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Contact tracing in epidemiology: Lessons learnt from COVID-19

Taiwo Akindahunsi [1,*], Victor Adeoye [2], Emmanuel Faderin [3], Olumayowa Adeleke Idowu [4], Chidiebere Izundu Chukwuka [5] and Oluwabunmi Blessing Adesina [6]

[1] *Lagos State Primary Health Care Board, Yaba Lagos, Nigeria.*
[2] *InStrat Global Health Solutions Ltd., Nigeria.*
[3] *Federal Neuro-Psychiatric Hospital, Yaba Lagos, Nigeria.*
[4] *Department of Economics, Lagos State University, Ojo Lagos, Nigeria.*
[5] *School of Medicine, Universidad Central Del Este, Dominican Republic.*
[6] *Department of Epidemiology and Medical Statistics, University of Ibadan, Ibadan, Nigeria.*

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Abstract

Contact tracing is a powerful public health tool used in identifying people that might have been in contact with an infected person to assess the potential of being infected and transmitting the diseases. This review explores the history, implementation, and effects of contact tracing, as a significant public health strategy during the COVID-19 pandemic. The review started by giving a historical summary of contact tracing, then links it to early efforts at disease control for diseases such smallpox and TB. We further examine pre-COVID-19 contact tracing approaches, such as manual and early digital tools employed during past epidemics like Ebola and Zika. While investigating the development of digital innovations—such as Bluetooth-based applications and location data tracking—that were used to improve tracing efforts—the review emphasises the efficacy and problems of conventional manual contact tracing during COVID-19. Notably, we examine the hybrid models that combine manual and digital approaches, proving higher compliance and efficiency. Along with the difficulties countries with less efficient tracing systems—such as the United States and India—the review also includes worldwide case studies showing successful implementations in countries such Taiwan, South Korea, and New Zealand. Emphasising the need of public trust and the effect of the digital divide, it also covers public compliance and social elements affecting involvement in contact tracing programs. In order to strengthen public health preparedness for next pandemics, we offer potential options for contact tracing resilience, arguing for contact systems backed by technological developments and ethical protections. Informing best practices for next epidemiological tactics, this thorough analysis uncovers important insights and lessons learnt from the COVID-19 pandemic.

Keywords: Contact tracing; COVID-19; Public health; Manual tracing; Digital tools; Hybrid models; Pandemic preparedness

1. Introduction

Contact tracing, a public health intervention to control infectious diseases has been essential for decades (1). Contact tracing first emerged from the control of early infectious diseases such tuberculosis and smallpox (2). These diseases forced public health authorities to acknowledge the need of spotting and separating those who had come into contact with an infectious agent (1). Authorities were able to stop the spread of infection by tracing and informing those who had come into touch with an affected individual.

Formalised as part of epidemiological practice in the early 20th century, contact tracing is known as Public health initiatives during tuberculosis outbreaks included locating close contacts of affected people, doing skin tests or chest X-

* Corresponding author: Taiwo Akindahunsi

rays, and isolating those who were exposed (2). As health authorities aimed to stop the spread of the disease, which passed by respiratory droplets, this habit became pillar of tuberculosis control. This era saw the founding of contact tracing as a main instrument for controlling infectious disease outbreaks (5). The management of smallpox provides still another early example of formalised contact tracing (6). Contact tracing was employed to identify those who might have been infected with the virus and vaccinate them to stop more transmission during the 1960s and 1970s global smallpox eradication campaign (6). With the World Health Organisation (WHO) declaring smallpox eradicated in 1980, this approach was crucial in helping the disease to be eradicated worldwide. The effectiveness of focused interventions, such contact tracing, in preventing the spread of infectious diseases was proved by the method's effectiveness (7).

