11] Contact tracing of asymptomatic cases can retrospectively identify source of infection which facilitates active case-finding around the source. Contact tracing in symptomatic cases can help in isolation and quarantine thereby breaking the chain of transmission. These two strategies have been used effectively to contain the infection as close contacts with symptoms can be tested and treated whereas asymptomatic but exposed can be quarantined. Household and work place contacts are usually well defined and hence better managed when compared to community contacts who are difficult to trace due to obvious logistic differences.[12]

The advantages of a conventional contact tracing lie in the details collected during the process for transmission risk between the contact and patient can be identified. A space time matrix can help in early identification and contact tracing of unknown contacts resulting in containment of the disease. A field visit by a team of public health experts including an epidemiologist can identify potential threats thereby building awareness on risk exposure and prevention. Immediate assessment of degree of risk followed by identification of potential high-risk points and implementation of appropriate control measures in the affected area can be implemented. A detailed contact tracing helps to identify source of infection in cases of missing links with the help of data collected during contact tracing for epidemiological analysis and research. The success of local containment or slowing down an epidemic by isolation and contact tracing depends on the percentage of infections that remain asymptomatic, pre-symptomatic or have mild disease.[13] It is also reported that with intensive contact tracing may be possible to trace the majority of secondary infections which could be the key to coming out of lockdowns and reopening the economies.[5] Identifying close contacts provides information on the cohort of patients who need immediate testing or self-isolation which can contain an outbreak. Contact tracing can be used in situations of widespread of a disease to understand disease spread and thereby curtail transmission. These COVID contact tracers can be divided into high risk and low risk in accordance to the level of contact which needs to be followed up to confirm infection status.[14]

The major challenges in relying on contact tracing as a primary strategy for control of COVID-19 epidemic is the space time matrix created for tracing contacts based on accuracy of history obtained from the cases and contacts. If the patient fails to disclose every aspect of his travel and contact history, the space time matrix generated will be incomplete and ineffective. The hiding of potential contacts due to social inhibitions, fear of quarantine or stigma can create confusion if factually incorrect details are published. Fear of infringement on privacy and freedom is thus a major barrier for effective contact tracing. Even when contacts are identified correctly many details like level of risk of exposure like closeness of contact, type of contact cannot be quantified by conventional methods. Contact tracing strategy cannot be applied for a large number of asymptomatic patients spreading the infection as they may never be diagnosed as testing are done only for symptomatic and high-risk individuals. These asymptomatic patients will be spreading the infection silently and contact tracing fails as a strategy in these cases. The ability of the COVID virus to infect at least 2.5 contacts per day makes the whole process difficult and the almost geometric progression of the spread makes contact tracing all the more challenging. Consensus on the exact mode of transmission of the disease is ongoing and hence all four modes should be taken into consideration during contact tracing which again makes this a Herculean task. Asymptomatic and pre-symptomatic transmitters will be missed if testing is mandated to symptomatic cases alone and hence isolation of symptomatic will fail in controlling transmission in the infected but asymptomatic stage.[15] Understanding the limitations of CTT should help in better understanding DCTT.

Digital contact tracing technology

DCTT has been embraced by many countries by implementing digital apps which assist in identifying, contact tracing and at times tracking the movements of cases and contacts. Many technologies have been used for digital tracking which are beyond the scope of this discussion but a thorough knowledge of the principles of DCTT can help in understanding its advantages and limitations. DCTT, as an epidemiological tool can identify if two people had been at the same location with the help of co-location tracking as the technology is already present in smart phones whereby rhetorical checks of proximity interaction between two smart devices can be identified.[16] This can be a simple system in which the app contains a GPS- based location logger which can help retrace GPS data of an infected person when fed into the application's central server. The app can provide the location map of the individual for a set period of time in accordance to the duration of his symptoms keeping while protecting his identity.[17] DCTT uses electronic information to identify contacts overcoming the limitations of manual contact tracing like scalability, notification delays, recall errors and contact identification in public spaces. If digital contact tracing is used early in an epidemic identification of positioning data, breaking the chains of disease transmission in community clusters can be effectively achieved.[18] It can improve the efficiency of manually collected field data collections and outbreak investigation platforms when used in synergy, especially by a team of epidemiologists.[19]

