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Gaps, Impediments, and Facilitators of Effective Laboratory Responses During a Pandemic

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Abstract

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Introduction

Laboratories play a critical role in controlling infectious disease threats. In recent years, multiple epidemics and pandemics have highlighted significant gaps in laboratory systems around the world. It is important to understand these gaps to facilitate efficient and effective laboratory responses. This literature review will determine the most common barriers laboratories face in an outbreak response, and describe mechanisms to achieve and maintain sustainable, efficient, and effective laboratory systems.

Methods

A scoping literature review was performed using the PRISMA method. PubMed was used to search for relevant articles related to the global laboratory capacity to respond to pandemics. All articles that were approved for full text review were stratified by region and infectious disease focus. Main themes were compiled and compared. From these themes, barriers and facilitators to an efficient, effective laboratory response to a pandemic were identified.

Results

The PubMed search yielded 898 articles for review. After screening using inclusion and exclusion criteria, 44 articles remained for data extraction. The selected articles represented a wide array of countries and infectious diseases. There were 9 major themes identified across the 44 articles. These themes included: biosafety; collaboration with other laboratories; use of laboratory networks; physical capabilities to perform laboratory tasks; political and financial support; use of quality assurance programs; sufficient laboratory staffing; reliable supply chains; and efficient workflow design. The literature also offered solutions to improve laboratory preparedness and response if any one of these components were lacking.

Conclusion

Laboratories are important for the control and surveillance of infectious diseases. They are particularly important during outbreaks, and improved laboratory capacity can lead to a more efficient and effective response to a pandemic. Improving upon the gaps present in biosafety, laboratory collaboration, physical capabilities, political and financial support, quality assurance programs, staffing, supply chains, and workflow design can lead to better laboratory responses.

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1. INTRODUCTION

The International Health Regulations (IHR) were updated by the World Health Organization (WHO) in 2005 to "prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade".[1] The purpose of IHR 2005 was to strengthen public health surveillance (PHS) and response capacities at the local, regional, national, and international levels to efficiently detect and control emerging disease threats. By strengthening these capacitates, it was hoped that IHR 2005 would successfully prevent significant emerging infectious diseases and worldwide pandemics.

However, since IHR 2005's implementation, the world has faced numerous infectious disease threats such as 2009 H1N1 influenza, 2012 MERS-CoV, 2014 Ebola, Zika, and recently, COVID-19. These recent outbreaks and pandemics have highlighted the gaps in the public health fabric that IHR 2005 does not address. As of April 2021, COVID-19 alone was responsible for over 139 million cases and 2.9 million deaths worldwide.[2] As such, it highlights the importance of improving worldwide preparedness and response.

Laboratory testing and public health surveillance (PHS) are critical components of preparing for, monitoring, and responding to emerging infectious disease threats. Since an infectious disease can emerge from anywhere, it is critical that global laboratories have the capacity to respond to and control an outbreak.

IHR 2005 lists core capacities regarding laboratories that member states (MS) should maintain in order to be prepared for a pandemic. One capacity indicates MS must "provide support through specialized staff, laboratory analysis of samples (domestically or through collaborating centers) and logistical assistance (e.g. equipment, supplies, and transport)”.[1] IHR 2005 also requires that MS must request assistance from other MS when they have “insufficient laboratory or epidemiological capacity to investigate the event (equipment, personnel, financial resources)”.[1]

Since global laboratory systems play such a critical role in mitigating infectious disease threats, it is important to understand the capacities that lead to effective and efficient laboratory responses. As such, this literature review aimed to determine common themes that either enhance or inhibit a laboratory’s ability to respond in a pandemic situation. Identifying these themes will help to highlight the gaps and impediments in the current IHR 2005 framework.

Understanding these gaps and impediments is the first step toward improved global laboratory systems. It is hoped that with improved pandemic preparedness framework, future infectious disease outbreaks will be contained quickly to avoid similar devastation that the COVID-19 pandemic has caused. A scoping review was chosen since it aims to highlight overarching themes in laboratory pandemic preparedness and response rather than answering a specific research question.

2. METHODS

Protocol and Registration

A scoping review was performed using the PRISMA method. The PRISMA method involves a database search followed by title and abstract screening, full-text assessment, and data extraction.

Eligibility Criteria

Sources of evidence included all relevant peer-reviewed articles written in English. All peer reviewed articles were included since useful information could come from primary sources or other review articles. Review articles were not filtered by date, since laboratory capabilities from all eras are useful in informing either efficient or inefficient laboratory responses.

Information Sources and Search

The PubMed database was used to search for relevant articles addressing the global laboratory capacity to deal with pandemics. To complete the search, MeSH terms were used to gather the articles of interest. The search phrase (global[tiab]) OR world[tiab] OR international[tiab] AND (laboratory[tiab] AND (pandemic[tiab]) was used to find articles related to laboratory responses to pandemics. The "tiab" notation limited the search terms to titles and abstracts to avoid including an excessive number of irrelevant articles.