2. Development of Contact Tracing Methodologies Through Different Epidemics

As global health challenges evolved, contact tracing methodologies were adapted and improved through various epidemics (9). Contact tracing, for instance, proved a crucial technique in managing the extremely contagious and fatal virus during the 2014 Ebola outbreak in West Africa (8). Tracing thousands of confirmed Ebola cases, health professionals identified and watched people for symptoms throughout a 21-day incubation period (7). The effectiveness of these initiatives was hampered, nevertheless, by the poor infrastructure and resources in impacted areas. The outbreak brought attention to the need for improved logistical support and stronger health systems in subsequent epidemics (5).

Similarly, during the 2002–2003 Severe Acute Respiratory Syndrome (SARS) outbreak brought on by the SARS-CoV virus, contact tracing was essential (10). Rapidly affecting over 8,000 individuals in 29 countries, SARS claimed almost 800 lives (10). Public health officials in afflicted nations including China, Hong Kong, and Canada responded by implementing rigorous contact tracing to identify and confine those who had been exposed (11). This approach helped to stop the pandemic greatly, and the knowledge gained from SARS was subsequently used to future outbreaks including the Middle East Respiratory Syndrome (MERS) outbreak in 2012 (10). Contact tracing techniques were considerably improved by the MERS outbreak brought on by a new coronavirus. Having a case fatality rate of 34.4% (13), MERS had a far greater mortality rate than SARS. In the Middle East and South Korea, where significant infection clusters developed, contact tracing emerged as a crucial component of the response. During the MERS outbreak, for example, authorities in South Korea used a mix of conventional contact tracing and technology techniques like mobile phone tracking to track down almost 17,000 contacts. The outbreak was contained and future transmission was stopped because to these methodological developments (12).

Basically, changes in public health interventions and the character of infectious diseases have helped to define the evolution of contact tracing in epidemiology. From its beginnings in controlling tuberculosis and smallpox to its vital involvement in more recent epidemics including Ebola, SARS, and MERS, contact tracing has shown to be a crucial tool in limiting outbreaks. As these historical cases show, contact tracing is still a crucial tactic in contemporary epidemiology, particularly in view of growing global health challenges (12).

3. Pre-COVID-19 Contact Tracing Strategies

3.1. Manual Contact Tracing

Before the COVID-19 pandemic, manual contact tracing had long been a fundamental approach in epidemiology for controlling infectious diseases (6). Manual contact tracing is a systematic process where public health workers identify individuals who have come into contact with an infected person, notify them of their exposure, and recommend isolation or quarantine to prevent further spread (14). This method has been a critical strategy in controlling diseases like tuberculosis, smallpox, and HIV/AIDS (15).

Manual contact tracing involves several steps: first, interviewing the infected individual to gather information about their movements and interactions (6). Second, health workers reach out to the identified contacts, inform them of their potential exposure, and assess their health status (14). Third, contacts are advised to quarantine or isolate if necessary, and they may undergo testing or treatment depending on the disease (15). According to the Centres for Disease Control and Prevention (CDC), manual contact tracing was notably successful in controlling tuberculosis in the 20th century. Through meticulous efforts to trace and isolate individuals who had been exposed, public health authorities were able to reduce transmission rates (16). For instance, during the 2014 Ebola outbreak in West Africa, manual contact tracing was crucial in containing the virus. Health workers conducted door-to-door interviews to identify individuals who had come into contact with Ebola patients (8). Once contacts were identified, they were placed under quarantine for the duration of the 21-day incubation period. This approach was essential in breaking the chain of transmission (8). Despite its effectiveness, however, manual contact tracing during the Ebola outbreak faced significant challenges, such as a shortage of trained personnel, logistical issues in remote regions, and public mistrust (8). These challenges highlighted the need for more advanced and efficient methods to complement traditional contact tracing (15).

3.2. Digital Contact Tracing Tools Before COVID-19

While manual contact tracing was the dominant method before COVID-19, digital tools for contact tracing had begun to emerge in response to various outbreaks, including Ebola, HIV/AIDS, and the Zika virus (17). These tools leveraged technology to enhance the efficiency and reach of contact tracing efforts, particularly in cases where manual processes were insufficient (17).

