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Article

Characteristics of the COVID-19 pandemic and role of laboratory medicine in containment: An insight from Saudi Arabia's policies and guidelines on containment strategies

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Abstract: COVID-19 is a highly contagious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The disease has caused several general occurrence cases, in Saudi Arabia and other Middle Eastern countries. The disease is characterized by a wide spectrum of clinical symptoms, including exhaustion, trouble breathing, cognitive impairment, and chest discomfort for several weeks to months following the infection. To contain the epidemic, every nation used multiple healthcare system strategies, including in the laboratory medicine. Saudi Arabia has developed many strategic policies and implemented scientific regulations to utilize laboratory medicine to control the pandemic. In this review, we have detailed the different aspects related to COVID-19 infections, the major challenges, and different strategies implemented by the Kingdom of Saudi Arabia to successfully contain the infections focused on laboratory expertise and new policy implementations in the specialty areas such as research and development, integration with public health strategies, implementation of advanced diagnostic technologies and operation of testing center.

Keywords: COVID-19; laboratory medicine; Saudi Arabia; public health; pandemic

1. Introduction

SARS-CoV-2 is the virus responsible for the highly transmissible disease called COVID-19, which stands for the persistent coronavirus disease 2019. In December 2019, this novel virus was initially identified in Wuhan, a city located in the Hubei province of China. A global pandemic resulted due to the rapid spreading of the virus worldwide (Hershan, 2021; Wu et al., 2020). In Wuhan, it was first identified as a cluster of pneumonia of unknown origin; later, the government of China declared it SARS-CoV-2, and later, it was notably known as COVID-19. As of 2024, the global impact of COVID-19 has been recorded, with over 750 million confirmed cases reported worldwide (Jaziri and Alnahdi, 2020; Liu et al., 2024). Beginning in late 2019, the epidemic has touched almost every nation and caused major social, financial, and health issues. Nevertheless, despite the great efforts made to stop the virus from spreading, over 6.8 million people have died from it. These fatalities highlight the major effects COVID-19 has had, especially on vulnerable populations, including older people and those with past medical conditions (Tobaiqy et al., 2020). Still, the numbers show a positive trend, with over 98% of people who came in contact with the virus recovering from their disease (Zuin et al., 2023). The great recovery rate seen can be attributed to these medical treatment innovations, worldwide vaccination campaigns, and public health initiatives like social distancing, mask-wearing and quarantine rules system. The fast development and distribution of vaccines have been rather crucial in order to lower the mortality and serious disease count. Starting in late 2019, the epidemic has brought about significant health, financial, and social concerns that have impacted almost every nation (Naseer et al., 2023).

Based on their particular circumstances and healthcare capacity, every nation has developed various policies to help stop the spread of COVID-19. Among the notable moves done were applying stay-home orders and lockdowns. Italy was the first country to institute whole nation strict lockdown policies; later, March 2020 saw the extension of these restrictions throughout Italy (Tassinari et al., 2024). China also instituted severe lockdowns in Wuhan, along with major testing and contact tracking initiatives (Sun et al., 2020). South Korea prioritized testing and contact tracing, tracking and quarantining using technology to be efficient. Germany similarly mixed testing with a robust healthcare system (Jain et al., 2024). Travel restrictions imposed on Australia and New Zealand were significant, comprising severe border controls, mandatory quarantines, and regional lockdowns (Liebig et al., 2021). While Sweden pushed voluntary rules with the intention of reaching herd immunity, the UK used slow methods of social distancing and public health initiatives. Among other significant economic aid programs the United States launched were stimulus payments and unemployment compensation (Spadafora, 2023). Similarly, the European Union gave financial support and vacation programs to support businesses and employees. Israel and the UK launched strong vaccination campaigns; Israel boasts one of the highest immunization rates, while the UK gives vulnerable groups top priority in order to reduce severe cases and death toll (Jabłońska et al., 2021). The Middle Eastern countries responded to COVID-19 with mixed strategies. While the UAE and Kuwait implemented curfews, other important courtiers such as Saudi Arabia, Iran, and Jordan shut down all the countries. All of them started contact tracing and mass testing alongside quarantines (Amamou and Ben-Ahmed, 2023; Olimat, 2022). These approaches helped the region negotiate the pandemic despite differences in execution and success.

Medical laboratory scientists, otherwise known as medical laboratory technicians, analyze various biological samples for clinical outcomes. Performing a range of crucial tasks to help confine the virus, medical laboratory scientists are vital members of the fight against COVID-19 (Ibeh et al., 2020; Wolszczak-Biedrzycka et al., 2022). Their job consists of running diagnostic tests, including PCR, antigen, and antibody testing to find SARS-CoV-2 in patient samples. They also guarantee exact sample collecting and follow processes to maintain quality control, guaranteeing consistent results. Data analysis and presentation of results help authorities and medical practitioners monitor diseases. Through COVID-19 research, people help to better understand viral spread and therapeutic efficacy. They also assist in identifying and tracking those who have been in touch with infected people, advise medical personnel, and monitor public health (Adeli, 2020; Uchejeso et al., 2021). These coordinated initiatives increase efforts to stop the virus from spreading and lessen its effects on public health. The success of such expertise is mainly based on the implementation of definite policies within the countries followed by international guidelines and recommendations from W.H.O. In this review, we have detailed the different aspects related to COVID-19 infections, the major challenges and different strategies implemented by the Kingdom of Saudi Arabia to successfully contain the infections focused on laboratory expertise and new policy implementations.