Selection of Sources of Evidence

Once the PubMed search was complete, it was saved and uploaded to Covidence for the review process. Once uploaded to Covidence, all duplicate articles were removed. In the first round of review, articles were screened by title and abstract and marked as either relevant or irrelevant. Irrelevant articles were removed, and relevant articles were further assessed in the full-text review. In the full-text review, the articles were determined to either fit the inclusion or exclusion criteria. Articles that were excluded were removed and articles that met the inclusion criteria were then used for data extraction.

Inclusion and Exclusion Criteria

To be included in the data extraction, articles had to meet the inclusion criteria. Inclusion criteria were …

- laboratories must be the focus of the article.
- the purpose of article was not to discuss specifics of laboratory diagnostic tests, but rather capacity to perform diagnostic tests
- the purpose of article was to discuss laboratory response to an infectious disease, not laboratory characteristics of a disease

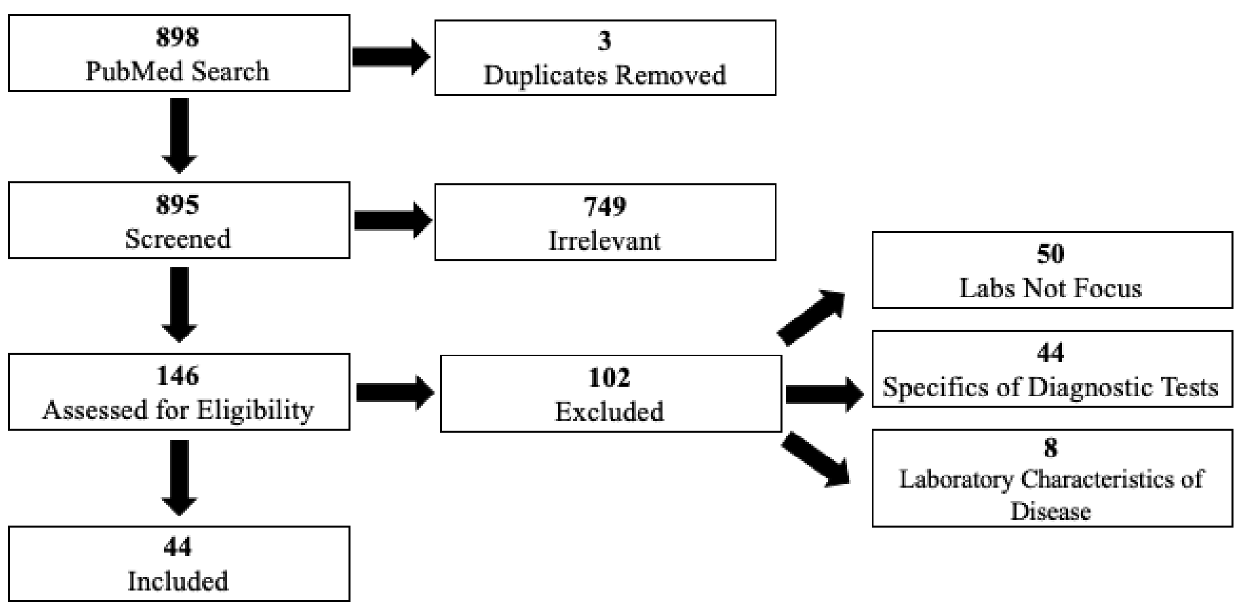
Synthesis of Results and Data Extraction

All articles approved for full text review were organized in an Excel spreadsheet by region and infectious disease focus. Organizing by region was helpful to identify if laboratory capacities to respond to a pandemic differ by region. Organizing by infectious disease was helpful to identify if laboratory responses differ by disease type. Main themes were identified from each article and recorded in the spreadsheet. This method was used for efficient visualization of the themes that were occurring across the articles. Main themes were compiled and articles describing each main theme were counted for easy comparison of the most prominent themes. Articles were counted based on whether the article described the theme as a barrier to achieving successful pandemic response. This method was a way to determine the most prominent barriers that laboratories face in an outbreak situation.

3. RESULTS

The PubMed database search resulted in 898 articles (Figure 1). Three of the 898 articles were duplicates and were therefore removed, leaving 895 articles to title and abstract screening. Through reading the titles and abstracts of the 895 articles, 749 were marked as irrelevant. Studies were deemed irrelevant if they did not have to do with laboratories, infectious diseases, and pandemics. The remaining 146 articles underwent a full-text review to determine if they met the inclusion criteria for the study, and 102 articles were excluded for not meeting the inclusion criteria. Fifty articles were excluded because laboratory systems were not the focus, 44 articles were excluded because they were analyses of specific diagnostic laboratory tests rather than laboratories a whole, and 8 articles were excluded because they were descriptions of laboratory characteristics of infectious diseases rather than the laboratories themselves. This resulted in data extraction from 44 articles (Figure 1).

