ASSESSING THE EFFECT OF COVID-19 ON LABORATORY PRACTICES: A REVIEW

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Abstract

The COVID-19 pandemic significantly disrupted laboratory practices worldwide, necessitating rapid adaptations in diagnostic workflows, biosafety measures, staffing, and resource management. This study assesses the impact of COVID-19 on laboratory operations, focusing on changes in testing capacity, safety protocols, supply chain challenges, and workforce dynamics. The pandemic accelerated advancements in diagnostic technologies, automation, and digital transformation, while also highlighting vulnerabilities such as reagent shortages, increased workload, and mental health concerns among laboratory personnel. Additionally, disruptions to non-COVID testing and research activities raised concerns about long-term consequences on healthcare and scientific progress. This assessment provides insights into lessons learned, strategies for resilience, and recommendations for future pandemic preparedness to ensure laboratories remain efficient and sustainable in the face of global health crises. The COVID-19 pandemic is the most significant worldwide medical crisis of our time. Pakistan has poorer health care standards, an unstable economy, and little funding to combat the outbreak when compared to its neighbors China and Iran, who were identified as the pandemic's epicenters. Clinical laboratories face numerous difficulties, much like other organizations and sectors in the nation.

INTRODUCTION

A pandemic of Coronavirus Disease 2019 (COVID-19), which is primarily caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) first emerged in early 2020 and has spread extensively, according to information published by the Organization for World Health (WHO).[1]

COVID-19 has triggered an unexpected and unprecedented global emergency, which has severely affected a great deal of firms in terms of the financial crisis and creation of money, encompassing clinical laboratories as well.[2] The function of laboratory medicine during infectious disease outbreaks eruption has a well-established history.[3] Review of the literature adds due to the inability to provide an etiological diagnosis for COVID-19 without using the lab's services, either by finding the infection in (RT-PCR) or by immunologically measuring the antibody response.

In light of the COVID-19 dilemma, clinical chemistry laboratories can make contributions in a number of areas, according to laboratorians range from aiding in the diagnosis, prognosis, and treatment of staging, monitoring of treatment drugs, and epidemiological surveillance research.[4] Due to the world economic downturn, during the previous few years, Global clinical chemistry laboratory services have declined significantly through significant, ongoing, and typically irrational cost-cutting procedures, which causes the suffering and anguish of the laboratory workers.[5] In Pakistan, a developing nation, over 90% of the clinical small labs with insufficient resources both human and physical are present.[6]

Working near the "minimal level of compensation" has consequently become standard practice in the great majority of laboratory services across the nation, particularly in clinical chemistry, where employees are routinely laid off because of the industry's increasing automation.Without a doubt, the outbreak has put an excessive amount of strain on the already susceptible laboratories by posing problems with personnel availability, transportation, and personal protective equipment shortages (PPE), postponed deliveries of necessary supplies, health concerns, decreased sales goals, and particularly worry and anxiety among the personnel on the front lines.[7] Despite these difficulties, the field of laboratory medicine is once more displaying its inherent and well-known suppleness, with the continuous delivery of diagnostic services around-the-clock.[8]

The COVID-19 pandemic highlighted the central position of clinical laboratories in responding to global health emergencies. Laboratories emerged as the foundation of diagnostic services, facilitating the timely detection of cases and facilitating epidemiological surveillance. In addition to diagnostics, laboratories played a role in investigating virus properties, vaccine production, and therapeutic measures. This two-pronged function—diagnostic and research—put immense strain on laboratory infrastructures, especially in low-resource settings where access to high-end equipment and skilled personnel was already limited.

The lab was the first in the US to start diagnostic testing for suspected COVID-19 cases. Even during the enforced lockdown, the clinical chemistry section operated around-the-clock and offered diagnostic services for both routine and COVID-19 patients. Although the section took prompt action to guarantee the safety and well-being of its employees, there was no record of preparations for such a disaster in the books of laboratories, particularly for resource-constrained setups in developing countries.

The pandemic compelled laboratories globally to evolve quickly to respond to unprecedented situations. Diagnostic pipelines were reorganized to focus on COVID-19 testing, at times at the cost of regular diagnostics. Laboratories had to contend with increased demand for molecular tests, including RT-PCR, while also coping with reagent and PPE shortages. These disruptions exposed weaknesses in supply chain management and highlighted the importance of proactive inventory planning. Also, automation and digital integration became a necessity to sustain efficiency in the face of manpower shortages due to sickness or quarantine measures.