In Israel, legislation was passed to allow the government to track the mobile-phone data of people with suspected infection.[20] Users downloading the app can follow the trail of the infected person to identify any overlap during the period of infection thereby determining significant contact. Such critical information have been used in tracking earlier epidemics like Ebola, and contact tracing through location tracking has been used successfully by South Korea and Taiwan, incidentally the two countries who have curbed

the epidemic at an early stage.[21] China had taken a more comprehensive approach with a central database collection of deploying a plugin for apps like WeChat and Alipay which are commonly used by the population but the use of the plugin was not deemed compulsory, except in cases of movement from certain areas like hotspots.[22] The 'Trace together' mobile app in Singapore was a community driven contact tracing program which used the Bluetooth relative signal strength indicator (RSSI) readings between devices across time to approximate the proximity and duration of an encounter between two users who had downloaded the app.[23] The advantage of this app is that no location data is collected and the proximity and duration information is encrypted in the device itself on a rolling basis for 21 days. If a person becomes infected, his phone is used by the Ministry of Health to work out his individual trail over 14 days for contact tracing and further epidemiological purposes through community participation in an ethical way with minimal intrusion into private information of the users. Most COVID-19 contact-tracing apps use Bluetooth signal strength to infer distance between smartphones and define exposure status based on distance and duration of proximity to an individual identified as infected and thereby identifying primary and secondary exposures.[24]

In May 2020, an Apple–Google collaboration planned to release an application programming interface that will assist public health agencies to develop customized apps and launched for both android and IOS platforms.[25] This digital tracking system included an application programming interfaces (APIs) and operating system-level technology to assist in contact tracing with maximum protection of the privacy of the user. These tech giants intend to roll out an API through their app stores which will help public health authorities use the data if the need arises. They are also planning to build a Bluetooth based contact tracing platform like 'Trace together' which will help individuals and health authorities interact in an optimal way for contact tracing and other epidemiological purposes. The foundation of this platform is transparency and maintenance of privacy of the stakeholders as it emphasizes on explicit user consent, non-collection of personally identifiable information or user location data. The advantages are that they will be decentralized in the sense that each device would collect the information individually, the anonymity of the positive cases to other users and will be used solely by a competent health authority for contact tracing.

The decision to deploy DCTT at a regional, national, or global level needs to take into consideration a balance between individual data privacy and societal benefit. The concept of data sharing to facilitate public good like location sharing through GPS with the permission of the user is well documented as in the case of Google Maps and other location finders. An exact balance between public good and private data ownership has to be the goal of DCTT as understanding the movement history of infected individuals could warn healthy users about potential exposure.[26]

Understanding the differences between CCT and DCTT will help us in better utilization of this technology. The effectiveness of CCT is well documented when compared to DCTT. CCT exclusively deals with confirmed cases and their suspected contacts based on clinical or serological evidence but DCTT involves a larger cohort of people in the general public who need not be infected.[27] CCT happens through human-to-human encounters which provide ample opportunities to clarify misconceptions, answer queries, express empathy and gains the confidence of the patient while the same cannot be true when applying technology through DCTT. CCT has an accountability chain which can be easily traced unlike the case of DCTT which has an increased number of entities handling data thereby collecting data which can result in unaccountable misuse of private information.[28]