Figure 1: Search, Screening, and Selection Process for Determining Gaps, Impediments, and Facilitators of Effective Laboratory Responses During a Pandemic



Most articles included were analyses of laboratory systems in Asian countries (25%). There were also many articles describing the laboratory systems of African countries (22.7%). Articles about North American laboratories made up 20.5% of the articles, European laboratories accounted for 6.8% of the articles, and Oceania and South America each made up 4.5% of the total articles reviewed. Over 15% of the articles reviewed were not specific to a particular region and were rather an analysis of global laboratory systems as a whole. The articles were mainly focused on African and Asian countries since there has been a significant focus in those areas to strengthen laboratory capacity and infrastructure in recent years (Table 1).

Table 1: Number and Percent of Articles Included in Literature Review by Region

Region	Articles (n)	(%) Total
Africa	10	22.7
Asia	11	25
Europe	3	6.8
North America	9	20.5
Oceania	2	4.5
South America	2	4.5
Not Specific	7	15.9

Due to the ongoing COVID-19 pandemic, many articles were focused on the laboratory response to COVID-19 (Table 2). There were also many articles (29.5%) outlining the global laboratory preparedness and response to influenza. Other diseases of focus were Ebola, HIV, SARS, and Zika. Two articles were not focused on a specific disease and rather discussed laboratory systems as a whole (Table 2)

Table 2: Number and Percent of Articles Included in Literature Review by Infectious Disease Focus

Infectious Disease	Articles (n)	(%) Total
COVID-19	25	56.8
Ebola	3	6.8
HIV/AIDS	2	4.5
Influenza	15	29.5
SARS	3	6.8
Zika	2	4.5
Not Specific to a Disease	2	4.5

In the literature, several topics were cited as important to an effective and efficient laboratory response to a pandemic. Staffing in labs was the most prevalent topic of discussion, with 70.5% of articles discussing the importance of adequate laboratory staff when responding to a pandemic. Physical capabilities to perform laboratory tasks were also mentioned very frequently (68.2%) along with the use of quality assurance programs (56.8% of articles). Other themes identified were biosafety, collaboration with other laboratories, use of laboratory networks, political and financial support, supply chain of laboratory materials, and workflow design (Table 3).

Table 3. Number and Percent of Articles Discussing Each Key Topic

Topic Discussed	Articles (n)	(%) Total
Biosafety	16	36.4
Collaboration with other Labs	16	36.4
Laboratory Networks	21	47.7
Physical Capabilities	30	68.2
Political/Financial Support	9	20.5
Quality Assurance Programs	25	56.8
Staffing of Labs	31	70.5
Supply Chain	19	41.3
Workflow Design	11	25.0

Several topics were identified as having gaps, therefore preventing an efficient and effective laboratory response (Table 4). The most frequent gap identified was staffing issues. The second most frequent gap to achieving successful laboratory response was the physical capabilities to respond (such as the presence of proper equipment and tools), and the third most frequent gap was the supply chain. The articles included in this study had fewer issues with collaborating with other labs or issues maintaining biosafety requirements (Table 4).

Table 4: Number and Percent of Articles Discussing Each Key Topic as A Barrier to Achieving Laboratory Preparedness

Topic Discussed	Articles (n)	(%) Total
Biosafety	6	13.6
Collaboration with other Labs	3	6.8
Laboratory Networks	10	22.7
Physical Capabilities	17	38.6
Political/Financial Support	9	20.5
Quality Assurance Programs	7	15.9
Staffing of Labs	23	52.3
Supply Chain	11	25.0
Workflow Design	9	20.5

4. DISCUSSION

The key themes included: laboratory networks; physical capabilities of laboratories; laboratory collaboration; laboratory staffing, quality assurance and accreditation; biosafety in laboratories; laboratory supply chain; and country characteristics. Each theme contains an overview of the theme, barriers to achieving laboratory capacity in that theme and solutions to improve laboratory capacity regarding the theme.

A. Laboratory Networks

Overview

Laboratory networks are helpful in laboratory surveillance and outbreak detection. A laboratory network is a group of laboratories that work together to boost overall laboratory capacity in an area or region. Laboratory networks typically consist of multiple types of labs, including international laboratories, national laboratories, public health laboratories, clinical laboratories, food laboratories, environmental laboratories, and veterinary laboratories. Laboratory networks have proven to enhance laboratory response to an outbreak. For example, Taiwan implemented a laboratory network in coordination with the Taiwan Centers for Disease Control and Prevention in 2000.[3] Implementation of this network allowed for significant control over influenza and other outbreaks within the country. This network was utilized and beneficial in both the 2003 SARS pandemic and the 2009 H1N1 pandemic.[3] Without laboratory networks, there is no system in place to ensure proper training, equipment maintenance, or provides standard operating procedures.[4]

Barriers

Some countries have experienced issues with the development and implementation of laboratory networks. For example, Rwanda made significant strides in implementing a laboratory network in 2005. However, there were still many obstacles to overcome. First, there were unclear roles and responsibilities for laboratories within the network. With unclear roles, laboratories had difficulty understanding their purpose within the nation-wide network.[5] Additionally, many laboratories within the network had different reporting systems, resulting in inefficiencies with reporting results.[5] Gaps in infrastructure also made network implementation difficult. For example, issues with transporting samples between network labs proved difficult due to long distances and difficult driving conditions.[5] Also, insufficient internet access, or a lack of interoperable platforms made communication between network laboratories difficult.[5,6]

