

Evaluation of Laboratory Biosafety Measures in Tertiary Hospitals: Challenges, Compliance, and Recommendations for Improvement

Loai A. Alqahtany¹, Abdulrahman M. Almosa², Saud M. Awaji³,
Abdulmajeed A. Alyousef⁴, Khalaf F. Alanazi⁵

Health Affairs at the Ministry of National Guard

Abstract

Background: Laboratory biosafety is crucial in tertiary hospitals, where a high volume of potentially hazardous biological specimens is handled. Biosafety protocols aim to protect personnel and prevent laboratory-acquired infections. However, challenges such as limited resources, inconsistent training, and infrastructure constraints can hinder compliance with these protocols.

Objective: This study evaluated biosafety compliance, identified challenges faced by laboratory staff, and provided recommendations for improving biosafety practices in a tertiary hospital setting.

Methods: A cross-sectional study was conducted across five laboratories in a 1,000-bed tertiary hospital. Data were collected through surveys, observational checklists, and a review of biosafety incident reports. Descriptive statistics and chi-square tests were used to analyze compliance rates, and thematic analysis was applied to open-ended responses.

Results: Overall, 90 laboratory staff participated. The compliance rate for personal protective equipment (PPE) use was 88.9%, while hand hygiene compliance was lower at 75.6%. Key challenges included PPE shortages (33.3%), overcrowded spaces (22.2%), and high workload pressures (38.9%). Incident reports highlighted spills (34.1%) and improper PPE usage (22.7%) as the most frequent biosafety breaches.

Conclusions: While adherence to biosafety protocols was generally high, challenges such as resource limitations, inadequate training, and infrastructure issues contributed to lapses in safety. Recommendations include improving PPE availability, regular refresher training, infrastructure upgrades, and enhanced workflow integration to address these gaps.

Keywords: Laboratory Biosafety, Tertiary Hospitals, Compliance, PPE, Biosafety Challenges, Infection Prevention, Safety Protocols, Healthcare Workers.

Introduction

Laboratory biosafety is a critical component of healthcare systems, particularly in tertiary hospitals that handle a high volume of specimens, including those that pose significant biological risks. Biosafety measures are designed to protect laboratory personnel, healthcare workers, and the surrounding environment from exposure to infectious agents, hazardous chemicals, and other potential dangers associated with

laboratory work. Proper implementation of these measures ensures the containment of biological hazards and reduces the risk of laboratory-acquired infections and cross-contamination (Callihan et al., 2021).

In tertiary hospitals, the complexity of cases and the variety of specimens processed daily demand strict adherence to biosafety protocols. These protocols, such as the use of personal protective equipment (PPE), proper handling and disposal of biohazardous materials, and the use of biological safety cabinets, are based on guidelines from international bodies like the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) (WHO, 2020). However, despite the availability of comprehensive guidelines, challenges remain in the consistent application of these protocols, particularly in high-stress environments such as tertiary hospitals (Cornish et al., 2021).

Key challenges to biosafety compliance in tertiary hospital laboratories include limited resources, inconsistent staff training, and infrastructure constraints, such as inadequate ventilation and space (Long et al., 2022). In addition, laboratory staff may face difficulties in balancing the need for rapid specimen processing with the strict requirements of biosafety protocols, leading to potential breaches in safety measures. These breaches can result in significant consequences, including laboratory-acquired infections and the potential spread of pathogens (Wilson and Chosewood, 2009).

Given these challenges, it is essential to evaluate the effectiveness of current biosafety measures in tertiary hospitals and identify areas for improvement. This study aims to assess the level of compliance with biosafety protocols, explore the challenges faced by laboratory staff, and provide recommendations for enhancing biosafety practices to ensure a safer working environment in healthcare settings.

Literature Review

Overview of Biosafety Regulations

Biosafety measures in laboratory settings are guided by stringent national and international regulations. Organizations such as the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) have developed comprehensive biosafety guidelines to ensure the safe handling of infectious agents and hazardous materials. The WHO's *Laboratory Biosafety Manual* (4th ed.) outlines four biosafety levels (BSL) that correspond to the level of containment required based on the risk posed by different pathogens (WHO, 2020). These guidelines emphasize the importance of proper use of personal protective equipment (PPE), biological safety cabinets, waste management, and training to mitigate risks associated with laboratory work.