The real impact of the COVID-19 pandemic brought on by the novel coronavirus SARS-CoV-2, which resulted in millions of people being placed under lockdown and numerous SRL temporarily closing, is not yet known. Thus, the focus of this paper will be on the consequences of the March–June 2020 lockout, as well as the ongoing effects on SRLs' operational management concerns global and will end witha list of suggestions should plan for such circumstances in the future. Most peoplebelieve that pandemics only happen once every few generations. The most recent notable instance was the 1918 Spanish Flu, which killed an estimated 20–50 million people globally. Cambridge University temporarily shuttered its doorsin 1665 as a result of the Great Plague. Isaac Newton was compelled to come home by this resolution. That allowed him time to think and refine his views at home. on gravity, calculus, optics, and the laws of motion. He actually completed a lot of his prism work at this period by drilling holes in his parents' window shutters to let light beams to pass through prisms, dividing the light into hues.[10]

Table 1: Roles of Clinical Laboratories During the Pandemic

Role	Description
Diagnosis	Conducting RT-PCR tests to confirm COVID-19 cases.
Prognosis	Supporting patient management through biomarker testing (e.g., CRP, Trop-I).
Epidemiological Surveillance	Monitoring infection trends and variants through testing.
Research	Developing new essays and studying SARS-CoV-2 characteristics.

Whether the COVID-19 pandemic will yield new scientific findings in a similar manner is a matter of time. We act be aware that it has made it possible for researchers and SRL managers to reconsider how laboratory operations, such as safety and training, and employee counts, are conducted and establish what constitutes a truly significant or critical experiment. In the majority of Institutes, the critical experiment's requirements are established and overseen by institutional oversight rather than at the level of the SRL. These modifications to operations are especially crucial because they have been forecast that the number of COVID-19 infections would remain transpire in there could be multiple waves and fresh, original viruses in the future.[11] One of the earliest instruments for the central bank to use monetary policy to solve economic issues is managing the surplus money supply and credit creations via bank rates.[12] The monetary policy shocks bring about negative differential effects in decreasing interest rates and raising asset prices. Enabling governance and capacity building for innovative sustainable programs, facilitating corporate vision towards green manufacturing.[13]

Most schools and institutions were forced to implement safety measures that restricted access due to the COVID-19 pandemic.[14] Even though these restrictions were necessary to mitigate the spread of COVID-19, the changes had a negative impact on experiential learning opportunities for students and human research labs.[15]

Clinical laboratory testing, such as the rapid creation of new assays, the requirement for highly trained staff, management of reagent and supply shortages, and potential staffing shortages resulting from COVID-19 infection, has been affected to a large extent by the sudden increase in cases and the resulting demand for specialty testing. The clinical laboratory is challenged to meet the diagnostic needs of patients and healthcare providers in an environment where treatment and monitoring methods are being explored and developed as a result of a new and rapidly spreading disease. Because COVID-19 is an acute condition caused by a communicable pathogen, immediate and accurate diagnosis results are crucial for patient management, directing drug therapy, and preventing the transmission of nosocomial and community infections.[16]

Laboratory staff carried a heavy emotional and physical toll throughout the pandemic. The threat of SARS-CoV-2 exposure, combined with long working hours and high-stakes tasks, created heightened levels of stress among personnel. In most instances, mental health support was inadequate to cope with these issues, especially in developing nations where healthcare systems were already compromised. In the future, mental health support for laboratory staff must be a central aspect of pandemic preparedness planning.

