Biosafety Measures for Public Health: Challenges and Strategies

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Abstract

Biosafety is an important component of public health, focusing on reducing risks associated with the intentional or unintentional release of chemicals. Incidents of infectious disease and bioterrorism have increased the need for strong biosafety measures. This chapter explored the importance of biosafety measures for public health and the associated challenges and mitigating strategies. Biosafety measures are the rules, regulations, and practices necessary for environmental and personal safety. These measures guarantee that biosafety policies and procedures are appropriately overseen and controlled at every level of laboratory management. Challenges in ensuring biosafety measures include inadequate infrastructure, resource limitations, a lack of trained personnel, inconsistent behaviour among lab workers, generic guidelines, lack of cohesiveness, dynamism, real-time monitoring systems, integrated information systems, and gaps in regulations. Existing literature highlights the need for effective strategies to ensure the biosafety measures in laboratories, such as the implementation of detailed biosafety protocols and risk management standards, regular and up-to-date personnel training programs, and framework development for standardization of laboratory biosafety management. Many organizations have started working on these issues. However, to address these challenges, a multidisciplinary approach and collaboration with international organizations are required for scientific advancement in public health policies.

Keywords: Public Health, Biosecurity, Biosafety Measures, Risk assessment, biological risk

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Introduction

Threats from persistent, new, and reemerging infectious diseases continue to plague the planet. The likelihood and seriousness of these dangers vary greatly. They also affect a complex range of social and economic outcomes, as well as morbidity and death, in different ways (Bloom and Cadarette, 2019). The risk that rogue governments and/or terrorists would use biological agents as weapons of war adds to the global biological threat environment. Any use of a biological agent, whether overt or covert, might have severe effects on human health or the environment. Because infectious illness knows no boundaries, worldwide cooperation is required to achieve effective, comprehensive biosecurity to avoid unauthorized control, loss, theft, abuse, change, or deliberate release of biological agents and toxins (Bakanidze et al., 2010). Biosafety and biosecurity are the foundations of public health security because they transcend individual state affairs and sit at the border of public health and security.

The rules, regulations, and practices necessary for environmental and personal safety are known as biosafety guidelines. These guidelines guarantee that biosafety policies and procedures are appropriately overseen and controlled at every level of laboratory management (Bayot and Limaiem, 2019). Consequently, developing safe conduct is essential to ensuring safety and requires safety awareness. One of the most important ways to guarantee safety is to pay attention. Therefore, it is necessary for everyone who works in laboratories to be aware of biosafety (Pastorino et al., 2024). Capacity building of laboratories to serve a public health system needs significant consideration of biosafety. Laboratory-based monitoring and detection of outbreaks are critical to prevent biological threats and their mitigation, and quality laboratory services rely on the execution of best biosafety and biosecurity practices, which are ensured by a suitable legislative framework (Bakanidze et al., 2010).

According to the World Health Organization (WHO), laboratory biosafety refers to the containment principles, technologies, and practices used to avoid exposure to pathogens and toxins and their accidental release. The biosafety measures are formulated to prevent the release of toxic chemicals into the environment. Laboratory biosecurity measures are not only confined to just the physical security of the staff; they also include management of staff and programs, records of inventory, information security, preventive measures during transportation of the material and chemicals, and management of the lab. Failures in the application of biosafety or biosecurity measures in the labs can affect the lab workers, community, and environment, as well as the operations of the institutions (Gaudioso et al., 2009).

Worldwide Standardization of Biosafety Guidelines

Biosafety rules started to be standardized across the globe from 1975 onward. In 1983, WHO released the first-ever laboratory manual named “Laboratory Biosafety Manual,” and the very next year, in 1984, “Biosafety in Microbiological and Biomedical Laboratories” made a huge contribution to the work of biosafety measures and biosafety levels (BSL) classifications. The work includes the construction of BSL labs: BSL-

1, BSL-2, BSL-3, BSL-4, and Australian Animal Health Laboratories (AAHL). The advancement in the laboratory design is also included in this. Fast forward nine years, in 1993, BMBL released the edition of the years in which biosafety measures and standards were updated to encourage the international collaboration. The standards were updated to solve the increasing issues in pathogen research, and it highlighted the need for updated biosafety rules for scientific research. WHO released its first guidance on laboratory biosecurity in 2006 (Gao et al., 2024). When biosafety measures are not followed properly, it causes the discharge of chemicals into the environment accidentally or deliberately via infections or a bioterrorist strike.