DISCUSSION

Challenges and limitations of DCTT

Desperate times lead to desperate measures and many countries had enforced draconian lockdowns to decrease the spread of the disease with extreme measures like arrests and prison sentences for disobeying these stringent rules resulting in disruption of normal life. Returning back to pre-COVID normal seems like an unachievable goal but reliance on DCTT to achieve a new normal would fast track identifying infected contacts paving way to an early reopening of economies.[29] The spread of the COVID virus is too rapid and rampant that manual contact tracing would be inefficient and a digital contact tracing app that builds a memory of proximity contacts with the ability to notify contacts can achieve epidemic control if used by enough people.[30] Once used at this point in the epidemic, the contact tracing app should be used by everyone thereby containing the epidemic without the need for lockdowns and quarantines. Like manual contact tracing digital contact tracing has to confirm the infected person through tests by a healthcare worker but once this is done, relevant clusters associated with the contact can be easily identified and contained according to the guidelines in the system. Contact tracing effectively reduces the R0 or R-naught which is the minimum number of cases which needs to be infected or recovered from the infection to provide blanket immunity for the population which are not yet infected.[32] The ethical aspect of the digital contact tracing is immensely challenging given the logistics involved in contact tracing. The importance of public participation, trust and confidence needs to be addressed so as to achieve optimum results. Since the process involves gathering of sensitive data, strong well-established arguments on the risk to benefit aspect of the process has to be understood and debated in the public domain. Achieving health benefits and avoiding harm especially in diseases as complicated as the COVID infection need to be addressed in a transparent way so as to gain public trust.[28] DCTT should not completely replace the conventional contact tracing system as questions on the effectiveness and security of the platform is yet to be fully understood. As

with embracing any new technology, these apps can present with new challenges of access and equity due to the difference in the availability of smart devices technology to everyone.[24] The tool will not help populations who have lower levels of smartphone ownership such as the elderly or homeless, who are also particularly vulnerable to the virus as with people who do not download the app due to apprehension or fear.[1]

Limitations of DCTT lie in the fact that the effectiveness of the app is dependent on the number of people who are ready to download it. The potential of the app to identify contacts varies with the square of the fraction of users using it in the whole population thereby having significant implications.[4] Most DCTT systems have measurement error thereby limiting its effectiveness especially with Bluetooth based apps due to the use of different signal strengths. These are device specific with high degrees of fluctuations especially when faced with obstacles like people between them during transmission.[16] This can result in false measurements mainly due to decreased sensitivity and specificity thereby missing exposures or false identifications leading to unnecessary isolation, quarantines with immense psychological, financial and social implications.[24] The constant fear of monitoring introduces privacy concerns of significant importance which is very limited in conventional contact tracing. There are no published studies showing the effectiveness of any DCTT and hence can lead to a false sense of security resulting in less adherence to other preventive measures or reduced cooperation with traditional contact tracing.[4] Looking beyond the media hype, the actual understanding of the DCTT which uses machine learning does not actually paint a very rosy picture at least in terms of the heavy price the common man will have to pay if things do not go according to plan. As discussed before, some governments have access to road maps and geo mapping of cases and contacts which can be used for surveillance which is beyond the use of a contact tracing app.[33] This leads to targeting and possible discrimination towards a certain group in accordance to political and social fabric of individual states. A person getting the infection has nothing to do with his private preferences, especially in this pandemic which has spread indiscriminatingly in the community. The fact that Google and Apple have come to the foray of producing APIs for healthcare systems needs to be taken with a pinch of salt as the mobile devices and their sensors make a very poor proxy for actual testing and treatment.[25]

The flaws of the system can range from false positives setting up a trail of unwanted roadmaps and alarm among contacts of uninfected individuals presumed to be potentially infected as picked up by the device despite minimum contact. DCTT does not have the ability to understand people who actually have taken precautions such as healthcare workers who obviously come in contact with cases. The DCTT will not take into consideration fleeting contact as in grocery stores and other essential places where the chance of transmission is relatively less.[34] The wisdom of conventional contact tracing is absent in DCTT resulting in false positives needing quarantine which has the potential to be disregarded eventually defeating the purpose of contact tracing. This can lead to the phenomenon of prevention paradox which has been witnessed following the release of strict lockdowns.[35] False negative contact tracing by DCTT is more dangerous than the false positives as they are effective only when eighty percent of the population download the app. Since the downloading of the app is optional it becomes a challenge to flag people at potential risk without the app in their device. A sure shot way of overcoming this is to make it compulsory for all positive cases to download the app before discharge from the screening facility.[33] Some countries have made it mandatory to download and report events regularly through such apps for continuing work in both public and private organizations. Further people may not always carry their phones and the cases cannot be traced in cases of environmental transmission and asymptomatic transmissions unless hotspots of transmissions are properly documented during the initial screening. These limitations have to be clearly understood and recommendations for how back-end systems should be secured and how long data should be retained, and criteria for public health entity's qualification for accessing these technologies have to be defined. The apps already approved need to be constantly audited for security, privacy, abuse testing and cyber threats to identify vulnerabilities and unintended consequences of this potentially global technology.[28]