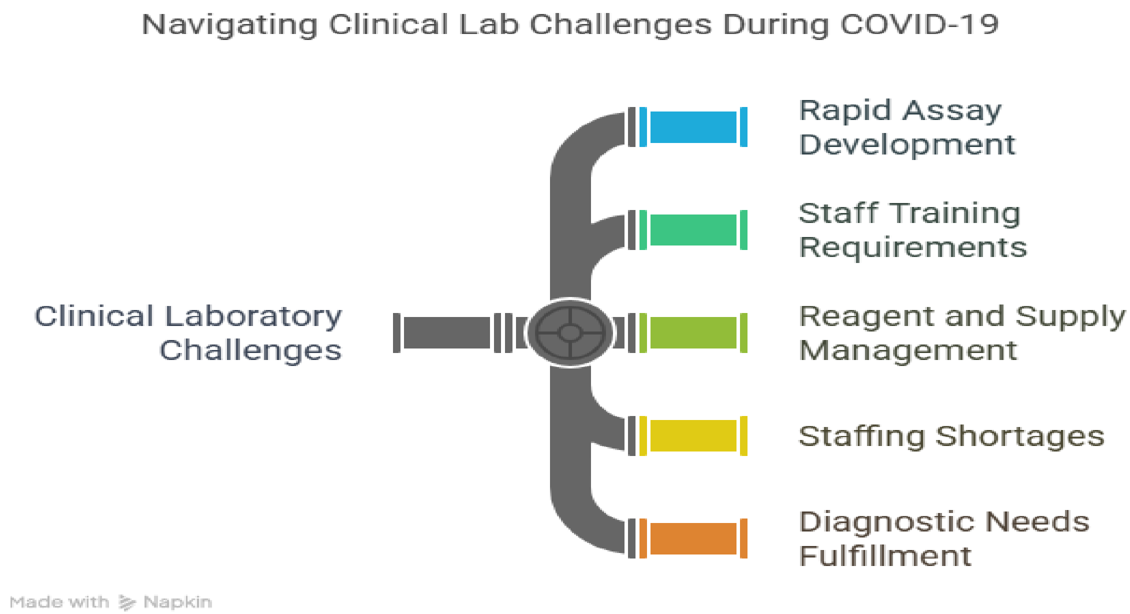

Figure 1: Clinical Laboratory Challenges during COVID-19

As of now, few published data exist on the clinical laboratory resource requirements specific to COVID-19 testing beyond, though some reports are starting to come out. As a result, most laboratory directors still do not have clear-cut ideas about anticipated demand for a range of laboratory tests and their clinical usefulness in the management of this new disease. This report summarizes our hands-on experiences in the clinical laboratory of a large academic healthcare network located near one of the first COVID-19 epicenters in the United States. We provide a summary of laboratory utilization patterns that coincided with an increase in COVID-19 cases, with the goal of providing information on diagnostic test use, required reagents, and staffing needs. After the initial emergency response and subsequent assessment, measures for the resumption of normal operations were drawn up and undertaken. Standardized emergency response procedures, consistent with recommended best practices for special reference laboratories (SRL), are necessary, considering the short time available to adapt to emerging situations during a natural disaster.[19]

Medical laboratory technicians (MLT) are an important component of the health care delivery system. MLT assist in the diagnosis of disease by conducting a variety of tests on specimen such as blood, tissues, urine, stool, and body fluids. MLT can contract SARS-CoV-2 infection through direct contact with patient during sample collection.[20] This is likely to occur if phlebotomy and sample collection fall within the role of MLT. The chance of SARS-CoV-2 transmission between infected patient and MLT, and vice versa, is enhanced when clinical sample collection requires MLT to be in close proximity with the patient. Moreover, MLT get in contact with other bodily fluids that may have SARS-CoV-2. In processing samples, such fluids can cause lab surfaces and equipment to get contaminated.[21]