2. Methodology

This review was conducted following a process compliant with scoping review to identify and synthesize an existing or emerging body of literature. A detailed literature search was conducted, and important data were retrieved from the relevant sources which were published in the English language and published from 1994 through 2024. Various databases such as PubMed (https://pubmed.ncbi.nlm.nih.gov/), Science Direct (https://www.sciencedirect.com/), Google Scholar (https://scholar.google.com/), Scopus (https://www.scopus.com/), Springer Link (https://link.springer.com/), Web of Science (https://www.webofscience.com/wos/), and some government agency websites have been used for the collection of data. The search has been conducted using keywords such as COVID-19, Coronavirus, SARS-CoV-2, Pandemic, WHO, Saudi Arabia, Ministry of Health, policies, infections, etc. A total of 180 articles and related data sources were retrieved from the above-mentioned databases, of which 90 articles were found to be useful and unique for the scope of study. Articles which were having incomplete information, language other than English and not directly related to COVID-19.

3. Coronavirus

Like many other viruses, the coronavirus has a simple structure. Basically, it is composed of genetic material, which is a single-stranded ribonucleic acid, which in the case of coronaviruses corresponds to enclose with spike proteins, a lipid coating shields this genetic material from the surroundings. The Latin word “corona” means “crown,” which gives the virus a unique appearance attributed to spike proteins. While infection happens, as SARS-CoV-2 buds, the host cell membrane forms the lipid bilayer envelope of the virus. This envelope performs a protective role and is absolutely essential for maintaining the structural integrity of the virus outside of the host cell. Because of their lipid makeup, the virus is sensitive to alcohol-based disinfectants and detergents, which turn the virus dormant (Chmielewski et al., 2023; Pronker et al., 2023).

The genome of SARS-CoV-2 consists of one single strand of RNA oriented in a positive sense. Under direct translation by the ribosomes of the host cell, the RNA genome serves as messenger RNA (mRNA) and generates viral proteins. Multiple structural proteins (S, M, E, and N) as well as non-structural proteins that support replication abound in the genome. The quick mutation and recombination of the virus helps it to be transmitted and creates new variants. These viruses have a special protein called S-proteins, also called spike glycoproteins (Kumar et al., 2023). This special protein makes the viral ingress into host cells easily. Specifically in the respiratory system, they connect only to the ACE2 receptors found on the surface of cells.

The first phase of the viral entry mechanism is this contact. Two subunits make up the S-protein: S1, which hooks to the receptor, and S2, which helps the viral envelope merge with the host cell membrane, allowing the viral RNA to enter the host cell. The host cell has membrane protein, otherwise called M protein, which plays a crucial role in helping the virus assemble and maintain its shape (Hermens and Kesmir, 2023). They interact with other structural proteins to coordinate the formation of new virus particles. In addition, this protein assists in general stability of virus and infectivity in host cells. Another protein involved with the cell is the E protein, which is found to have several purposes (Santos-Mendoza, 2023). These envelope proteins help build fresh virons from the host cell by assembly and shaping. E proteins affect the surrounding environment of the host cell and, hence, alter the permeability of the cell membrane and, control the immunological reactions of the host and help the virus to develop. Another important protein called nucleocapsid proteins (N protein) forms a ribonucleoprotein complex, which interacts with the viral RNA genome (Wu et al., 2023). Viral DNA replication and transcription depend critically on this multifarious complex. By controlling many signaling pathways, N proteins can disturb the immunological response of the host and help to package RNA into new virons (**Figure 1**).