During the 2014-2016 Ebola outbreak, digital tools were used to complement manual contact tracing efforts (8). Mobile phones were employed to record and track the movements of contacts, enabling health workers to monitor those who were placed under quarantine. In some cases, GPS data was used to ensure that individuals adhered to quarantine measures (18). According to the World Health Organisation (WHO), these digital tools helped improve the speed and accuracy of contact tracing efforts in remote areas where manual tracing was logistically challenging (19).

In the context of HIV/AIDS, digital tools had been utilised to a limited extent for contact tracing before the COVID-19 pandemic (20). For example, partner notification services, supported by digital platforms, allowed individuals diagnosed with HIV to inform their sexual partners of potential exposure anonymously (21). Although these tools were not as widespread as they became during COVID-19, they demonstrated the potential for digital solutions to address privacy concerns and improve the efficiency of contact tracing efforts (20).

Similarly, during the Zika virus outbreak in 2015-2016, digital contact tracing tools were used to track the movement of individuals in regions with high rates of transmission (8). Zika, which was primarily spread through mosquitoes but also through sexual contact, posed unique challenges for contact tracing due to the wide geographical spread of the outbreak. In response, public health agencies used mobile apps and digital platforms to collect real-time data on the locations of infected individuals and their contacts (22). These tools enabled health workers to map transmission patterns and target interventions more effectively (21).

Despite the promise of digital tools before COVID-19, their adoption was limited due to concerns about privacy, data security, and accessibility (22). For instance, while GPS tracking could ensure compliance with quarantine measures, it also raised ethical concerns about surveillance and individual rights (21). These challenges limited the widespread use of digital contact tracing tools in outbreaks prior to COVID-19, although they laid the groundwork for the rapid expansion of such technologies during the pandemic (22).

4. Contact Tracing Methods during the COVID-19 Pandemic

The COVID-19 pandemic presented an unprecedented global health challenge that required rapid and scalable interventions (24). Contact tracing became a crucial tool in identifying and breaking transmission chains to control the spread of the virus. Public health authorities worldwide employed a combination of manual and digital contact tracing methods to curb the pandemic (23).

4.1. Manual Contact Tracing Approaches

4.1.1. Description of Traditional Manual Contact Tracing Efforts during COVID-19

Manual contact tracing has long been the cornerstone of public health efforts in combating infectious diseases (25). During the COVID-19 pandemic, this approach involved identifying people who had been in close contact with an infected individual, informing them of their exposure, and recommending testing, isolation, or quarantine (24). The process typically involved interviews with confirmed COVID-19 patients to identify their recent contacts, followed by notifying these contacts, monitoring them for symptoms, and advising appropriate health measures (24).

Given the highly transmissible nature of COVID-19, manual contact tracing was rapidly scaled up worldwide (25). Health authorities and local governments deployed thousands of contact tracers to reach individuals at risk of infection. In the United States, for example, many states quickly expanded their workforce by recruiting volunteers and training them in the fundamentals of contact tracing (25). The World Health Organisation (WHO) also issued guidelines on implementing contact tracing efforts globally, emphasising the importance of isolating suspected cases, testing, and conducting thorough contact follow-ups (26).