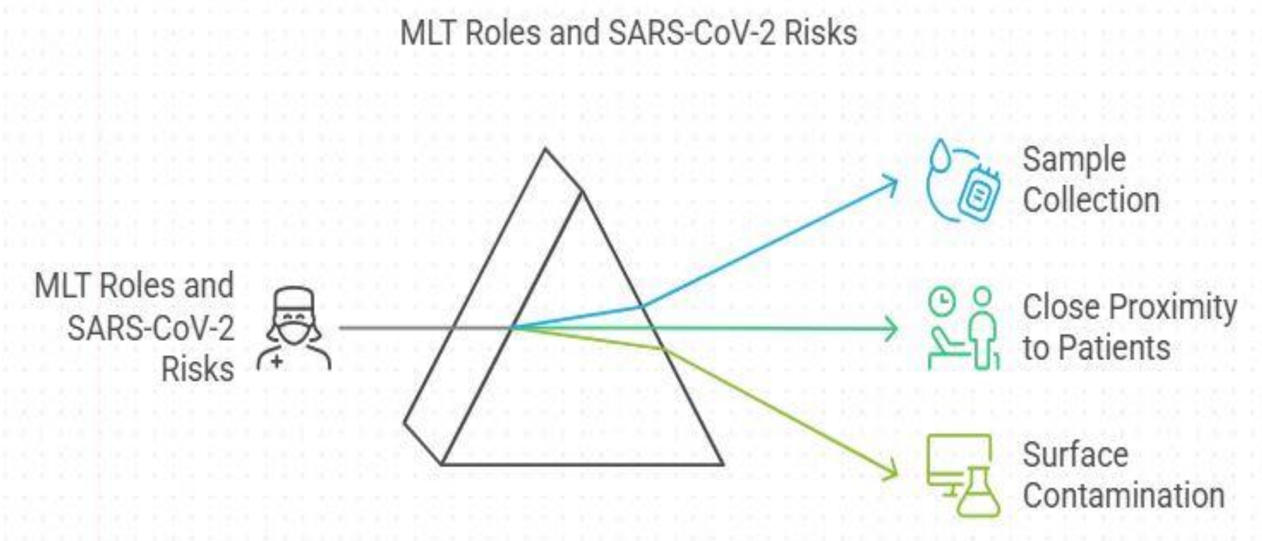

Figure 2: MLT roles and COVID-19 risks

WHO announced COVID-19 as a pandemic on March 11, 2020, when there were 118,319 confirmed cases in the world. Our country's first lab-confirmed COVID-19 case was announced by the Ministry of Health of the Republic of Turkey on March 11, 2020. There were 119.218,587 globally confirmed cases and 2.642,673 total deaths worldwide as of March 14, 2021, according to the WHO situation report.[22]

Challenges faced during Covid-19

Changes in Laboratory Workflows:

The goal of the lab workflow was to provide a new division of labor so that, when necessary, duties did not depend entirely on the lab manager. Together with the Lab Manager and assistance from the rest of the team, a project leader could do many of the standard tasks in the project management process cooperatively and with shared responsibility.[23] To assist reduce the danger of COVID-19 while working in clinical laboratories, a number of national and international health bodies have issued interim recommendations on biosafety precautions for regular laboratories that operate at biosafety levels 1 and 2. It's unknown if more laboratory biosafety precautions and modifications to laboratory procedures will significantly reduce the risks of biohazards during the COVID-19 pandemic. There have been no reports of clinical laboratory-acquired SARS-CoV-2 infections that cause severe acute respiratory syndrome to yet.[24]

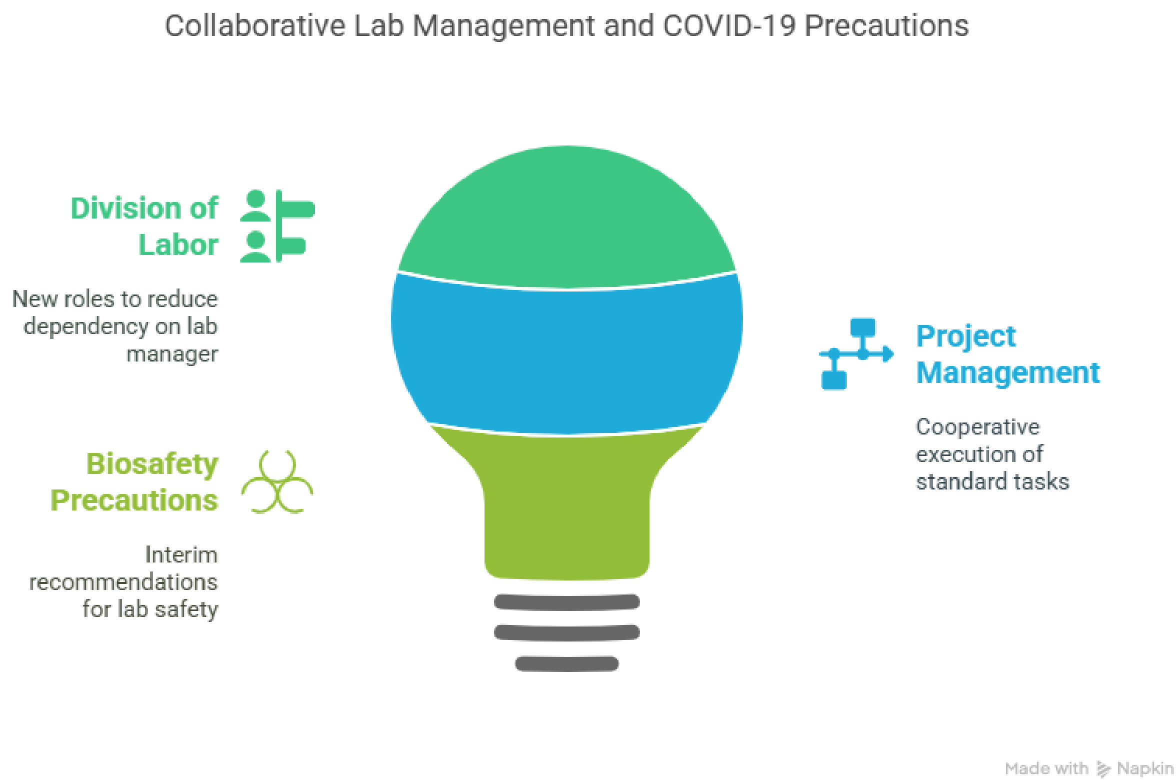

Figure 3: Collaborative Laboratory Management during COVID-19

Supply Chain Disruptions and Resource Management:

The buying department helped to guarantee that there was a sufficient supply of personal protective equipment (PPE), which is a necessary need. Employees were advised to use PPE and sanitizers sparingly. In order to sustain the demand-supply chain, bench in-charges were encouraged to revisit their inventory needs in light of the anticipated shipment delays brought on by the air space closure. Some tests, such as albumin, troponin-I (Trop-I), and C-reactive protein (CRP), showed higher than typical demands despite the general decrease in test volumes. These tests were employed for COVID-19 cases as a supplement to the molecular diagnosis and subsequently for prognosis.

Additionally, the hospital that the laboratory services saw a sharp increase in demand for point of care tests (POCT), such as arterial blood gases and glucose, as a result of the quick influx of inpatients with COVID-19. Additional instruments were urgently purchased and installed in order to handle the growing POCT workload. In addition to the POCT operator trainings, which were provided on an as-needed basis, the POCT team also promptly completed the validation criteria.

Table 3: Impact of COVID-19 on Testing Capacities

Test Type	Demand Trend	Reason for Change
COVID-19 Molecular Tests	Increased	Essential for diagnosis and monitoring of the pandemic.
Routine Diagnostics	Decreased	Focus shifted to COVID-19-related testing.
POCT (Glucose etc.)	Sharply Increased	High demand due to inpatient care for COVID-19 patients.

Figure 4: COVID-19 response strategy overview

Quality Assurance and Regulatory Compliance:
Because of logistic difficulties tests for proficiency from CAP were also not successful in meeting the deadlines and the CAP instructed the collaborative labs to perform and record alternate assessment testing by either clinical correlation studies or split sample analysis as needed.[25]

To ensure that the laboratory thrives to offer the best standards of quality, the quality assurance team swiftly came up with a plan in consultation with the sectional chemical pathologists, and it was implemented. As a result of limited supplies of testing kits and consumables, regular method validations/verification activities were also impacted. The lab was gearing up for an upcoming CAP accreditation compliance audit later in 2020, but since most audits, the majority of which involve physical presence of inspectors, were canceled by CAP owing to the COVID-19 pandemic, the fate of the said event also hung in balance.[26]

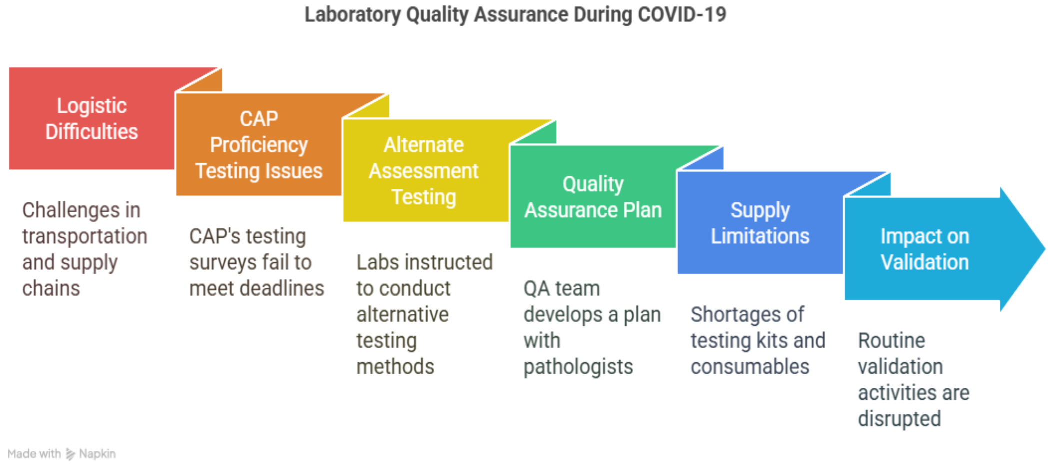

Figure 5: Challenges in Laboratory Operations During Covid-19

Workload and Staffing Challenges

Our lab activities grappled with multiple sick calls (COVID-19-induced) and an increase in professional burnout issues from the overworked, overwhelmed, and emotionally drained personnel throughout this unexpected vacancy and the resulting increased workload. The recruitment process for a new lab technician was initiated. Because the pandemic had slowed down human resources processes, the relative shortage of qualified applicants, and the increasing number of vacancies in other clinical laboratories, it took several months to post and hire an appropriate candidate. Meanwhile, a laboratory technologist near retirement age resigned due to health reasons and stress because of the increasing workload, and another technician was offered a better-paying job by a private lab.[27] Managers could have to deal with some challenges; for instance, insufficient personnel to fill night, weekend, and double shift shifts, fewer qualified candidates to hire to fill slots, and less time for adequate training.[28]