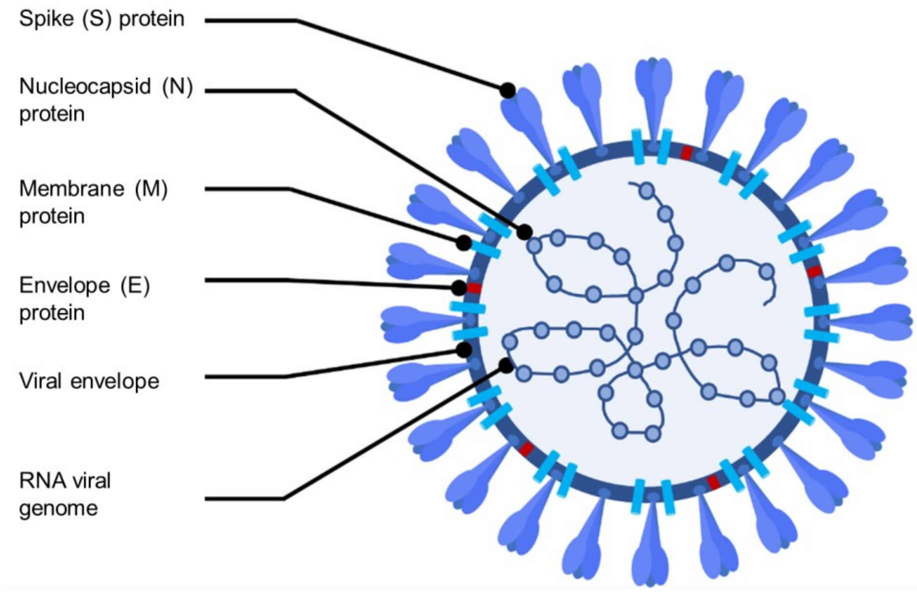

Figure 1. Structure of the coronavirus.

Reproduced with permission from MDPI under Creative Commons Attribution (CC BY) license (Kwiatkowska and Granicka, 2023).

4. Viral transmission

The primary method of transmission of coronaviruses is through respiratory droplets generated when an infected person coughs, sneezes, talks, or breathes. These microscopic liquid particles can carry virus particles and, should they be inhaled by someone close by, can cause illness. This kind of transmission highlights the need to follow physical distances and use masks to help slow down the dissemination. Smaller droplet aerosols can travel more distances than larger droplets and remain suspended in the air for more extended periods of time (Shafaghi et al., 2020). Most importantly, aerosol transmission occurs in limited regions with poor ventilation where virus particles can gather and increase personal breathing risk. This underlines the need for enough air filtering and ventilation in indoor surroundings (Hindson, 2020).

It is not necessary to transmit the virus only through air; rather, some special surfaces also serve as one of its important transmission points. Depending on the makeup of the substance and the surrounding environmental conditions, the virus can survive on several surfaces for a range of hours to days (Carraturo et al., 2020). When someone comes into touch with a contaminated surface and then touches their face, especially, their eyes, nose, or mouth leads to infection. This mode of transmission can be stopped by washing and sterilizing surfaces that come into regular touch regularly. It is important to note that personal contact and direct physical touch with an infected person, such as handshaking and or participating in personal interaction is also considered as a threat for infection.

Many preventive measures are proposed by health authorities to help stop viral infections from spreading. Wearing masks, especially in crowded or limited areas, can significantly help to reduce the spread of respiratory droplets and aerosols (Wang et al., 2021). Maintaining a proper distance from people helps to minimize the danger of transmission by lowering the probability of breathing in respiratory droplets. Improving ventilation in indoor spaces helps to lower the atmospheric viral particle density. Sanitary practices such as frequent hand washing with soap and water, hand sanitizing using alcohol and avoiding touching the face, etc. will help to consistently stop the transmission of germs through contaminated surfaces (Bazaid et al., 2020). It is also recommended to have frequent cleaning and disinfection of regularly handled surfaces help lower the fomite transmission risk.

5. Clinical manifestations and pathophysiology

The SARS-CoV-2 virus causes COVID-19, which presents with a wide spectrum of clinical symptoms ranging from mild symptoms or none at all to severe illness. While asymptomatic people might not show any symptoms, others with mild infections could show fever, dry cough, tiredness, sore throat, or loss of taste or smell (Çalıca Utku et al., 2020). Moderate cases have more noticeable symptoms, including higher body temperature, extended coughing, dyspnea, muscular pain, headache, shivering, and chest discomfort (Baj et al., 2020). Severe cases can develop considerable difficulties in breathing, low levels of oxygen in the blood (hypoxemia), Acute Respiratory Distress Syndrome (ARS), and failure of the respiratory system (Krynytska et al., 2021). Conversely, catastrophic cases include failure of several organs, septic shock, and severe ARDS, myocarditis, and acute renal injury.

The pathogenesis of COVID-19 starts when the virus enters the body via the respiratory system and particularly hooks itself to ACE2 receptor-expressed cells predominantly found in the lungs, gastrointestinal tract, and heart (Li et al., 2021). The innate system starts the immune response and causes the synthesis of chemokines and cytokines. Then, these substances draw more immune cells to the location of infection. Great degrees of severity cause a cytokine storm that causes widespread inflammation, tissue destruction, and organ failure. Respiratory pathophysiology includes a number of mechanisms, including alveolar damage, inflammation, fluid accumulation, impaired gas exchange, and ARD development potential, all of which can finally cause respiratory failure. Furthermore, damage to the endothelial cells and an enhanced tendency for blood clotting cause thrombotic issues, which produce tiny clots in the blood arteries of the lungs and aggravate respiratory failure (Mason, 2020; Yang et al., 2020). Other body systems are also affected by the disorder; it causes heart failure and myocarditis as well as acute kidney injury, diarrhea, and neurological effects, including encephalopathy and stroke. Also referred to as Long COVID, post-acute squeal of SARS-CoV-2 infection is the persistent persistence of symptoms, including exhaustion, trouble breathing, cognitive impairment, and chest discomfort for several weeks to months following the original illness. Successful therapy and control of COVID-19 depend on a thorough knowledge of these clinical signs and underlying physiological processes (Ali et al., 2021).