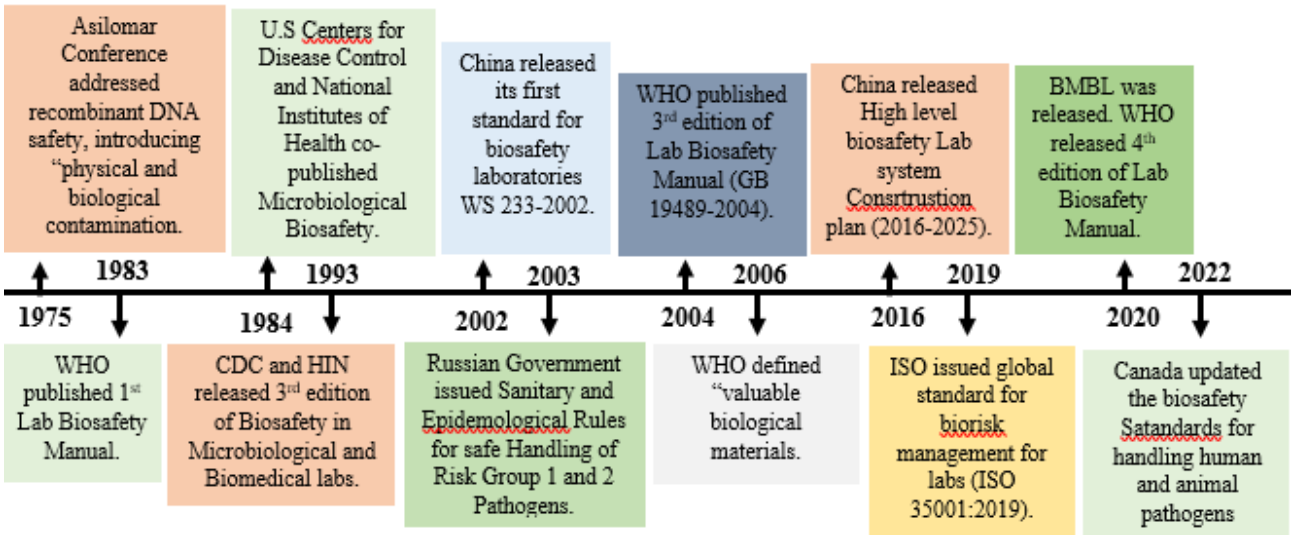

Fig. 1: History of standards and guidelines for global biosafety laboratories

Challenges in Biosafety

Technological advancements in science can lead to significant achievements, but they also create waste and pose risks to human health and the environment (Da Silva Figueiredo et al., 2020). Laboratory workers were previously at risk of contracting pathogens, with over 4000 laboratory-acquired infection (LAI) cases documented between 1949 and 1974 (Gugnani & Randhawa, 2020). The term LAIs refers to any illnesses developed through laboratory work or laboratory-associated activities, with or without the development of infections, and typically outcomes of occupational exposure to infectious agents (Wei et al., 2011). Typhoid fever was the first LAI to be reported in 1885. Kisskalt's inquiry, published thirty years later, was the first recorded account of LAI (Plotkin, 2014). In 2003, severe acute respiratory syndrome (SARS) and subsequent LAI outbreaks. LAIs have started to receive more attention in recent years relative to highly contaminated (BSL-3) and maximum contaminated labs (BSL-4) (Bakanidze et al., 2010). LAIs are a serious concern for public health because an infected laboratory staff could transmit risk to others. The most prevalent modes of infection are inhalation, mainly by aerosols; dermal inoculation (animal bites, needlestick injuries, or broken glass injuries); direct contact with contaminated surfaces (gloves and by hands); or ingestion (accidental aspiration, eating, or smoking) (Traxler et al., 2013).