4.1.2. Challenges of Scaling Manual Contact Tracing during a Global Pandemic

Despite its proven efficacy, manual contact tracing faced significant challenges during the COVID-19 pandemic. First, the sheer scale of the virus's spread overwhelmed public health infrastructures (19). In many countries, the high volume of cases meant that contact tracers could not keep up with the growing lists of potential contacts. Contact tracing is most effective when fewer than 1,000 cases are identified per day. Beyond this threshold, contact tracers struggled to reach individuals in a timely manner, leading to gaps in isolation and quarantine measures (19). Another challenge was the time-intensive nature of manual contact tracing. Each confirmed case required extensive interviews to trace potential contacts, which could take hours (27). In large cities or densely populated areas, these efforts were hampered by logistical challenges, such as poor communication infrastructure or difficulties in tracking individuals who moved frequently. Furthermore, many regions experienced public resistance to contact tracing due to fears of stigma or quarantine measures, further complicating efforts (26). Additionally, there were ethical concerns regarding data privacy (27). Contact tracing often required sharing personal information, which raised concerns about how the data would be used and stored. Some individuals were hesitant to disclose their contacts due to fears of data misuse or lack of trust in government agencies, further hampering manual efforts (26).

4.2. Digital and Technological Innovations in Contact Tracing

The COVID-19 pandemic accelerated the development and adoption of digital contact tracing tools, which leveraged mobile apps and digital platforms to enhance traditional tracing efforts (22). Governments and health authorities worldwide turned to digital tools to overcome the limitations of manual tracing, particularly in regions with high transmission rates (12).

Several countries launched mobile contact tracing apps to facilitate the tracking of potential exposures (28). These apps used Bluetooth, GPS, or QR code scanning to identify and notify individuals who had been in proximity to confirmed cases (28). For example, Singapore's *TraceTogether* app, one of the first digital contact tracing tools launched in 2020, used Bluetooth signals to detect nearby users and track their proximity (29).

4.2.1. Bluetooth-Based Contact Tracing Applications

One of the most prominent digital contact tracing solutions was the Apple-Google Exposure Notification System (ENS), which was deployed in several countries (30). The ENS utilised Bluetooth technology to exchange anonymous keys between smartphones when users were near each other (31). If one user tested positive for COVID-19, they could voluntarily share their diagnosis through the app, triggering notifications to others who had been in close contact (31). The Apple-Google ENS was adopted by multiple countries, including the United States, Canada, Germany, and the United Kingdom. It addressed several privacy concerns by ensuring that no personally identifiable information or location data was shared (32). All data exchanged between users remained anonymous and encrypted, and users had to opt-in to share their COVID-19 status (32). This decentralised approach aimed to strike a balance between public health and privacy, addressing concerns that hindered adoption of earlier digital tracing tools (32).

In addition to Bluetooth-based systems, other digital contact tracing solutions incorporated location data, QR codes, and artificial intelligence (AI) to enhance the efficiency of tracing efforts (28). In China, for instance, QR codes were widely used for contact tracing. Individuals scanned QR codes when entering public places, allowing authorities to track their movements and identify exposure to COVID-19 cases (33). This system allowed for rapid and targeted responses to potential outbreaks, although it raised significant concerns about surveillance and privacy (34). AI-driven tools also played a role in contact tracing by analysing large datasets to identify transmission patterns. AI algorithms were used to predict areas of high transmission risk and target resources accordingly (33). In Taiwan, for example, AI was integrated with digital contact tracing systems to track the movements of confirmed cases and identify high-risk areas, enabling more efficient allocation of public health resources (34).

4.2.2. Evaluation of Effectiveness

Digital contact tracing tools provided several advantages over manual methods, particularly in terms of speed and scale. They allowed for rapid identification of contacts, often notifying individuals of exposure within hours of a confirmed case. This helped break transmission chains faster than traditional methods, which could take days or even weeks (35). For example, a study conducted in the United Kingdom found that digital contact tracing, combined with manual efforts, helped prevent hundreds of thousands of COVID-19 cases (36). By using Bluetooth and location data, these digital tools were able to reach individuals who would have otherwise been missed by manual tracing (35). However, the effectiveness of digital contact tracing tools was contingent on high levels of adoption and public trust. In many countries, these tools struggled to achieve widespread use due to privacy concerns and technical limitations (30). For instance, the Apple-Google ENS required a significant portion of the population to download the app and enable Bluetooth tracking for it to be effective, and many users were hesitant to do so (34).