Solutions

One solution to overcoming issues with developing laboratory networks is using already-existing infrastructure rather than starting from scratch to create an entirely new network.[7] For example, many African countries experienced difficulties with influenza surveillance. In the past, influenza surveillance has been of low priority due to the presence of other infectious diseases. Since influenza has non-specific symptoms, a strong laboratory network is required for effective surveillance of the virus. While there is not a specific influenza laboratory network in place, South Africa plans to build upon their polio and measles laboratory networks to build capacity for influenza testing and surveillance.[7]

Another solution for developing laboratory networks is partnering with other nations to facilitate the process. Since infectious diseases can spread and cause disease around the world, it is in the best interest for nations to contribute to the laboratory capacity of other nations. For example, after the SARS outbreak in 2004, U.S. CDC partnered with China CDC to improve the laboratory network and surveillance system in China.[8] This was designed specifically for enhanced PHS and characterization of emerging influenza.

While Rwanda had some initial issues with implementing their laboratory network, they were able to overcome these issues and highlighted the importance of taking the necessary steps when implementing a network. When developing a laboratory network, it is important to outline clear roles, responsibilities, and communication channels among all labs.[5] Additionally, it is important to work directly with Ministry of Health divisions to ensure proper oversight and coordination.[5] It is also essential to collaborate with funding and technical partners in the development of the network.[5]

B. Physical Capabilities

Overview

The physical capabilities of a laboratory include things such as access to laboratory space, access to equipment needed for laboratory tests, the ability to perform maintenance on equipment, access to gold-standard testing supplies, and ability to maintain cold-chain requirements. If a laboratory is missing any item that allows for the physical capability to perform laboratory testing, it can lead to inaccurate results, delays in testing and therefore reporting, or even prevent the laboratory from running tests altogether. It is crucial that laboratories have access to and maintain access to the physical supplies they need to respond in a pandemic situation.

Barriers

Resource-constrained countries may struggle with maintaining laboratories due to lack of financial or political support. As such, these labs may not have the materials and resources they need to physically complete the lab tasks in a timely and accurate manner. One study performed an analysis of laboratories in resource-constrained countries and found that many laboratories had insufficient testing capabilities, had bench tops that were either damaged or difficult to clean, contained expired reagents, or had poor maintenance of their equipment.[4]

Another issue that laboratories around the world have with physical capabilities of laboratory testing is a lack of gold-standard testing equipment. For outbreak PHS and detection, it is important to have the proper equipment to perform PCR and genome sequencing. For example, prior to the 2009 H1N1 pandemic, only 10 of the 18 laboratories in the WHO Africa Region (WHO/AFRO) had the capabilities to perform diagnostic PCR for influenza surveillance.[8] Advanced molecular techniques are also important for rapid disease identification but are not readily available in all laboratories around the world.[9]

Another issue that often arises in resource-constrained countries is inefficient maintenance of laboratory equipment. If equipment is not maintained, it can lead to issues in the analyses or may prevent a laboratory from performing certain tasks altogether. One study, which aimed to find indicators of laboratory capacity, found that laboratories that had issues with equipment maintenance had low capacity for laboratory surveillance of infectious diseases.[10] In many settings, laboratory technicians are not trained in equipment maintenance and there are very few equipment-repair services available.[4] In addition to issues with equipment maintenance, issues with cold chain, lack of reliable utilities such as internet or electricity, and constrained laboratory space all hinder a laboratory’s ability to physically perform necessary laboratory tasks.[11]

Some low-to-middle income countries also have issues maintaining physical capabilities to perform laboratory testing because their testing resources rely on donations from other countries or they are only able to import a limited number of testing supplies.[12] This dependence can especially cause issues when supply is low.

Solutions

To overcome limited access to diagnostic testing, one article suggested using variations of PCR such as RT-PCR, nested PCR, and two-step PCR rather than only using RT-qPCR.[13] While these tests are not the gold standard, their usage has been shown to fill gaps during the COVID-19 pandemic where RT-qPCR capabilities were more difficult to acquire.[13]

WHO/AFRO, which was notably lacking PCR capabilities, partnered with the National Institute for Communicable Diseases in Johannesburg to improve laboratory capacity.[7] It was decided that they would provide active training for laboratory personnel in PCR with plans for labs to acquire PCR once training was complete.[7] This increased access to PCR will be helpful going forward for influenza outbreak surveillance and response.

When it comes to equipment maintenance, another study looking at WHO/AFRO's efforts to improve laboratory capacity discussed the importance of leveraging contracts for equipment maintenance and service.[4] One study suggested using central reference labs to provide maintenance for other in-network lab equipment so that laboratories are not on their own in maintaining their equipment. The study also suggested providing routine calibration and maintenance of laboratory equipment and providing mechanisms for repair if needed.[4]

To address the issues that some laboratories in resource-constrained areas face with maintaining unexpired reagents and testing materials, one study suggested that national or central labs provide all in-country laboratories with the primers, probes, PCR reagents, controls, and standard operating procedures necessary to carry out laboratory testing.[14] This not only helps with the supply of necessary materials, but also ensures that all laboratories are using the same quality of materials to carry out their testing.