- Many laboratories struggle to develop optimal biosafety procedures due to significant resource limitations, including insufficient funds for necessary supplies like PPE and biosafety cabinets (Heckert et al., 2011). In the early 20th century, biological laboratories faced safety risks due to abundant insects, unfavorable surroundings, and crude equipment, with personnel unaware of protective gear requirements. 16 of the 23 LAI cases recorded in 1915 were linked to oral pipetting (Plotkin, 2014; Muhammad et al., 2024).
- Insufficient laboratory infrastructure can also hinder biosafety practices, including inadequate electrical supply, ventilation systems, and waste disposal. Standardized risk assessment procedures and inadequate training can also contribute to this issue, making it difficult to identify potential biological hazards (Tang et al., 2024).
- A weak regulatory framework for biosafety measures results in the erratic application of the rules and regulations regarding the lab. Biosafety standards are not properly implemented in many locations due to an apparent lack of regulatory monitoring. This may result in labs operating without proper control or responsibility (De Souza Araújo et al., 2018).
- Organizational culture has a considerable impact on the implementation of biosafety measures. Many laboratory employees believe they lack the authority to change or improve procedures, which can limit creativity and the implementation of safety regulations. Laboratory workers don't want to actively participate in the biosafety activities if they perceive there are no opportunities for professional advancement in biosafety (Heckert et al., 2011). A previous study indicated that the careless and uninterested behaviour of the workers is the direct cause of over 90% of safety events related to ignorance (Long, 2011).
- Current biosafety guides are extremely generic and are not revised frequently, mainly in terms of specific Standard Operating Procedures (SOPs), leaving laboratory workers without updated operating guidelines. For example, there is a lack of precautionary information and instructions for laboratory workers to deal with risky infectious diseases, which makes it tough for them to deal with emerging biological risks. This limits the usefulness of the manual in addressing evolving risk concerns and makes it useless in real-world applications (Liu et al., 2021).
- Many laboratory workers don't have specific training related to biosafety and fail to comprehend the most recent risk assessment process and control knowledge and skills. The lack of a conducting emergency drill system regularly decreases the confidence of laboratory

workers and their eligibility to deal with laboratory crises. Employees cannot fully learn the proper application of Personal Protective Equipment (PPE) and carry out preventive operations following standardized procedures because there is no continuous training system in place (Baron & Miller, 2007).

- Current management systems don't have real-time monitoring and assessment processes, hindering laboratories' ability to gain and understand the existing biosafety situations and adjust biosafety risk management strategies swiftly. Moreover, the absence of incorporation in management systems, insufficient inter-departmental cooperation, and inadequate mechanisms of sharing of information hinder interaction and the sharing of resources with departments that are responsible for infection control and medical units, affecting inclusive biosafety precautions and quick reaction capacity (McClave et al., 2016).
- Lack of integration in information systems with other departments, which confined the workers to rely on phone calls, notifications, and manual recording of data to report infectious diseases, causing low efficiency and accuracy in their work. Furthermore, the turnaround time (TAT) for specimen transportation cannot be reliably tracked using critical quality indicators, and information systems before testing are hard to find out. Furthermore, data collection and statistical analysis are manual procedures, making it impossible to systematize information statistics and illness warnings, reducing the effectiveness of biosafety management (Yoon, 2021).
- Despite guidelines requiring risk assessments, knowledge and understanding of laboratory personnel for these assessments are often insufficient, resulting in a flawed risk assessment method, especially in recognizing risky pathogens, thus escalating the danger of biosafety events. The absence of a uniform risk assessment approach implies that possible biological hazards are frequently neglected during the identification of risky infections.
- Biosafety procedures and practices are critical in day-to-day laboratory procedures; therefore, a highly trained, motivated, and trained supervisor is required not only to monitor and control laboratory risks. Currently, most laboratories do not have specialized biosafety managers or engineers. Part-time researchers make up some of the skilled workforce at labs. This makes it tough to detect and manage possible safety dangers in labs and equipment operating at an early stage (Zhiming, 2019).
- Because of operational constraints, laboratory personnel frequently complain that they do not have enough time to read biosafety guidelines or put new procedures into place. They don't have administrative support to form SOPs, and organizing training programs exacerbates this situation (Shakoor et al., 2016). As a result, establishing safe practices is critical to guaranteeing safety and necessitates safety awareness. One of the most crucial strategies to ensure your safety is to pay attention. Therefore, lab staff must be informed of biosafety requirements (Pastorino et al., 2024).
- The recent manual recording and reporting of all the data are susceptible to errors, which makes it difficult to prevent any biosafety event successfully and on time. Without forming inclusive emergency plans, laboratory staff are incapable of receiving enough training, which decreases their capacity to respond swiftly to threats (Mohsin et al., 2022). Even though emergency documentation has been established, laboratory workers often do not have extensive knowledge or have misunderstandings, leading to failure in implementing procedures, along with impacting the effectiveness of handling the biosafety emergency (Fruhling et al., 2006).
- The present biosafety management system doesn't have coherence and innovation, and the restricted routes for inter-departmental contact make it hard to communicate biosafety information. The laboratory is incapable of completely comprehending the present condition of biosafety concerns or adapting management measures on time. Due to the split nature of the system, the absence of the flow of information and synchronization of resources across divisions makes it tough for the laboratory to react promptly to occurrences, lowering the inclusive level of protection and impacting collaboration with other branches (Myneni et al., 2015).
- Several other factors that hinder the application of laboratory-related biosafety measures within the facility are the absence of technical documents, poor biosafety skills, such as spill management, poor execution of bio-risk assessment, and poor equipment maintenance (Sukri et al., 2024).