6. History of epidemics in Saudi Arabia

Characterized by their unique geographical, social, and religious relevance, the history of epidemics in Saudi Arabia is intimately linked to the general history of the Arabian Peninsula. Periodic epidemics have heavily influenced the region's public health policies and medical development. From history, it can be seen clearly that this country successfully overcame its epidemics through effective strategies and control policies.

One of the first recorded epidemics on the Arabian Peninsula was the Plague of Justinian in the sixth century; it affected areas of the Eastern Roman Empire and stretched to the Arabian Peninsula (Fancy and Jones, 2022). The Yersinia pestis bacteria brought this epidemic, which caused significant death and social unrest. The Black Death in the 14th century was the most notable event among successive plague episodes that nevertheless affected the area in the years that followed. An important event occurred in the 17th century when the plague came as an outbreak in the Al-Qatif region of Saudi Arabia (Shahraki et al., 2016). Several times, Mecca recorded plague outbreaks, specifically in 1897 and 1898 (Low, 2008). Another very important outbreak happened in 1821 during Hajj, and it was cholera (Roff, 2017). Approximately 20,000 people have died. In 1865, another 15,000 pilgrims were died during hajj due to cholera (Roff, 2017). The smallpox epidemic had a major impact on Saudi Arabia. Originating from Variola virus infection, the disease was highly transmissible and usually caused death. One prominent modern illness originating in Saudi Arabia is the Middle East Respiratory Syndrome (MERS). First identified in 2012, MERS is a respiratory infection brought on by a particular strain of coronavirus, MERS-CoV. With a notable fatality rate, the disease has caused several cases of general occurrence, mostly in Saudi Arabia and other Middle Eastern countries (Fagbo et al., 2017). Though human-to-human transmission mainly occurs in hospital environments, camels are thought to be the main reservoir of the virus.

Even though these viral outbreaks happened in Saudi Arabia, the Kingdom has a very strong history of controlling it effectively. Sometimes alone and with international aid, all these outbreaks were brought into a pause with the policies and decisions made by the country. Even before the formation of the Kingdom, the earlier outbreaks were controlled by the Ottoman Empire, which controlled the region at the time, to implement quarantine rules and improve infrastructure for water distribution and sanitation to help lower the spread of the disease (Kashani-Sabet, 1998). In the event of a smallpox outbreak, the World Health Organization (WHO) helped the Kingdom to be free of the disease. Saudi Arabia's last smallpox outbreak occurred in the 1970s; the disease was officially declared eradicated world-wide in 1980. To restrict the spread of MERS, the Saudi government has passed policies that include increased surveillance, hospital infection control procedures, and public awareness campaigns in tandem with those of foreign health groups (Al Shehri, 2015). Saudi Arabia's historical epidemic record reflects the larger challenges and measures implemented to fight infectious diseases in the country. From ancient plagues to modern pandemics, epidemics have historically greatly affected the public health status of the Kingdom. These pandemics have improved disease surveillance, medical infrastructure, and international cooperation, among other things. The knowledge acquired from past epidemics will remain essential in building a strong and flexible healthcare system as Saudi Arabia keeps navigating the complexities of global health (Al Ammi et al., 2023).

7. Pandemic COVID-19 in Saudi Arabia

Saudi Arabia is a large country in the Middle East, comprising 2,000,000 square kilometers. The Kingdom is strategically surrounded by other countries such as Yemen, UAE, Qatar, Bahrain, Oman and Jordan. As a major part occupied by deserted regions, the climate is generally hot and low relative humidity. Studies earlier showed that this climate is a very suitable atmosphere for the viral infections and spread (Altamimi and Ahmed, 2020).