4.3. Hybrid Models: Integration of Manual and Digital Approaches

4.3.1. Examples of Countries/Regions that Successfully Integrated Manual and Digital Contact Tracing

Several countries adopted hybrid models that integrated manual and digital contact tracing approaches to leverage the strengths of both systems (22). These hybrid models were particularly effective in addressing the limitations of either approach when used alone (22). For instance, Germany's *Corona-Warn-App* combined digital contact tracing with manual efforts (37). Public health workers used the app to track contacts digitally, while also conducting manual follow-ups to ensure that exposed individuals were contacted and quarantined (37). This approach allowed for more comprehensive tracing, especially in cases where digital tools could not reach individuals without smartphones or those who had not downloaded the app (23). Similarly, Australia's *COVIDSafe* app was designed to complement manual tracing efforts. While the app used Bluetooth to identify and notify potential contacts, health workers still conducted traditional interviews and follow-ups with confirmed cases (38). This hybrid approach allowed Australia to maintain a robust contact tracing program throughout the pandemic, contributing to the country's relatively low transmission rates (38).

4.3.2. Comparative Analysis of Hybrid vs. Purely Digital/Manual Approaches

Hybrid models proved to be more effective than purely manual or digital contact tracing methods, particularly in large-scale outbreaks like COVID-19 (40). Manual tracing, while thorough, was too slow and labour-intensive to keep pace with widespread community transmission. On the other hand, purely digital approaches struggled with issues of adoption, technical limitations, and privacy concerns (40). A comparative study by (39) found that hybrid models combining manual and digital contact tracing reduced transmission rates more effectively than either method alone. Hybrid models allowed for more comprehensive coverage, reaching individuals who might not have been notified through one approach alone. They also addressed some of the challenges of digital tools, such as low app adoption rates, by relying on manual follow-ups (34).

In contrast, countries that relied solely on digital tools, such as the United States, faced challenges in achieving widespread adoption (43). Despite the advantages of digital contact tracing, such as speed and scalability, the United States experienced significant barriers to widespread adoption, including privacy concerns, technical glitches, and a lack of public trust (42). The reliance on voluntary app downloads meant that a significant portion of the population did not engage with these tools, limiting their effectiveness. For example, studies revealed that adoption rates for digital contact tracing apps were as low as 16% in many regions, which severely hampered their ability to break transmission chains (43). Purely manual methods, as seen in early-stage responses in some countries, had the advantage of human interaction, which often helped build trust and encouraged cooperation. Health workers conducting contact tracing could provide real-time explanations, address concerns, and offer personalised guidance on isolation or testing procedures (41). However, the limitations of manual tracing were quickly exposed as COVID-19 overwhelmed healthcare systems. The sheer volume of cases meant that contact tracers could not keep up, especially in densely populated areas (41). For instance, in New York City, manual contact tracing was overwhelmed during the first wave of the pandemic, with some infected individuals being contacted only after they had already recovered or further spread the virus (42).

Hybrid approaches, therefore, emerged as a necessary middle ground. Countries like New Zealand and Singapore, which effectively integrated manual and digital methods, demonstrated the potential of these combined efforts (44). New Zealand's hybrid system used digital platforms for rapid data collection and exposure notifications, while manual tracers followed up with personal outreach to ensure compliance and fill gaps where digital tools fell short (3). This dual approach allowed for both rapid notifications and human interaction, leading to better public compliance and more comprehensive contact coverage (44). Singapore's TraceTogether app also showcased the benefits of hybrid models. The app used Bluetooth technology for automatic contact logging, but the government ensured that manual contact tracers were available to conduct interviews and verify contacts (45). This model helped overcome the limitations of digital reliance, such as missed contacts due to app opt-outs or technical issues, while also benefiting from the efficiency of automated contact logging (45). In essence, hybrid contact tracing models demonstrated greater flexibility and adaptability compared to purely manual or digital approaches. They combined the best of both methods—leveraging the speed and reach of digital tools while maintaining the personalised, trust-building aspects of manual contact tracing (43).