Strategies for Enhancing Biosafety

Although Robert Koch had already created a biosafety cabinet, one of the first people to establish biosafety precautions following World War II was A. G. Wedum of the U.S. Biological Research Laboratories in Fort Detrick, Maryland. He assessed the dangers of working with dangerous biological agents and created procedures, tools, and facility security measures to reduce them (Emmert, 2013). Since his original research, it has become widely accepted that ventilation and enclosure of polluted work environments are critical components in removing LAIs. Primary barriers (personal protective equipment and safety gear) and secondary barriers (facility safeguards) are now considered essential components of containment measures in addition to safe microbiological approaches. Early on, it was acknowledged that looking at LAIs could provide insight into the dangers of working in a lab (Zuo et al., 2024).

Risk Assessment

Many biosafety challenges are encountered in laboratories worldwide and must be addressed with the proper risk management guidelines for lab workers (Farhan et al., 2023). Risk assessment is the initial and essential phase and comprises hazard detection and identification, comprehension of exposure potentials, the probability of occurrence, appraisal of work activities and machinery, and allocation of protective measures to the specific tasks associated (Feng et al., 2020). In the last few years, with a rising incidence of public health events, risk identification and assessment have turned out to be essential aspects of laboratory management. The development of numerous risk assessment guidelines shows not only the international community's stress on laboratory biosafety but also reveals that uniform risk assessment procedures can meaningfully improve a laboratory's capacity to react to emergent pathogens and other biohazards (Robson et al., 2022).

Personnel Training

Detailed training for all staff members is essential to ensure that each member is familiar with the most recent system and can utilize it

for laboratory operations. The training must be organized by the skilled experts who designed the management system and should involve lectures, hands-on practice, and demonstrations to ensure that everyone thoroughly knows the updated regulations and procedures (Beeckman and Rudelsheim, 2020). The training program comprises many levels of the new management framework alongside particular SOPs to help experts use them correctly in daily laboratory activities. Furthermore, the training focuses on key topics such as risk assessment, managing biological samples, swift action, data documenting, and reporting to higher authorities (Gannon et al., 2020).

Table 1: Risk Group according to WHO (Mourya et al., 2014)

Risk Group	Individual Risk	Community Risk	Description
1st Risk Group	No or low	No or low	A microbe that is unable to cause illness in humans or animals.
2nd Risk Group	Moderate	Low	A microbe that can cause disease in humans/animals but does not pose a serious threat to laboratory workers. Despite laboratory exposure can cause severe infections, there are highly effective medications and preventative techniques available, and the danger of illness transmission is limited.
3rd Risk Group	High	Low	A pathogen that causes severe sickness in humans or animals but does not transfer between affected individuals. Efficient treatment and prevention strategies are available.
4th Risk Group	High	High	A pathogen may cause transferable disease in humans or animals and unfortunately, doesn't have any effective treatments or preventative measures available.