Future of contact tracing

Contact tracing either through DCTT or the conventional way is a supportive measure to prevent the spread of an infection but the cornerstone in the management of any epidemic is a comprehensive testing strategy which needs to be given due importance. The transmission through pre symptomatic carriers and asymptomatic carriers range to up to fifty percent of transmission which can occur three days before the onset of infection leaving a lot to chance in the current system.[3] Thus, the integration of DCTT into the conventional contact tracing for future epidemics seems the most logical way ahead despite the flaws of the digital version. The value of timely interventions is one important lesson learned from the present pandemic and DCTT helps in identifying potential contacts instantly and notifying them for possible quarantines. This is especially relevant given the long period of infectivity of COVID, which begins before people are symptomatic and aware of their disease themselves.[4] The self-limiting nature of the current pandemic in healthy individuals gives the option of using DCTT to identify and self-isolate without involving health authorities. In cases when health authorities are involved DCTT provides a means of following up the cases for complications or reinfections.[36] The ideal DCTT which will be decentralization, with de-identified information, user anonymous, bans on collection of location data, and minimal reliance on integration into public health authorities is yet to be a reality. Early adoption of DCTT

can improve the public health response, thereby decreasing lockdowns which are harmful to economies and liberty of individuals.[37]

Conventional contact tracing should be considered as a highly specific way to identify exposures which need to be expanded according to the needs. DCTT can improve the efficiency of data collection, automate contact notification, provide geo tagged contact map and support quarantined individuals.[24] DCTT can provide option to record contact logs which allow users to enter location data in their devices which could aid the conventional contact tracing.[38] The gap between case identification and contact notification can be reduced by using DCTT as a rapid screening tool with distance and duration thresholds defined in accordance to standards to enable sensitive detection of contacts. Rapid notification to potential contact with recommendation for isolation till follow up by manual contact tracing will help mitigate the imprecision of DCTT but enhance the efficacy of conventional contact tracing. Identifying the ideal DCTT and training the future epidemiologists in the intricacies of DCTT will be a step in the right direction. Artificial intelligence is the next logical step in contact tracing as dive plane, an AI driven company has launched 'Aware', a contact tracing app which acts on the principles of interruption of ongoing transmission and reducing the spread of infection, alert contacts and public services personnel to the possibility of infection at a specific location, information and context needed for more accurate epidemiology, diagnosis, and treatment, data to help prevent reinfections and a guidance system for a broader population health management platform that greatly informs analysis and decisions. Appropriate use of artificial intelligence, DCTT and healthcare guidelines along with the skill set of expert epidemiologists could be the future of contact tracing technology.[39]

CONCLUSION

Digital contact tracing technologies are the future of contact tracing given their easy access, proactivity and ability for community participation which can result in better containment and mitigation of future epidemics. The level of embracement of this technology into conventional contact tracing systems will depend on the effectiveness documented through published evidence bases. The future of successful contact tracing could be a hybrid of the principles of conventional contact tracing with a diligent use of digital contact tracing technology and artificial intelligence.