5. Lessons Learnt from Global Case Studies

Contact tracing has played a critical role in the global response to the COVID-19 pandemic. Different countries adopted varying approaches to contact tracing, depending on their technological capacity, public health infrastructure, and societal factors (46).

5.1. Successful Implementation in Different Countries

5.1.1. Case Study: Taiwan's Approach to Contact Tracing and Outbreak Control

Taiwan emerged as one of the standout examples of successful pandemic management, largely due to its robust contact tracing and public health measures. After the 2003 SARS outbreak, Taiwan had invested heavily in its healthcare infrastructure, which positioned the country to respond quickly when COVID-19 began to spread (47). Taiwan's approach to contact tracing combined manual tracing methods with technological innovations. Health authorities swiftly implemented digital tracking through the National Health Insurance (NHI) system, which integrated data from health records, immigration, and customs databases to trace contacts of confirmed COVID-19 cases (42). In addition, Taiwan introduced a mandatory 14-day quarantine for all inbound travellers, who were monitored via mobile phones. The use of QR codes for entry into public spaces and mask distribution through the NHI system allowed for efficient monitoring and control (45). This multi-faceted approach was highly effective in containing outbreaks before they spiralled out of control. As of mid-2021, Taiwan had reported one of the lowest per capita death rates from COVID-19 globally, despite its proximity to China, the original epicentre of the virus (48).

5.1.2. Case Study: South Korea's Rapid Response with Digital Contact Tracing

South Korea's response to COVID-19 was another model of success, rooted in lessons learned from the 2015 MERS outbreak (49). Like Taiwan, South Korea acted swiftly, utilising both manual and digital contact tracing (49). A key element of the South Korean strategy was its use of digital tools to track potential cases. The government employed GPS data, credit card transactions, and surveillance footage to trace contacts of infected individuals, combined with rapid, large-scale testing to isolate cases before they could spread (49). South Korea also developed the *Corona 100m* app, which alerted users if they had been within 100 meters of a confirmed COVID-19 case in the last 14 days. The app provided real-time updates on confirmed cases and helped authorities track potential exposures with unprecedented speed (49). Despite concerns about privacy, the transparency and speed of South Korea's contact tracing system were pivotal in flattening the curve early on. By mid-2020, South Korea had successfully managed to keep its case numbers relatively low without implementing the type of widespread lockdowns seen in many other countries (50).

5.1.3. Case Study: New Zealand's Hybrid Contact Tracing System and Its Outcomes

New Zealand adopted a hybrid contact tracing system that combined manual efforts with digital tools, and it emerged as a global success story (51). The country's strategy involved a strict lockdown combined with aggressive testing, isolation of positive cases, and thorough contact tracing. The *NZ COVID Tracer* app, which utilised Bluetooth technology and QR codes, was introduced to supplement manual contact tracing (52). Unlike other countries, New Zealand's approach focused heavily on early containment (50). By rapidly isolating contacts and using digital tools to enhance manual tracing efforts, the country effectively eliminated community transmission for extended periods. In June 2020, New Zealand declared itself COVID-free for a time, allowing the government to ease restrictions and resume near-normal activities (52). The success of New Zealand's hybrid model was largely due to its early and decisive actions, public compliance, and trust in the government's transparency. However, experts also credit the nation's geographical isolation and smaller population as factors that made contact tracing and outbreak control more manageable (51).

5.2. Challenges Faced by Countries with Less Effective Contact Tracing

5.2.1. Case Study: The United States' Challenges in Scaling Contact Tracing

The United States faced significant challenges in scaling contact tracing during the pandemic (53). While manual contact tracing was employed early on, the sheer number of COVID-19 cases overwhelmed public health departments across the country (54). The decentralised nature of the U.S. healthcare system, combined with inconsistent federal and state responses, hampered efforts to implement a unified contact tracing strategy (53).