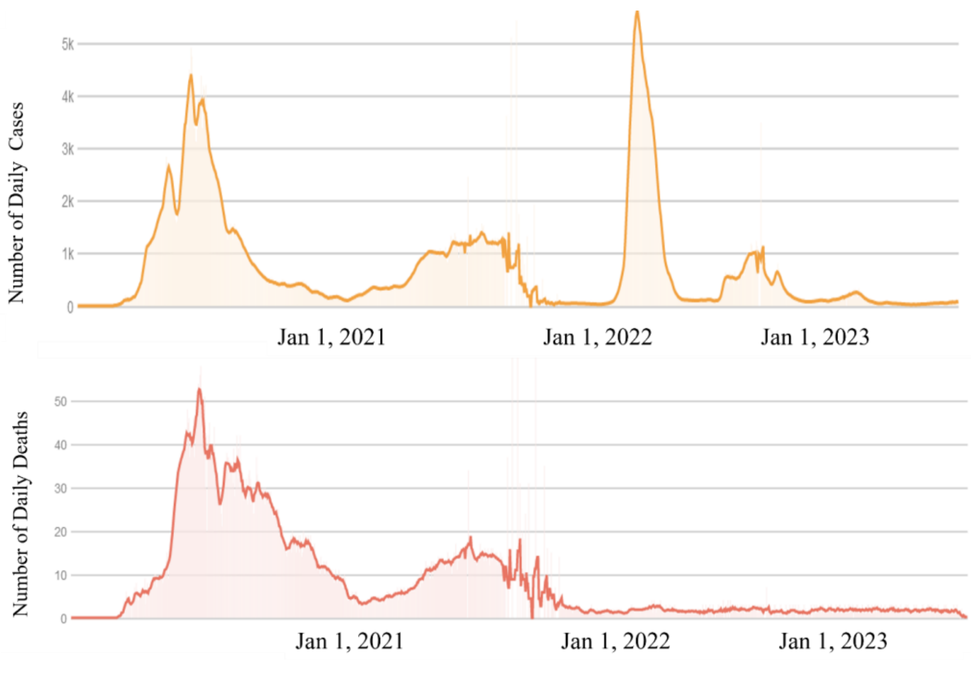

Figure 2. Number of cases and deaths recorded in Saudi Arabia.

Data were accessed from Johns Hopkins coronavirus resource (Johns Hopkins University Medicine, 2023).

The first case of positive COVID-19 was reported in Saudi Arabia on 2 March 2020. Then it showed different phases and severity of very high spread in the middle of 2020, a decline of cases at the end of 2020, and till 2021 September mid there was a steady state level of cases. The second wave hit again the country after that, but with practical strategies, by October 2021 the cases were put under control. According to the data by John Hopkins University of Emergency Medicine, Saudi Arabia has significantly reduced COVID-related deaths by implementing several health policies (**Figure 2**) (Johns Hopkins University Medicine, 2023). The outbreak significantly affected the Hajj pilgrimage, leading to a significant drop in the pilgrim count as a precautionary action against viral spread (Salam et al., 2022). All credit goes to the Saudi government, which they instituted severe policies including lockdowns, travel restrictions, thorough testing, and vaccination drives.

Studies have shown that at first, the Saudi Arabian government gave more priority to controlling public behavior during the epidemic (Sheerah et al., 2023). Particularly through online resources, the government shared information and raised awareness among the public and healthcare personnel on the need to follow preventive measures, including hand cleanliness, avoiding crowded public places, and refrain from touching their face. Several polls have shown that these steps were mainly successful. Moreover, the government carried out policies meant to minimize the psychological effects of the epidemic (Alyami et al., 2021). The Kingdom actively promoted several forms of psychological support and counseling, thereby helping vulnerable groups such as women, medical professionals, and those living in poor socioeconomic levels. Furthermore, the government has carried out various actions to solve public resistance to vaccination. The Kingdom could only properly run the healthcare system if it promoted the immunization strategy (Al-Zalfawi et al., 2021; Sheerah et al., 2023). Originally concentrating on healthcare professionals and the elderly population, the Kingdom used a hierarchical method of vaccination distribution, progressively extending it to include all qualified people all throughout the country. In the end, the government imposed travel restrictions and took control over religious mass events. The Umrah and annual Hajj trips were subject to restrictions. Travel restrictions stayed in place until May 2022, when the nation had grown somewhat confident about its capacity to control the epidemic (Sheerah et al., 2023). Studies have reported that all these strict healthcare policies and regulatory implementations including the testing and vaccination significantly reduced the death rate in the COVID-19 related patents. According to the studies carried out by Algarni et al., (2022) it is very evident that new policies and vaccination reduced the speared of COVID-19 infection. As showed in the **Figure 2**, it is very clear that there was a significant reduction of death after implementation of new regulations and policy, which was 1.25% of death out of overall infected patients in 2022, which came down significantly to 0.044% of death by 2022 (Johns Hopkins University Medicine, 2023).

8. Pivotal role of laboratory services in COVID-19 containment

In Saudi Arabia, the laboratory role and policies within the health system played a crucial part in containing the COVID-19 pandemic. The Kingdom implemented a comprehensive strategy that included ramping up testing capacity, ensuring the availability of accurate and reliable diagnostics, and integrating laboratory data into the broader public health response. Here are some key aspects of these efforts.

8.1. Implementation of the testing center

The very important step taken by all over the world to control the spread of

COVID 19 was the test strategy. This is considered one of the prime duties offered by laboratory services (Wells et al., 2021). It is impossible to recognize the great relevance of testing facilities available during the COVID-19 epidemic, which directly and indirectly supports many other sections of society (**Figure 3**). Identification and separation of infected, even non symptomatic people is vital for stopping the spread of the virus. They thus play a crucial role in controlling the viral propagation. In epidemiological tracking, testing is an essential need (Cui et al., 2021). This means closely observing the patterns of disease and using effective contact tracing to find locations of great infection rates. It improves healthcare management by means of regular testing and information on resource allocation, so the protection of healthcare professionals. The decisions taken in public health, especially those concerning vaccination strategies and policy, depend on the correctness of testing findings. By giving the public confidence and data that could influence personal behavior, doing comprehensive testing helps the community to grow. Economically, frequent testing helps the travel and tourism industries by guaranteeing occupational safety and lowering the likelihood of outbreaks, therefore ensuring their benefits (Škare et al., 2021). Since they improve our knowledge of the virus and help to promote vaccinations and therapies, the test findings are significant for scientific studies. Assuring fair access to testing facilities not only aids vulnerable populations but also helps to lower health inequalities. The whole reaction to the COVID-19 pandemic depends much on testing facilities. They make effective administration, and control possible, and finally help to resolve the public health issue possible.