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REFERENCES

1. Nosyk B, Armstrong WS, del Rio C. Contact tracing for COVID-19: An opportunity to reduce health disparities and End the HIV/AIDS Epidemic in the US. Clin Infect Dis. 2020;ciaa501.
2. Hellewell J, Abbott S, Gimma A, Bosse NI, Jarvis CI, Russell TW, et al. Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. Lancet Glob Health. 2020;8(4):e488-96.
3. World Health Organization. Contact tracing in the context of COVID-19. 2020. Available at: https://www.who.int/publications/i/item/contact-tracing-in-the-context-of-covid-19. Accessed on 11 July 2022.
4. Ferretti L, Wymant C, Kendall M, Zhao L, Nurtay A, Abeler-Dörner L, et al. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. Science. 2020;368(6491):eabb6936.
5. Keeling MJ, Hollingsworth TD, Read JM. The Efficacy of Contact Tracing for the Containment of the 2019 Novel Coronavirus (COVID-19). Public and Global Health. 2020;74(10):861-6.
6. Zhang J, Litvinova M, Wang W, Wang Y, Deng X, Chen X, et al. Evolving epidemiology and transmission dynamics of coronavirus disease 2019 outside Hubei province, China: a descriptive and modelling study. Lancet Infect Dis. 2020;20(7):793-802.
7. Chen N, Zhou M, Dong X. Clinical Characteristics of Covid-19 in China. N Engl J Med. 2020;382(19):1859-62.
8. Wölfel R, Corman VM, Guggemos W, Seilmaier M, Zange S, Müller MA, et al. Virological assessment of hospitalized patients with COVID-2019. Nature. 2020;581(7809):465-9.
9. Park SW, Sun K, Viboud C, Grenfell BT, Dushoff J. Potential roles of social distancing in mitigating the spread of coronavirus disease 2019 (COVID-19) in South Korea. Infect Dis. 2020 Mar [cited 2020 Jun 11]. Available from: http://medrxiv.org/lookup /doi/10.1101/2020.03.27.20045815.
10. Kumar CPG, Sugunan AP, Yadav P, Kurup KK, Aarathee R, Manickam P, et al. Infections among Contacts of Patients with Nipah Virus, India. Emerg Infect Dis. 2019;25(5):1007-10.
11. Fawole OI, Dalhat MM, Park M, Hall CD, Nguku PM, Adewuyi PA. Contact Tracing Following Outbreak of Ebola Virus Disease in Urban Settings in Nigeria. Pan Afr Med J. 2017;27(1):8.
12. Kretzschmar ME, Rozhnova G, van Boven ME. Isolation and contact tracing can tip the scale to containment of COVID-19 in populations with social distancing. Infectious Diseases (except HIV/AIDS). 2020.
13. Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, et al. The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application. Ann Intern Med. 2020;172(9):577-82.
14. Contact tracing for COVID-19: current evidence, options for scale-up and an assessment of resources needed. European Centre for Disease Prevention and Control. 2020. Available at: https://www.ecdc.