Development of a Framework for Biosafety Measures

During framework development, the management system is organized into four levels of hierarchy, with each level encompassing all major aspects of biosecurity management. At the strategic level, it is critical to establish and emphasize inclusive targets, goals, and management regulations that govern laboratory biosafety, as well as to provide clear basics and direction to guarantee that the plan meets labor expectations (Emmert, 2013). Subsequently, specific operating instructions and SOPs are created to assist laboratory personnel through each phase of normal safety procedures, therefore avoiding potential safety hazards inside processes. Lastly, a robust system for recording and reporting is required to successfully track biosafety incidents and the successful completion of enhancement policies, assuring that each enhancement is scientifically reflected in the management system (Hewera et al., 2020). The quality management system incorporates inclusiveness and carefulness via this four-tiered document structure, resulting in complete uniformity of laboratory biosafety management.

International Working Organizations on Biosafety Measures

To address biosafety challenges, global collaborations have been developed to identify and mitigate the risks, as well as to combat the root cause of such threats. On a global scale, several organizations and treaties important for biosafety and biosecurity have been created, most of which originate from the United Nations (UN) or work with it in close collaboration.

- The American Biological Safety Association International (ABSA International) was created in 1984. Today, this organization not only meets the expanding demands of biosafety workers in the United States but also participates in extensive global connections with other organizations across the world.
- The International Federation of Biosafety Associations (IFBA), previously known as the International Biosafety Working Group, was founded in 2001. Today, this organization is a vibrant network supporting the safe and protected management of biological materials at a global scale.
- Some regional groups such as the European Biosafety Association (EBSA) and the Asia Pacific Biosafety Association (A-PBA), were established in 1996 and 2005 (Reed,2010).
- The World Health Organization (WHO) was founded in 1948 and has created networks to monitor and manage developing infectious diseases. These networks include both WHO projects and collaborations with independent programs, such as the Global Infection Prevention and Control Network and Global Influenza Surveillance and Response System (Galloway et al., 2015).

International Projects for Biosafety Measures

Many multinational efforts have been undertaken to govern biosafety standards around the world.

The United States and its worldwide allies started the Global Health Security Agenda (GHSA) in 2014. To address global infectious disease concerns, it is a multisectoral program including over 70 nations, private sector enterprises, national and international organizations, and non-governmental organizations (NGOs). In addition to engaging with partner governments across the globe on biosafety, the GHSA is committed to lowering the impact of naturally occurring epidemics and discharges of hazardous chemicals (Fair, 2017).

- The Global Virome Project (GVP) was founded in 2018 by specialists from the US, Brazil, China, Nigeria, and Italy. It detects viral hazards and offers timely data support for public health interventions to prevent pandemics (Carroll et al., 2018).
- The UN Economic and Social Council's Committee of Experts (UNECE) developed the UN Model Regulations on the Transport of Dangerous Goods. These regulations describe recommendations for transporting dangerous items and chemicals to protect the health and safety of workers, property, and the environment during all means of transportation. These dangerous items are separated into nine groups, one of which is for poisonous and infectious compounds (Class 6), whereas Genetically Modified Organisms (GMOs) are classed as miscellaneous dangerous substances. The UN Model Regulations for each class of dangerous commodities address issues such as general packaging standards, labeling, and transportation papers. Although they are merely guidelines, they serve as the foundation for national and international transport rules, therefore contributing to global harmonization in this sector (UNECE, 2020). The requirement for transporting infectious items is triple packing (consisting of leakproof main and secondary receptacles) to ensure biological material containment throughout transit and in the event of an accident or incident. As a result, when biological products are transported outside of confinement, proper packing protects them against unintended exposure or release (Beeckman & Rüdelsheim, 2020).

Conclusion

Biosafety is crucial for public health, reducing risks from chemical release. The rise in infectious diseases and the unethical use of chemicals as biological weapons have increased the need for strong and comprehensive biosafety measures. These rules, regulations, and practices ensure environmental and personal safety at all levels of laboratory management. Challenges include inadequate infrastructure, resource limitations, lack of trained personnel, inconsistent behavior, generic guidelines, and regulatory gaps. Effective strategies include detailed protocols, risk management standards, regular personnel training, and standardization of laboratory biosafety management. A multidisciplinary approach and collaboration with international organizations are needed to integrate scientific advancements with public health policies.

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