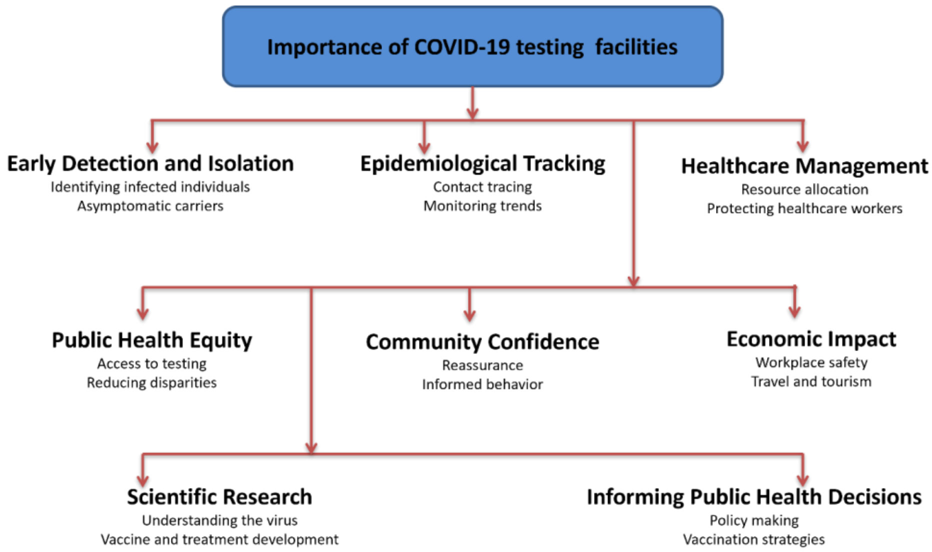

Figure 3. Importance of COVID-19 testing facility.

Saudi Arabia has shown exemplary performance in the test strategy. Firstly, it established a new testing facility by expanding its network of laboratories capable of conducting COVID-19 tests (Khan et al., 2021). This included setting up new laboratories and upgrading existing facilities to handle the increased demand. The testing centers were established firstly in health care clinics named "Tatamman," where symptomatic and non-symptomatic individuals were tested (Alassaf et al., 2021). More than 300 such clinics were established in the early phase of the pandemics. The Ministry of Health established numerous drives through testing centers named "Ta'akad" across the country to facilitate easy and widespread access to testing for the population (Alshammari et al., 2021). In addition to government centers, the Ministry facilitated private sector involvement also into this exercise which significantly enhanced testing capacity and coverage.

8.2. Implementation of advanced diagnostic technologies

A wide spectrum of diagnostic tools have been developed and applied in the framework of the COVID-19 epidemic to detect the SARS-CoV-2 virus. Molecular testing, antigen tests, and antibody evaluations are three approximately separate groups within which these diagnostic technologies fit (Chau et al., 2020; Kubina and Dziedzic, 2020). Molecular assays, comprising the gold standard RT-PCR, digital PCR, and isothermal amplification techniques, including LAMP and RPA, achieve high sensitivity and specificity (Kang et al., 2022). These tests pick up virus RNA. Rapid lateral flow immunoassays and other antigen testing can spot viral proteins and yield results quickly (Hsieh et al., 2021). This makes them valuable both for point-of-care diagnostics and mass screening. Antibody tests, including ELISA, CLIA, and rapid antibody testing, help one to identify the immunological reaction to a past illness. The diagnosis of pneumonia brought on by COVID-19 makes use of imaging technologies like CT scans; nonetheless, these tools do not show the virus's presence (Churruca et al., 2021). The selection of diagnostic technology is influenced by several factors including sensitivity, specificity, turnaround time, sample type, and test objective. Usually used for the identification of an active infection, molecular and antigen testing are used; antibody tests are used for the identification of an infection that past happened and the immune response (**Figure 4**).