C. Collaboration

Overview

Since pandemics have the potential to affect every country, collaboration among laboratories is crucial for pandemic response. Collaboration in a laboratory setting can mean collaboration between labs within the same country, collaboration with international laboratories, or even collaboration with the community to enhance laboratory capacity. Collaboration is particularly useful for countries with limited laboratory capacity or areas where resources are limited. However, issues can arise when laboratory systems become too dependent on collaborators and struggle to function in the absence of help from other labs.

Barriers

The major problem with laboratory collaboration is a reliance on external entities for help in sustaining laboratory capacity. For example, one study analyzed the laboratory response to COVID-19 in African countries. It found that many labs suffered from poorly trained laboratory technicians and insufficient BSL laboratories to properly carry out COVID-19 testing.[15] They suggested that these limitations could be a result of over-reliance in external assistance to maintain laboratory capacity.[15]

Another issue that arises with laboratory collaboration is that harmonizing laboratory activities can be difficult without the proper capacity to do so.[16] If laboratories have different ways of operating or reporting, there can be challenges when working together. Due to this issue, laboratories typically rely on local partners for collaboration who are already familiar with the laboratory system.[16]

Solutions

The COVID-19 pandemic highlights the importance in laboratory collaboration in pandemic response. There are many ways in which laboratory collaborations have occurred. For example, university labs, which were otherwise closed due to the pandemic, were utilized as diagnostic testing centers all over the world.[13,17] Using this already-existing infrastructure was beneficial because it allowed for increased laboratory capacity without having to create new facilities. Similarly, veterinary laboratories have been utilized for extra resources during both the COVID-19 and influenza pandemics.[18,19] Additionally, collaboration with other labs allow for gaps in equipment, reagents human resources, and technical support to be filled when resources are limited due to an outbreak or pandemic situation.[5]

Laboratory collaboration has also proven to be successful on an international scale. WHO collaborating centers facilitate virus sharing, training, and mentoring to laboratories in resource-constrained areas.[20] WHO also facilitates a shipment fund project which is used to safely transport samples between laboratories in areas where shipping may be difficult.[21]

D. Staffing

Overview

Staffing of laboratories refers to the human resource availability as well as the competency of laboratory workers in performing laboratory tasks. It is important for laboratories to be well-staffed, especially in an outbreak situation where the workload increases significantly. Additionally, laboratory workers must be well-trained, reliable, and able to perform laboratory tests effectively and efficiently. Shortfalls in laboratory staffing can lead to strains on the current laboratory workforce and can also lead to delays in laboratory testing and surveillance.

Barriers

One barrier to achieving sufficient levels of laboratory staffing is that there is an overall shortage of well-trained staff in many places in the world. This issue has been a particular barrier in resource constrained countries.[22,23] In addition to a lack of workforce availability, in many settings, the staff working in laboratories have not received proper training to perform their laboratory tasks.[24] A study looking at the capacity of public health laboratories in Afghanistan found that many employees of public health labs had limited scientific knowledge of the tasks they were performing and also had inadequate awareness of proper laboratory practices.[11]

Inconsistencies among staff training and requirements have also created staffing issues in laboratories. A study analyzing the laboratory response to SARS in Singapore found that laboratories had inconsistent requirements for laboratory employees in regard to biosafety and messaging.[25] This ultimately created confusion among staff about the protocols they should follow. Additionally, a study looking at laboratory capacity in African countries found that laboratories often had varying educational requirements for staff.[4] These varying educational requirements can lead to inconsistency in staff capabilities and knowledge when performing laboratory tasks.

Large pandemics such as the COVID-19 pandemic put further strain on laboratory staffing. For example, outbreaks among lab workers[26] as well as burn out and physical fatigue of laboratory staff have led to reduced staffing at a time when laboratory staffing is critically important.[27] One laboratory in Canada experienced a high incidence of sick time used by staff after they experienced repetitive strain injury from high volumes of manual pipetting.[28] Many laboratories also had to deal with staff reduction to accommodate social distancing requirements early on in the COVID-19 pandemic, further escalating the issues with staffing.[29]

Solutions

To improve laboratory staffing, it is important to provide laboratory staff with proper training, mentoring, and professional development.[30] A study of laboratory capacity in Angola found that the most effective ways of training involve utilizing both pre and post training surveys to ensure that staff has learned the appropriate materials.[31] They also encourage staff to perform self-assessment of perceived ability to perform proper testing techniques.[31]

The literature offers many solutions for dealing with staffing constraints during a pandemic. A pandemic creates unique challenges in that there is an increased workload for laboratory professionals, but there is also a need to prevent professionals from becoming sick in the laboratory. One laboratory in the UK found success managing staffing by having laboratory technicians work in shifts to limit the number of individuals in the lab at a given time, staggering breaks to prevent crowding in break areas, symptom monitoring of laboratory staff, and using quarantining and contact tracing if necessary.[26] This lab also stressed the importance of communicating to laboratory workers if there was an expected increase in workload or reduced staffing on particular days so they could prepare and adjust as necessary.[26] Another lab in the UK tested laboratory staff for COVID-19 weekly to prevent any possible spread of the virus and suspended all non-essential work.[29]