The remaining workers might feel compelled to pick up the slack, keep quality, not report flaws, and ward off worker dissatisfaction if a treasured individual leaves. To recruit, interview, hire, and train a replacement employee, hiring might take three to six months. To provide overtime coverage until a new worker is brought aboard, managers may be able to foresee added payroll costs in this period.[29]

Financial and Economic Impact on Laboratories

Developing nations are particularly vulnerable due to the lack of international assistance and the low adaptation of new technology, which hinders their ability to grow economically. The strain on the already dire financial crises in poor nations was exacerbated by the unanticipated spike in demand for global healthcare infrastructure. In order to avoid the pandemic and the financial crisis, it is necessary to seek healthcare compatibility and creative solutions.[12]

Laboratory Waste Management and Environmental Concerns

- **ncrease in biomedical waste due to high PPE usage**

Since so much old PPE is regarded as infectious waste, it needs to be handled as hazardous or medical waste. If not managed properly, they can have an impact on the environment and human health.[30]

- **afe disposal of infectious waste and sustainability challenges**

Since medical waste procedures are intended for normal settings, the sudden increase in medical waste during the COVID-19 pandemic may cause disruptions. The amount of medical waste in Wuhan, the city where COVID-19 was originally detected, skyrocketed from 40 tons per day to over 240 tons per day, surpassing the 49 tons per day medical waste treatment capability.[31]

- **azardous Healthcare Waste**

These facilities use a lot of chemicals, and the waste they produce can harm both the environment and human health. Approximately 3% of waste coming from healthcare operations is of this kind. Chemical compounds containing waste, i.e. laboratory chemicals/consumeables, film developing reagents, unused/expired disinfectants, solvents, and heavy metals containing waste is classified chemical healthcare waste.[32]

Table 4: Key Challenges Faced by Laboratories During COVID-19

Challenge	Description
Challenges In Workflow	Reorganization Of Duties To Reduce Dependency On Lab Managers And Ensure Continuity Of Operations.
Supply Chain Disruptions	Delays In Shipments, Shortages Of Ppe, And Increased Demand For Critical Tests Like Crp And Trop-I.
Workforce Dynamics	Staff Shortages Due To Infections, Increased Workload, And Mental Health Concerns
Biosafety Protocol Adjustments	Implementation Of Interim Biosafety Guidelines To Minimize Risks In Biosafety Levels 1 And 2 Labs.

Safety and Biosafety Measures

As far as PPE is concerned, laboratory personnel should adhere to routine laboratory practice, i.e. put on mask, use disposable gloves, use eye protection equipment and wear a lab coat or gown. The type of activity dictates what type of lab coats and/or gowns are advised. When working with general biological materials, like blood, urine, cerebrospinal fluid, etc., where there is little chance of direct contagion, standard lab coats can be used. When working with highly contagious materials, like respiratory specimens (e.g., sputum, nasal or throat swabs, pleural fluid), nonsterile, disposable gowns should be worn.[33]

It has proven to be difficult to employ face masks in a regular laboratory environment with no direct contact with patients. Considering the fact that the number of asymptomatic individuals can be very high, even more than 70%, as has been attested to by highly concentrated research, the rationale for this is that it is seen more as an enhanced social distancing device rather than a worry for direct patient contact or contaminated samples.[34]

Table 5: Strategies Implemented to Address Challenges

Strategy	Details
Inventory Management	Revisiting inventory needs to address shipment delays.
Rapid Training Programs	On-demand POCT operator training to handle increased workload.
Collaborative Workflow Redesign	Shared responsibilities among team members to ensure smooth operations.
Regulatory Compliance Adjustments	Adapting quality assurance practices despite logistical challenges with proficiency testing.

Figure 6: Navigating PPE protocols in Laboratory during COVID-19

In spite of its setbacks, the COVID-19 pandemic hastened innovation in laboratory practices. Automation technologies became more prominent as laboratories looked for solutions to increase throughput while reducing human interaction. Digital transformation also came into play, with telemedicine platforms incorporating laboratory information for remote patient care. These developments not only enhanced efficiency but also paved the way for long-term laboratory operations improvements.