One major challenge was the lack of sufficient public health infrastructure to support large-scale contact tracing (55). Many state and local health departments were underfunded, understaffed, and unable to handle the volume of cases that surged in the early months of the pandemic. Efforts to implement digital contact tracing tools, such as apps based on the Apple-Google Exposure Notification System, were also hindered by privacy concerns and low adoption rates (55).

Public resistance to contact tracing also posed a significant barrier in the U.S. Many individuals were hesitant to provide information to contact tracers due to concerns about privacy, government surveillance, and mistrust in public health authorities (56). This reluctance limited the effectiveness of both manual and digital contact tracing efforts (57).

5.2.2. Case Study: India's Contact Tracing Program and Its Barriers

India faced its own set of challenges in implementing contact tracing, particularly due to its large population, diverse geography, and varying levels of access to technology (59). The Indian government launched the *Aarogya Setu* app, which used Bluetooth and GPS to trace contacts, but adoption of the app was uneven, especially in rural areas where smartphone penetration was low (58). Manual contact tracing efforts were also difficult to scale, given the vast size of the country and the rapid spread of the virus in densely populated urban areas. Many contact tracers faced logistical difficulties in reaching individuals, particularly in remote or underserved regions (59). Moreover, the rapid surge in cases overwhelmed health authorities, making it nearly impossible to conduct timely and effective tracing (58). India's contact tracing efforts were further complicated by a lack of clear communication and coordination between state and central governments. Political factors and inadequate healthcare infrastructure also played a role in limiting the effectiveness of the contact tracing programs (59).

6. Public Compliance and Social Factors Affecting Contact Tracing

6.1. Factors Influencing Public Compliance with Contact Tracing Initiatives

Public trust in government institutions and health authorities significantly influences the success of contact tracing initiatives (60). Trust is essential because contact tracing requires individuals to share personal and potentially sensitive information with authorities, including details about their health status, location, and social interactions (62). In countries where the government has a strong relationship with the public, compliance with contact tracing programs has been higher (61).

Cultural differences and societal values also play a role in determining public compliance (63). In many East Asian countries, such as South Korea and Taiwan, collectivist cultural values prioritise the well-being of the community over individual privacy (63). As a result, citizens were more willing to comply with contact tracing efforts for the collective good, even if it meant sacrificing some personal freedoms (64). In contrast, countries with more individualistic cultures, such as the United States, saw greater resistance to contact tracing due to concerns over privacy, personal autonomy, and distrust in government (62). Political factors can also influence public trust. For example, in countries where the response to the pandemic became politicised, such as the U.S., people were less likely to comply with contact tracing measures (65). In these cases, political polarisation exacerbated mistrust in public health authorities, leading to lower participation in both manual and digital contact tracing programs (63).

6.2. Digital Divide and Access to Contact Tracing Tools

6.2.1. Barriers to Adoption: Age, Technology Literacy, and Internet Access

Several demographic factors also influenced the adoption of digital contact tracing tools (66). Age was one of the primary barriers, with older populations often struggling to use the technology required for digital contact tracing apps. Studies have shown that older adults are less likely to own smartphones and have lower levels of digital literacy, which limited their ability to participate in digital tracing efforts (66). Technology literacy was another significant barrier. People with limited experience using smartphones, apps, or the internet were less likely to adopt digital contact tracing tools (67). This issue was particularly pronounced in communities with lower educational attainment, where individuals were less likely to be familiar with the technology (68). Internet access, especially in rural or underserved areas, also hindered the effectiveness of digital contact tracing. In countries like India, many people in rural regions lacked reliable internet access, making it difficult to download or use digital contact tracing apps (21).