To overcome laboratory staff shortages during the COVID-19 pandemic, laboratories had to make changes in operation to ensure all laboratory testing was performed in a reasonable timeframe. A laboratory in Canada worked to reallocate its highly trained staff to where their expertise would be most beneficial to assist with the high demand for testing.[32] One laboratory in Australia had a different approach, where they worked to retrain and recruit additional staff. This

Australian lab also highly encouraged overtime work, with which they saw a 1000% increase in overtime hours worked compared to the year prior.[19]

E. Quality Assurance and Accreditation

Overview

Quality assurance programs hold laboratories accountable and ensure that results are up to standard. They ensure that laboratory results are accurate, valid, and reliable. Quality assurance programs often involve the use of standard operating procedures, proficiency testing, and rules and regulations regarding laboratory activities. Accreditation and quality assurance often go hand in hand since laboratories typically need to meet quality assurance requirements to be accredited.

Barriers

When quality assurance programs are not in place, laboratory capacity and results can suffer. In a study of laboratory capacity to detect influenza outbreaks, it was found that there were significant variations in results obtained by different laboratories when quality assurance programs were not in place.[21] Quality assurance programs typically provide reference materials and testing guidelines.[4,15] Without these materials, laboratories can struggle with consistency and accuracy when running tests.

A study of laboratories in India found that non-adherence to SOPs, a lack of internal and external quality assessment activities, and not verifying results were major factors associated with poor laboratory performance. Each of these factors also fall under the realm of quality assurance.[33] Internal quality assessment is also important in maintaining accurate and reliable results. For example, poor internal quality assessment can lead to issues such as incorrect temperatures in refrigerators, or poor calibration of instruments.[10] These factors can be major contributors to inaccurate data.

Solutions

One solution to achieving quality assurance is to participate in an external quality assessment program. There are a variety of external quality assessment programs such as WHO's external quality assessment program.[20] External quality assessment programs are able to find systematic testing errors, provide objective evidence of testing quality, and are able to compare laboratory performances across labs.[34] The objective nature of external quality assessment programs is helpful in ensuring all laboratories are held to the same standard.

Proficiency testing is useful in ensuring that laboratories are producing accurate and reliable results.[35] Taiwan utilizes proficiency testing for all of its public health laboratories. Each laboratory must undergo proficiency testing yearly and results are monitored by Taiwan CDC.[36] China uses similar yearly assessments to monitor and maintain laboratory quality.[8]

Quality assurance can also be maintained during an outbreak situation. For example, laboratories within India's public health laboratory network used quality control mechanisms during the COVID-19 pandemic to ensure that their laboratory testing was accurate. The laboratories were required to share their first ten negative results and all positive results with the national-level laboratory for confirmation of results.[14]

For effective quality assurance, it is helpful to hire QA officers within each laboratory to oversee the processes.[4] Quality assurance officers are also important in helping to update SOPs and provide standard materials to the laboratory staff. A well-maintained quality assurance system is helpful in identifying gaps within laboratories and allow for priorities to be made to address those gaps.

F. Biosafety

Overview

Biosafety ensures that laboratory staff are safe while completing their laboratory tasks. To maintain biosafety, laboratory staff must have access to proper protective equipment, laboratories must have proper safety equipment and cleaning supplies, and trainings of laboratory staff must take place.

Barriers

In the context of a new outbreak, such as the COVID-19 pandemic, biosafety can be difficult due to the novel nature of the pathogen. For example, in an article describing the biosafety requirements for laboratories performing COVID-19 testing, the uncertainty of the new virus created issues with biosafety requirements. Initially, there was limited guidance concerning the biohazard risks of COVID-19, particularly due to the uncertain route of transmission at the very beginning of the outbreak.[37] Additionally, during a new outbreak, laboratory staff are often fearful for their safety.[27]

While pandemics tend to bring more awareness to the importance of proper biosafety measures, routine laboratory testing is subject to issues with biosafety regulation compliance. For example, when analyzing a biochemistry laboratory in Singapore, it was found that many laboratory staff members would not adhere to PPE guidelines when supervisors were not present.[25] This lack of compliance can be risky both to the staff and to the quality of the laboratory testing.