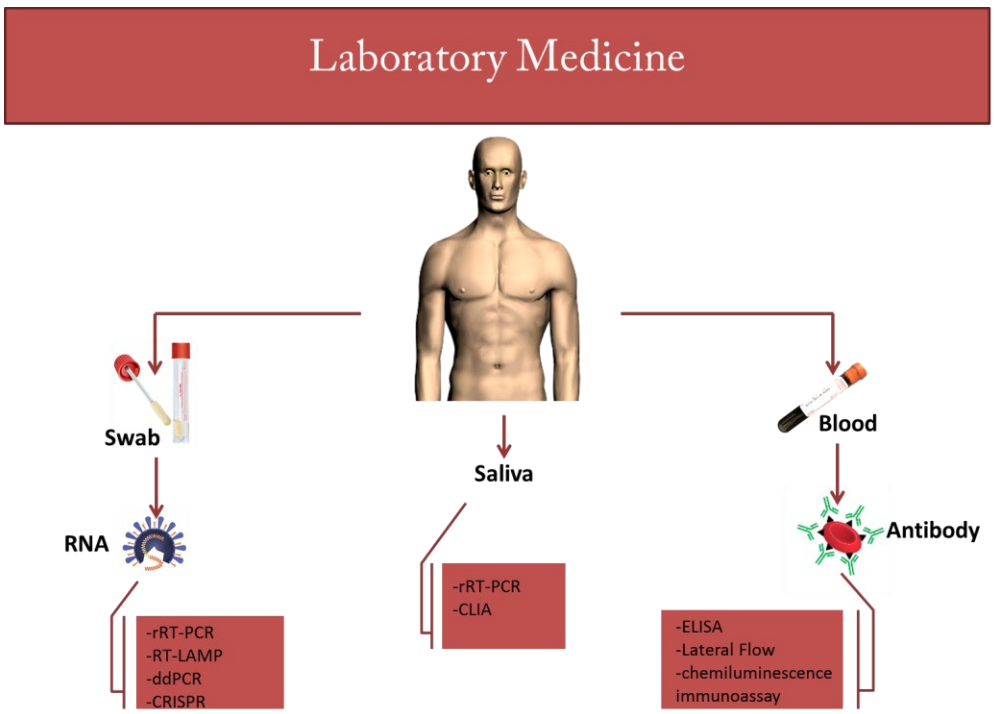

Figure 4. Methods for COVID-19 detection in laboratory medicine.

Saudi Arabia has acted very fast in the diagnosis test for identifying the positive COVID cases. Initially, they implemented RT-PCR-based detection (Alfadda et al., 2021). The Ministry implemented strict policies to ensure that only qualified laboratories and those recommended by public health authorities with a Class II BSC in the BCL-2 facility should conduct the test. Initially, the authorities allowed using the rapid detection technique of RT PCR assay with the samples, but with a strict recommendation that should patients be highly suspected of having COVID-19 and the initial RDT come back negative, RT-PCR should be utilized for re-testing. These recommendations were applicable to all hospitalized patients and those with recent travel history. It was one of the strict endorsements from the Ministry that in case of viral isolation, it must be carried out in a BSL-3 facility (COVID19.cdc.gov.sa, 2021). In addition, studies have been conducted in Saudi Arabia to use the very sensitive CT scan in the detection of COVID infections, but the results were not in the supporting stage as they found that CT may not be useful in the detection of infection as a routine procedure (Al Mutair et al., 2020).

8.3. Integration with public health strategies

The integration of laboratory medicine services with public health strategies is important in the containment of any pandemic. In the case of COVID-19, it starts with contact tracing. At the beginning of 2020, there were contradicting guidelines regarding contact tracing related to COVID-19. For instance, the US CDC recommends initial contract tracing for active cases. Still, when the cases become huge, they recommend that they do so only if the jurisdiction has sufficient capacity to do it. In Europe, around 10 billion pounds were spent on contact tracing, but it was not practical due to the limitations of finding contacts (Juneau et al., 2023). But the experience of other countries, such as in India, the contact tracing helped the testing of cases to a significant level and subsequently helped in the easiness of laboratory medicine service (Das et al., 2021). In the case of Saudi Arabia, they used digital instruments and special apps for contact tracing. Many countries have introduced digital APPs to control the pandemic, for instance the COCOA App developed in Japan was one of the important one in this service. Kingdom implemented mobile app called Tabaud and Tawakkalna, which designed to tract infection tracing. Both applications were developed by the Saudi Data and Artificial Intelligence Authority, and they are very successful in dealing with the pandemic and it helps the health workers such as laboratory medicine specialists in ease their role in infection control (Hidayat-ur-Rehman et al., 2021a). In addition to these apps the kingdom also developed other various mobile apps, all of these works seamlessly in the protection of public and healthcare system (**Table 1**).

Another very important service provided by the laboratory specialist was Genome Sequencing. By tracking mutations, helping to create vaccinations, and directing public health policies, genomic sequencing has been absolutely crucial in understanding and fighting COVID-19. Often used are techniques including Whole Genome Sequencing (WGS) and Next-Generation Sequencing (NGS) (Chen et al., 2021). Along with the COVID-19 Genomics UK (COG-UK) Consortium, global initiatives, including GISAID and Nextstrain have provided substantial data for tracking the virus's spread and evolution. This information has affected the travel restrictions implemented, the development of vaccination strategies, and the handling of epidemic reactions (Jackson et al., 2021). Notwithstanding challenges in data sharing, resource allocation, and data interpretation, ongoing efforts are being undertaken to enhance surveillance, forward bioinformatics, and use genomic data for individualized medicine. Global health policies in reaction to the epidemic have been greatly shaped by genomic sequencing.

Table 1. List of mobile apps used by Saudi Arabia in strengthening laboratory medicine and healthcare system.