Table 6: Lessons Learned and Recommendations for Future Preparedness

Lesson Learned	Recommendation
Vulnerability of Supply Chains	Develop local manufacturing capacities for critical supplies like PPE and reagents.
Importance of Workforce Resilience	Provide mental health support and cross-train staff for flexibility during crises.
Need for Emergency Preparedness	Establish comprehensive disaster management plans tailored to laboratory settings.

COVID-19 pandemic has irrevocably transformed laboratory practice, exposing both weaknesses and avenues for innovation. The explosion of diagnostic testing, compounded by supply chain limitations and workforce limitations, highlighted the pressing need for laboratory systems that are resilient. Although the initial priority was to control the crisis, the experience gained underscores the need to invest in automation, bolster supply chains, and ensure laboratory workers' well-being. As laboratories move forward in dealing with the continuing impacts of the pandemic and gearing up for upcoming health emergencies, an active response that welcomes technological innovation, strong emergency response plans, and dedication to workforce support will be crucial to providing sustainable and effective laboratory services. In the future, it is important that laboratories take the experiences and learnings during the COVID-19 pandemic into their long-term strategic planning. This involves not just upgrading diagnostic capacity and biosafety measures but also inculcating a culture of resilience and flexibility in laboratory personnel. In addition, enhancing coordination between laboratories, healthcare facilities, and regulatory agencies is important to achieve a concerted response to future public health crises. By applying the lessons learned and investing in readiness, laboratories can more effectively play their critical role in protecting public health and advancing scientific understanding.

CONCLUSION

The COVID-19 pandemic had a significant effect on laboratory practices, requiring quick changes to biosafety procedures, workforce management, diagnostic workflows, and technology. By increasing testing capacity, putting strict safety procedures in place, and accepting digital solutions to increase productivity, laboratories were instrumental in the pandemic response. Problems in laboratory systems were brought to light by issues such supply chain disruptions, increased workload, mental health burden on lab staff, and interruptions to non-COVID testing.

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Author Contribution:
I. N: (Investigation) acquisition of data, (Writing – Original Draft) Drafting the manuscript, (Formal analysis) analysis and/or interpretation of data
H. J: (Conceptualization) Conception and design of study, (Formal analysis) analysis and/or interpretation of data
W. F (Writing - Review & Editing) revising the manuscript critically for important intellectual content

REFERENCE

1. Jafri L, Ahmed S and Siddiqui I. Impact of COVID-19 on laboratory professionals-A descriptive cross sectional survey at a clinical chemistry laboratory in a developing country. Annals of medicine and surgery 2020; 57: 70-75.
2. Lippi G and Plebani M. The critical role of laboratory medicine during coronavirus disease 2019 (COVID-19) and other viral outbreaks. Clinical Chemistry and Laboratory Medicine (CCLM) 2020; 58: 1063-1069.
3. Lippi G and Plebani M. Laboratory abnormalities in patients with COVID-2019 infection. Clinical chemistry and laboratory medicine (CCLM) 2020; 58: 1131-1134.
4. Lippi G and Plebani M. The add value of laboratory diagnostics: the many reasons why decision-makers should actually care. Journal of Laboratory and Precision Medicine 2017; 2.
5. Ahmad M, Khan FA and Ahmad SA. Standardization of pathology laboratories in Pakistan: Problems and prospects. Clinical Biochemistry 2009; 42: 259-262.
6. Plebani M, Laposata M and Lippi G. A manifesto for the future of laboratory medicine professionals. Elsevier, 2019, p. 49-52.
7. Lippi G and Plebani M. Laboratory medicine resilience during coronavirus disease 2019 (COVID-19) pandemic. Advances in Laboratory Medicine/Avances en Medicina de Laboratorio 2020; 1.
8. Ahmed S, Jafri L and Khan AH. Evaluation of'CKD-EPI Pakistan'equation for estimated glomerular filtration rate (eGFR): a comparison of eGFR prediction equations in Pakistani population. Journal of the College of Physicians and Surgeons--Pakistan 2017; 27: 414.