A significant barrier to achieving biosafety in a laboratory setting is the lack of proper biosafety level laboratories in a given area. For example, Biosafety Level 2 laboratories are required for diagnostic testing and surveillance of many viral pathogens such as Influenza and COVID-19, and Biosafety Level 3 laboratories are required to isolate viruses.[33] This can be problematic in resource-constrained countries that may not have the infrastructure in place to maintain high-level biosafety labs. For example, there are very limited BSL 3 laboratories in Africa, making proper virus isolation almost impossible.[15]

Solutions

One helpful solution for ensuring biosafety in a laboratory setting is to establish a biosafety team. This team would be responsible for training and holding laboratory staff accountable in following biosafety guidelines. Training is crucial for laboratory staff to understand the biosafety procedures and reasons those procedures are in place.[10] In a pandemic setting, it is recommended that biosafety training is completed online to avoid unnecessary extra personnel in the lab.[37]

During an outbreak, it is important that laboratory personnel are protected from becoming sick from the pathogen itself. To protect laboratory staff, there must be SOPs for handling clinical specimen, as well as availability of PPE for all.[38] The importance of handwashing should also be stressed to all laboratory employees.[38] To avoid unnecessary contact between laboratory staff, it is recommended that laboratory teams adhere to social distancing guidelines within the lab, and quarantine if they become infected.[27] To help facilitate social distancing, a COVID-19 testing laboratory in the UK utilized a drop off location for samples to reduce face to face contact and held meetings through online video calling.[29] Utilizing automated instruments and analyzers whenever possible can help to limit the number of individuals needed within a laboratory at a given time and can promote social distancing.[37] Laboratories should also maintain extended cleaning regimens in an outbreak situation.[29]

G. Supply Chain

Overview

A reliable supply chain is necessary for efficient testing in a laboratory setting. A supply chain ensures that laboratory supplies, equipment, reagents, PPE, collection materials, media, and testing kits are all available to perform required testing.[32] Supply chain issues can arise when there becomes a large demand for a limited number of supplies, leading to shortages in equipment, supply, and reagents.[5]

Barriers

The COVID-19 pandemic has highlighted the issues involved with relying on supply chain for necessary equipment, reagents, and PPE. The global demand for laboratory reagents during the COVID-19 pandemic created inefficiencies in the laboratory response and led to delayed testing and surveillance.[39] The supply chain issues experienced during the COVID-19 pandemic were magnified by the fact that there were shortages in reagents at the local, national, and global levels.[19] Not only were there concerns about efficient testing with limited reagents, but there were also issues with PPE shortages[25]—creating potentially unsafe environments for laboratory personnel.

Solutions

While the unexpected nature of a pandemic makes supply chain issues difficult to plan for, the literature emphasizes the importance of preparedness for issues with insufficient supply of laboratory equipment, reagents, and PPE.[23] A laboratory network in Alberta, Canada recommended stockpiling enough supplies that would be sufficient for 6 months.[28] However, this may not always be feasible, particularly in resource-constrained countries. If stockpiling is not an option, the selective use of PPE may be a solution.[25] Stringent inventory control is also an option to provide a sense of supplies that may need to be rationed.[14] There are also ways of reducing the use of reagents such as using pooled sample methods,[39] or creating triaging protocols for priority testing when there are limited testing supplies.[31] While these situations are not ideal, in severe supply shortages, they may be the best ways to respond.

A public health laboratory network in Alberta, Canada had a successful experience in maintaining sufficient laboratory supplies during the COVID-19 pandemic. First, they quickly borrowed equipment from laboratories that were not responding to the COVID-19 pandemic.[40] This was helpful in ensuring equipment capacity. They also searched worldwide for procurement of reagents and supplies. When reagents were not available, they attempted to make reagents in house. They also proactively established multiple supply chains with redundancy for reagents to account for supply chain issues.[40] This successful response was made possible by a strong supply chain management team which worked tirelessly to procure the reagents and supplies the laboratories needed.[40]

H. Workflow

Overview

Laboratories must maintain a balanced and efficient workflow to provide appropriate surveillance and diagnostic testing. During a pandemic, workflow needs to be as efficient as possible to keep up with the unpredictable and frequently changing number of tests required to be run in a laboratory.[19]

Barriers

One of largest issues in dealing with laboratory workflow during a pandemic is the surge capacity of required testing.[41] With the COVID-19 pandemic, laboratories went from initially testing dozens of samples per day to thousands of samples per day.[40] This put a huge strain on workflow, particularly in areas where laboratories had a low daily test capacity to begin with.[42] Additionally, the mixed workload of pandemic-related testing in combination with routine testing can disrupt a laboratory's workflow.[25] In the early days of the pandemic, there are also frequently changing laboratories guidelines from national and global-level agencies such as WHO and CDC.[22] It can be difficult for laboratories to keep up with these frequently evolving guidelines.

Laboratory workflow may also be disrupted when there are restrictions in laboratory space available to accommodate additional equipment and staffing.[29] Changes in space and personnel can alter the mechanisms in which tasks had previously been performed. Laboratories also need to quickly incorporate new practices into their training regimens that follow the guidelines of the new pathogen in a pandemic.[29] These new practices can also alter workflow and may receive some resistance from staff.

Solutions

Laboratories across the globe have utilized many innovative solutions to improve workflow. A laboratory network in British Columbia, Canada, performed an analysis of their workflow and determined areas in the laboratory testing process where time was wasted. They found that it was more efficient to have one laboratory technician assigned to each step of the testing process rather than having each laboratory technician carrying out all of the steps of the testing process.[41]

Other laboratories have made smaller changes to improve workflow. For example, some laboratories have experienced success from rearranging laboratory equipment to enforce unidirectional workflow to save time and limit close contact between laboratory technicians.[10] Other labs have found success by providing daily updates to alert laboratory staff of new guidelines and recommendations that could influence workflow.[25] Daily updates are also important to alert staff of changes in sample volume or time constraints.[25] If staff are well-informed, workflow is likely to be greatly improved.