europa.eu/en/publications-data/contact-tracing-covid-19-evidence-scale-up-assessment-resources. Accessed on 11 July 2022.
15. Steinbrook R. Contact Tracing, Testing, and Control of COVID-19—Learning From Taiwan. JAMA Intern Med. 2020; 180(9):1163-4.
16. Moreno-Pozas L, Lopez-Martinez FJ, Cotton SL, Paris JF, Martos-Naya E. Comments on Human Body Shadowing in Cellular Device-to-Device Communications: Channel Modeling Using the Shadowed $\kappa-\mu$ Fading Model. IEEE J Sel Areas Commun. 2017;35(2):517-20.
17. Cho H, Ippolito D, Yu YW. Contact Tracing Mobile Apps for COVID-19: Privacy Considerations and Related Trade-offs. ArXiv200311511 Cs. 2020. Available at: http://arxiv.org/abs/2003.11511. Accessed on 11 July 2022.
18. Farrahi K, Emonet R, Cebrian M. Epidemic Contact Tracing via Communication Traces. PLoS One. 2014;9(5):e95133.
19. Ekong I, Chukwu E, Chukwu M. COVID-19 Mobile Positioning Data Contact Tracing and Patient Privacy Regulations: Exploratory Search of Global Response Strategies and the Use of Digital Tools in Nigeria. JMIR MHealth UHealth. 2020;8(4):e19139.
20. Abeler J, Bäcker M, Buermeyer U, Zillessen H. COVID-19 Contact Tracing and Data Protection Can Go Together. JMIR MHealth UHealth. 2020;8(4):e19359.
21. Wang CJ, Ng CY, Brook RH. Response to COVID-19 in Taiwan: Big Data Analytics, New Technology, and Proactive Testing. JAMA. 2020;323(14):1341-2.
22. Yan A, Zou Y, Mirchandani DA. How hospitals in mainland China responded to the outbreak of COVID-19 using IT-enabled services: an analysis of hospital news webpages. J Am Med Inform Assoc. 2020;ocaa064.
23. Lin RJ, Lee TH, Lye DC. From SARS to COVID-19: the Singapore journey. Med J Aust. 2020;212(11):497-502.
24. Kleinman RA, Merkel C. Digital contact tracing for COVID-19. Can Med Assoc J. 2020;cmaj.
25. Greenberg A. Apple and Google Respond to Covid-19 Contact Tracing Concerns | WIRED. 2020. Available at: https://www.wired.com/story/apple-google-contact-tracing-strengths-weaknesses/. Accessed on 11 July 2022.
26. Kapa S, Halamka J, Raskar R. Contact Tracing to Manage COVID-19 Spread-Balancing Personal Privacy and Public Health. Mayo Clin Proc. 2020;95(7):1320-2.
27. Cohen IG, Gostin LO, Weitzner DJ. Digital Smartphone Tracking for COVID-19: Public Health and Civil Liberties in Tension. JAMA. 2020;323(23):2371-2.
28. Kahn J. Digital contact tracing for pandemic response: ethics and governance guidance. Baltimore: Johns Hopkins University Press. 2020.
29. Berwick DM. Choices for the "New Normal". JAMA. 2020 Jun 2;323(21):2125-6.
30. Zastrow M. Coronavirus contact-tracing apps: can they slow the spread of COVID-19? Nature. 2020;d41586.
31. Pei S, Kandula S, Yang W, Shaman J. Forecasting the spatial transmission of influenza in the United States. Proc Natl Acad Sci. 2018;115(11):2752-7.
32. Kwok KO, Lai F, Wei WI, Wong SYS, Tang JWT. Herd immunity - estimating the level required to halt the COVID-19 epidemics in affected countries. J Infect. 2020;80(6):e32-3.
33. Sacks JA, Zehe E, Redick C, Bah A, Cowger K, Camara M, et al. Introduction of Mobile Health Tools to Support Ebola Surveillance and Contact Tracing in Guinea. Glob Health Sci Pract. 2015;3(4):646-59.
34. Wang CJ, Ng CY, Brook RH. Response to COVID-19 in Taiwan: Big Data Analytics, New Technology, and Proactive Testing. JAMA. 2020;323(14):1341.
35. Raza SA, Salemi JL, Zoorob RJ. Historical perspectives on prevention paradox: When the population moves as a whole. J Fam Med Prim Care. 2018;7(6):1163-5.
36. Alizargar J. Risk of reactivation or reinfection of novel coronavirus (COVID-19). J Formos Med Assoc Taiwan Yi Zhi. 2020;119(6):1123.
37. Bernstein J, Holroyd TA, Atwell JE, Ali J, Limaye RJ. Rockland county's proposed ban against unvaccinated minors: Balancing disease control, trust, and liberty. Vaccine. 2019;37(30):3933-5.
38. Hart V, Siddarth D, Cantrell B, Tretikov L, Eckersley P, Langford J, et al. Outpacing the Virus: Digital Response to Containing the Spread of COVID-19 while Mitigating Privacy Risks. 2020. Available at: https://ethics.harvard.edu/outpacing-virus. Accessed on 11 July 2022.
39. Smith R. Artificial intelligence startup dives into COVID-19 contact tracing, targets privacy worries | WRAL TechWire. 2020. Available at: https://www.wraltechwire.com/2020/05/28/artificial-intelligence-startup-dives-into-covid-19-contact-tracing-targets-privacy-worries/. Accessed on 11 July 2022.

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