9. Westfall RS. Never at rest: A biography of Isaac Newton. Cambridge University Press, 1983.
10. Kissler SM, Tedijanto C, Goldstein E, et al. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science 2020; 368: 860-868.
11. Kaul K, Singh K, Sabatini L, et al. The value and institutional impact of an in-system laboratory testing during the COVID-19 pandemic. Academic Pathology 2021; 8: 23742895211010253.
12. Anser MK, Khan MA, Zaman K, et al. Financial development during COVID-19 pandemic: the role of coronavirus testing and functional labs. Financial Innovation 2021; 7: 1-13.
13. Adejumo OO. Environmental quality vs economic growth in a developing economy: complements or conflicts. Environmental Science and Pollution Research 2020; 27: 6163-6179.
14. Durant TJ, Peaper DR, Ferguson D, et al. Impact of COVID-19 pandemic on laboratory utilization. The journal of applied laboratory medicine 2020; 5: 1194-1205.
15. Stenson MC, Fleming JK, Johnson SL, et al. Impact of COVID-19 on access to laboratories and human participants: exercise science faculty perspectives. Advances in Physiology Education 2022; 46: 211-218.
16. Zhou F, Yu T, Du R, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. The lancet 2020; 395: 1054-1062.
17. Sepulveda J, Westblade LF, Whittier S, et al. Bacteremia and blood culture utilization during COVID-19 surge in New York City. Journal of clinical microbiology 2020; 58: 10.1128/jcm. 00875-00820.
18. Tan SS, Yan B, Saw S, et al. Practical laboratory considerations amidst the COVID-19 outbreak: early experience from Singapore. Journal of Clinical Pathology 2021; 74: 257-260.
19. Back JB, Chadick CH, Garcia Vallejo JJ, et al. Shared Resource Laboratory Operations: Changes Made During Initial Global COVID-19 Lockdown of 2020. Cytometry Part A 2021; 99: 22-32.
20. SA HG and Ikram A. Application of Biosafety Principles in Laboratory Analysis of Clinical Samples from Patients with COVID-19. JPMA The Journal of the Pakistan Medical Association 2020; 70: S48-S51.
21. Nimer R, Swedan S, Kofahi H, et al. Increased adherence to infection control practices among medical laboratory technicians during the COVID-19 pandemic: a self-reported survey study. Annals of global health 2021; 87: 56.
22. Zorbozan O. The impact of COVID-19 pandemic on access to healthcare: the experience of the Diagnostic Parasitology Laboratory of Ege University. Turkiye Parazitol Derg 2022; 46: 124-128.
23. Larsen EP, Silvestro E, Ferro DF, et al. Using human factors principles to redesign a 3D lab workflow during the COVID-19 pandemic. 3D Printing in Medicine 2022; 8: 34.
24. Choy KW. Changes in clinical laboratory operations and biosafety measures to mitigate biohazard risks during the COVID-19 pandemic. The Lancet Microbe 2020; 1: e273-e274.
25. Zneimer SM and Hongo D. Preparing for Clinical Laboratory Improvement Amendments (CLIA) and College of American Pathologists (CAP) Inspections. Current Protocols 2021; 1: e324.
26. Ahmed S, Jafri L, Majid H, et al. Challenges amid COVID-19 times - Review of the changing practices in a clinical chemistry laboratory from a developing country. Annals of Medicine and Surgery 2020; 55: 300-304. DOI: 10.1016/j.amsu.2020.06.004.
27. Huq Ronny FM, Sherpa T, Choesang T, et al. Looking into the laboratory staffing issues that affected ambulatory care clinical laboratory operations during the COVID-19 pandemic. Laboratory Medicine 2023; 54: e114-e116.

28. Halstead DC and Sautter RL. A literature review on how we can address medical laboratory scientist staffing shortages. Laboratory Medicine 2023; 54: e31-e36.
29. Verlander EG and Evans MR. Strategies for improving employee retention. Clinical Leadership & Management Review 2007; 21.
30. Hantoko D, Li X, Pariatamby A, et al. Challenges and practices on waste management and disposal during COVID-19 pandemic. Journal of environmental management 2021; 286: 112140.
31. Tang W. The medical waste related to COVID-2019 is cleaned up every day—the medical waste treatment market needs to be standardised. 21st Century Business Herald. Herald, 2020.
32. Das AK, Islam MN, Billah MM, et al. COVID-19 pandemic and healthcare solid waste management strategy–A mini-review. Science of the total environment 2021; 778: 146220.
33. Lippi G, Adeli K, Ferrari M, et al. Biosafety measures for preventing infection from COVID-19 in clinical laboratories: IFCC Taskforce Recommendations. Clinical Chemistry and Laboratory Medicine (CCLM) 2020; 58: 1053-1062.
34. Baggett TP, Keyes H, Sporn N, et al. Prevalence of SARS-CoV-2 infection in residents of a large homeless shelter in Boston. Jama 2020; 323: 2191-2192.