Pooled testing has also been a successful tool used during the COVID-19 pandemic to improve workflow and limit reagent and supply usage.[43] The process involves combining multiple patient samples together and analyzing them as one sample.[43] This process cuts down on the testing time and reagent usage significantly. However, due to the nature of the process, pooled testing is only beneficial in areas of low disease incidence.[43]

Overall, organization, process control, and using documentation and records of testing are important factors in maintaining an efficient laboratory workflow.[4] Additionally, having defined roles and responsibilities within the lab and maintaining standard operating procedures allows for a smooth transition when testing needs to be scaled up significantly.[28]

I. Political/Financial Support

Overview

In order for successful laboratory response, laboratories must have sufficient political and financial support from their countries.[21,30] Without support, it is difficult for laboratories to maintain high quality standards or perform testing in an accurate and reliable manner. Countries with poor laboratory support often depend on the help of other nations, global organizations, or donor funds to assist with sustainability efforts in their laboratory systems.[22]

Barriers

In resource-constrained countries, there are often more pressing needs that require funding and support than laboratory systems. For example, in some Sub-Saharan African countries, public health funding resources need to go to other areas such as HIV, TB, and malaria programs as well as polio vaccination campaigns. As such, there is limited funding left over to provide for extensive laboratory networks or surveillance programs.[44]

Solutions

Since a lack of political and financial support is a deep-rooted issue, it can be difficult to obstacle to overcome. One solution in this case is to receive assistance from global agencies such as WHO, other countries' laboratory systems, or donor funds. It is important that the support and funding received is sustainable to ensure the long-term success of the laboratory system.

5. CONCLUSIONS AND PUBLIC HEALTH IMPLICATIONS

Study Limitations

One limitation to this study is the lack of articles from high-resource settings. The majority of articles included were analyses of interventions from areas where laboratory capacity had been traditionally low. Interestingly, the COVID-19 pandemic has been just as devastating, if not more devastating, in countries that have the best laboratory technology and systems in the world. A greater number of articles from these high-resource settings would help to better understand what went wrong in areas that should have been well-prepared.

Another limitation to this study is the timing of the literature review. Articles were selected at a peak of the COVID-19 pandemic, so there may be useful articles that were not selected because of the timing of their publication.

Public Health Implications

This scoping literature review aimed to find the facilitators and barriers of an effective public health laboratory response in an infectious disease outbreak. The literature discussed nine main capacities that contribute to laboratory preparedness and response. These capacities included: biosafety; collaboration with other laboratories; use of laboratory networks; physical capabilities to perform laboratory tasks; political and financial support; use of quality assurance programs; sufficient laboratory staffing; reliable supply chain; and efficient workflow design. The literature also offered potential solutions to improve laboratory capacity if any one of these components are lacking.

Issues with staffing appeared to be the most frequent barrier to achieving an efficient and effective laboratory system. This is interesting because the literature described very few interventions focusing on staff improvement. Most interventions were focused on larger tasks such as improving laboratory networks or incorporating quality assurance systems into laboratories. Many articles also described problems with the physical ability to perform tasks due to lack of working equipment, insufficient reagents, or lack of space.

From the literature, it appears that the larger, more time-consuming projects such as building laboratory infrastructure, creating networks, and participation in quality assurance programs have been successful. However, looking at the devastation caused by the COVID-19 pandemic, it is necessary for laboratories to continue to make improvements to be better suited to respond to large-scale outbreaks and perform effective surveillance. As such, laboratories may need to work towards gaining capacity in the smaller, more nuanced areas of laboratory preparedness. Things such as improving staffing, making changes in workflow design to be more efficient, and maintaining a strong supply chain will all be important areas to address in the future.

IHR 2005 did outline the importance of staffing, logistics, personnel, and resources for laboratories. However, global pandemics such as the H1N1 Influenza pandemic in 2009 and the COVID-19 pandemic were not prevented. Perhaps more specificity within the IHR requirements could lead to a more effective and coordinated global laboratory response to a pandemic. It could be beneficial to use more innovative ways to enhance laboratory capacity than just “providing support” and “logistical assistance” as IHR recommends.[1]

Overall, laboratories are extremely important for the control and PHS of infectious diseases. They are particularly important during an outbreak, and improved laboratory capacity can lead to a more efficient and effective response to a pandemic. Therefore, it is important that global laboratories strive to improve their capacity. Additionally, IHR 2005’s recommendations for laboratories should include more specific, actionable recommendations to better guide laboratory improvement. Hopefully the COVID-19 pandemic has brought awareness to the importance of laboratories and their improvement will be a priority in the coming years. The improvement of laboratory capacity will be crucial in preventing and controlling the next infectious disease outbreak.

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