Mobile apps	Launch year	Purpose	References
Mawid	2017	Mobile app developed by Saudi Arabia government for the purpose of booking appointments in primary health care hospitals.	(Alanzi et al., 2022)
Seha	2017	Mobile app developed by Saudi Arabia government for health care consultation from remote places via teleconsultation.	(Alharbi et al., 2021)
Wasfaty	2018	Mobile app developed by Saudi Arabia government for doctors to prescribe medicine for patients to procure from private pharmacies.	(Almaghaslah et al., 2022)
Sehhaty	2019	Mobile app developed by Saudi Arabia government for updating the health status of peoples of country.	(Alkhalifah et al., 2022)
Anat	2020	Website developed by Saudi Arabia government for doctors in government and private sector for education.	(Alghamdi et al., 2021)
Tawakkalna	2020	Mobile app developed by Saudi Arabia government for people's health status and travel information. It is used for travel permission during COIV lockdown.	(AlGothami and Saeed, 2021)
Tetamman	2020	Mobile app developed by Saudi Arabia government for doctors to book appointment for COVID testing.	(Alharbi et al., 2022)
Tabaud	2020	Mobile app developed by Saudi Arabia to identify if a person come in contact with COVID positive person for the last 14 days	(Hidayat-ur-Rehman et al., 2021b)

Saudi Arabia's attempts to control the epidemic have been much enhanced by the process of examining the genetic material of COVID-19 there. Using this technology, the Kingdom has tracked virus spread, identified mutations, and offered direction for public health policies. These are some basic principles of how Saudi Arabia has applied genome sequencing. Along with alliances with universities and research groups, Saudi Arabia has built state-of-the-art genetic sequencing facilities such as the Saudi Center for Disease Prevention and Control or Weqaya (Al-Otaiby et al., 2022). To increase the capacity to rapidly and precisely examine genomes, considerable resources have been directed toward the development of bioinformatics tools and sequencing technologies. Renowned research institutes known for their major contribution to COVID-19 genome sequencing include King Abdulaziz City for Science and Technology (KACST) and King Abdullah International Medical Research Centre (KAIMRC) (Hajeer et al., 2022). They have made significant contributions to the study of regional viral genetic variations. Several SARS-CoV-2 variants, including Alpha, Beta, Delta, and Omicron, have been found inside the country thanks in great part to the use of genome sequencing.

8.4. Research and development

In fact, the COVID-19 changed the world how it was before. In medicine, there is an era considered before and after COVID. These changes included the development of new technology, new vaccines, new drug development, new habits, and new awareness about life-threatening pandemics. Like these, there were many such developments happened in the diagnostics of diseases and viral infections. For example, CRISPR-Cas12 and Cas13 Systems changed life science and research with many options for manipulation, imaging, and annotating specific RNA sequences (Xiang et al., 2020). Earlier, the main diagnostic tools for COVID-19 detection were RT PCR, which took long hours, whereas CRISPR-Cas12 and Cas13 Systems can do it in 1 hour of time (Teng et al., 2019). There were new rapid antigen-based tests were developed to detect the virus, which uses saliva as a sample. They are quick and cost-effective. Moreover, many AI-based diagnostic areas were developed in conjunction with CT and X-rays (Arora et al., 2021). In Saudi Arabia, the King Abdullah University of Science and Technology has effectively produced the Kingdom's first RT PCR kit, which was approved by SFDA. This kit was a single-step, multi-use kit, which was far superior to the existing one (Dx, 2021).

In the early days of the pandemic, the Kingdom came up with a clear policy in the diagnostic area. The Kingdom launched a new program to accredit the diagnostic labs in the government and in the private sector in order to control the spread of the virus according to the regulations of the Saudi Center for Disease Prevention and Control. This enabled the laboratories to carry the capacity to test 80,000 samples per day. The country developed a national epidemiological testing service, which implemented community-based testing; large grip population testing based on large companies and residencies, and confirmed contact cases testing. All these developments, together with research polies enabled the Kingdom in contain the spread of infection (Experience, 2020).

9. Conclusion

One of the most important pandemics the current generation has seen is the COVID-19. The outbreak claimed large numbers of lives and seriously affected people's livelihoods as well as the general state of the economy from the losses suffered. Some nations faced many challenges even if laws were effectively implemented and scientific methods were used to control the epidemic. Saudi Arabia's innovative and successful strategies helped it to remarkably suppress the epidemic. With other international strategies such as quarantine and vaccination, Saudi Arabia's innovative and successful policies in the field of laboratory medicine had helped it to remarkably suppress the epidemic. The Kingdom used several creative ideas to run the country's healthcare system effectively. The involvement of laboratory science and laboratory scientists in this project was inevitable. Indeed, the country made success in its attempts to contain this epidemic largely due to the great help of laboratory medicine understanding. It is significant to underline that, should a future pandemic strike any nation, the knowledge gained from Saudi Arabia can be beneficial for any other nation. Still, several innovations are needed to properly control the degree of these pandemics. Saudi Arabia is actively participating in the continuous search for creativity with the world.

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