6.2.2. Solutions Proposed During the COVID-19 Pandemic to Bridge the Digital Divide

To address the digital divide and improve access to contact tracing tools, several solutions were proposed during the COVID-19 pandemic (69). Governments and public health organisations sought to improve access to smartphones and internet connectivity, particularly in low-income and rural areas (71). In India, for example, local governments worked to distribute smartphones to healthcare workers in underserved regions, enabling them to manually trace contacts where digital tools were not feasible (70). In addition, public health campaigns aimed at increasing digital literacy were launched in several countries (71). These efforts included tutorials on how to download and use contact tracing apps, as well as outreach initiatives to educate older adults and other marginalised groups about the importance of participating in contact tracing programs (70). Some countries also adopted hybrid contact tracing models that combined digital tools with manual efforts to ensure that those without access to smartphones or the internet could still be traced (69). For example, New Zealand's hybrid approach, which integrated digital apps with traditional manual tracing, allowed for broader public participation, regardless of digital access (63).

7. Future Directions for Contact Tracing in Epidemiology

The COVID-19 pandemic revealed both the strengths and weaknesses of global contact tracing systems, underscoring the need for resilient, adaptable, and technologically integrated approaches for managing future pandemics (72). Moving forward, building robust contact tracing systems, leveraging artificial intelligence (AI), and ensuring public trust through ethical safeguards will be crucial in improving public health responses to infectious diseases (72).

7.1. Lessons Learned for Pandemic Preparedness

One of the key lessons from the COVID-19 pandemic is the critical need for early detection and rapid containment of infectious diseases. Contact tracing has proven to be an essential tool in preventing widespread outbreaks (14). However, the pandemic also highlighted significant challenges in scaling these efforts during a global crisis (72). Countries with well-prepared public health infrastructures, like Taiwan and South Korea, were able to quickly implement contact tracing systems, which limited the spread of the virus in the early stages (17). In contrast, nations that lacked pre-existing infrastructure for tracing and public health coordination, such as the United States, struggled to control the pandemic during its initial phases (46). Pandemic preparedness must focus on building scalable and flexible contact tracing systems that can be rapidly deployed in future health crises. This involves not only maintaining the infrastructure for manual contact tracing but also ensuring digital systems can be swiftly integrated into broader public health responses (74).

7.2. Policy Recommendations

To ensure sustainability, governments and health organisations need to adopt policies that incorporate contact tracing into routine public health practices. One recommendation is to develop a permanent framework for integrating contact tracing into the global health surveillance system (74). In addition, proper documentation and presentation of data in epidemiological scenario will aid government and relevant bodies in policy making to prepare for future (75). This could include a standing workforce of contact tracers, continual investment in training programs, and the creation of a rapid-response system that can be activated when outbreaks occur (73).

Policymakers must also prioritise funding for digital health tools that support contact tracing, including maintaining and improving the digital platforms created during COVID-19 (76). Governments should work closely with technology companies to ensure that these platforms can be updated and adapted for future use (76). Building partnerships between public health agencies and private tech companies can create more resilient infrastructures for future pandemics (74).

8. Conclusion

This literature review has explored the multifaceted role of contact tracing in managing infectious diseases, particularly during the COVID-19 pandemic. The global experience has highlighted the importance of well-coordinated contact tracing systems that are both manual and digital, with a strong emphasis on public health infrastructure, technological integration, and public compliance.

Looking forward, the future of contact tracing will be shaped by innovations in artificial intelligence, machine learning, and digital tools. These technologies promise to enhance predictive modelling and early warning systems, creating more resilient public health systems capable of responding swiftly to future pandemics. However, the importance of ethical safeguards, particularly in terms of data privacy and transparency, cannot be overstated. To build public trust and cooperation, governments and global health organisations must prioritise data security and the development of international standards for privacy.

Overall, the COVID-19 pandemic has provided invaluable lessons for the future of contact tracing. Effective contact tracing requires a combination of technological innovation, public trust, and robust health infrastructures, all supported by clear policies and international cooperation. By addressing the challenges and building on the successes of the past, nations can be better prepared to combat future infectious disease outbreaks

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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