In the U.S., the *Biosafety in Microbiological and Biomedical Laboratories* (BMBL) document, published by the CDC, serves as a foundational guide for laboratory safety practices. It provides specific recommendations for handling infectious materials, managing laboratory environments, and ensuring the safety of laboratory personnel (Wilson and Chosewood, 2009). Other countries adopt similar frameworks, tailored to their healthcare systems and institutional capacities, to protect laboratory workers and prevent the accidental release of harmful biological agents (Cornish et al., 2021).

Common Biosafety Practices in Laboratories

A variety of biosafety practices are used to safeguard laboratory environments. Personal protective equipment (PPE), including lab coats, gloves, goggles, and masks, forms the first line of defense against exposure to biological hazards. Proper use of biological safety cabinets (BSCs), particularly in Biosafety Level 2 and 3 laboratories, is critical for containing aerosols and preventing the spread of infectious agents

(Wilson and Chosewood, 2009). Waste management systems for disposing of contaminated materials, such as sharps and biological waste, must follow strict protocols to prevent environmental contamination and accidental exposure.

Regular staff training and risk assessment are integral to maintaining biosafety. Training programs must cover biosafety principles, emergency response, and updates on new regulations and technologies (Homer et al., 2013). Additionally, laboratories in tertiary hospitals must implement continuous monitoring systems to detect breaches in safety protocols or equipment malfunctions, such as failures in biosafety cabinet ventilation or PPE shortages (Long et al., 2022).

Challenges in Implementing Biosafety

Despite the existence of established biosafety guidelines, laboratories in tertiary hospitals face significant challenges in consistently implementing these protocols. A major barrier is the lack of resources, particularly in low- and middle-income countries where laboratories may struggle to maintain adequate PPE supplies or biosafety equipment such as BSCs (Callihan et al., 2021). Infrastructure constraints, including overcrowded laboratory spaces and insufficient ventilation, further complicate the implementation of biosafety measures. In many cases, laboratories in tertiary care facilities process high volumes of complex specimens, increasing the risk of biosafety breaches due to the pressure for rapid testing and diagnosis (Cornish et al., 2021).

Training and compliance are also critical concerns. Studies have shown that laboratory personnel often receive inadequate or irregular training on updated biosafety protocols, which can lead to lapses in safety practices (Cornish et al., 2021). Staff compliance with biosafety protocols is essential, yet it can be difficult to ensure in high-stress environments, where workload pressures and fatigue may lead to inadvertent breaches. A study conducted by Long et al. (2022) in Chinese tertiary hospitals highlighted that laboratory staff reported challenges in adhering to PPE protocols and proper waste disposal procedures, especially during peak workloads.

The need for effective risk communication is another challenge. Laboratory workers must be fully aware of the risks associated with their work, and risk assessment processes need to be thorough and frequently updated to reflect new hazards, such as emerging infectious diseases (Cornish et al., 2021). In many cases, poor communication between different departments within a hospital can exacerbate the risk of biosafety incidents, as seen in previous outbreaks of laboratory-acquired infections (Wilson and Chosewood, 2009).

Lessons from the COVID-19 Pandemic

The COVID-19 pandemic has brought to light the critical role of biosafety in healthcare settings, particularly in laboratories that process infectious samples. Many laboratories faced unprecedented challenges during the pandemic, including surges in testing volumes, shortages of PPE, and the rapid need to adapt to evolving safety protocols (Callihan et al., 2021). These challenges underscored the importance of flexibility and preparedness in biosafety practices. A study by Callihan et al. (2021) reported that laboratories that implemented regular training and simulation exercises were better prepared to handle the biosafety risks posed by COVID-19, demonstrating the value of ongoing education and risk preparedness.

Biosafety in High-Risk Laboratory Environments

Tertiary hospital laboratories often deal with a variety of high-risk specimens, including bloodborne pathogens, drug-resistant bacteria, and other infectious agents. These high-risk environments require a

higher level of containment and stricter adherence to biosafety measures. A study by Mtafyaet al. (2023) highlighted the particular challenges faced by laboratories handling drug-resistant tuberculosis (TB) in tertiary hospitals, where even small lapses in containment could lead to severe outbreaks. The study emphasized the importance of routine biosafety audits, frequent equipment maintenance, and risk-based training to ensure laboratory personnel are equipped to handle such pathogens.

Moreover, biosafety in high-risk environments extends beyond biological hazards. Laboratories also deal with chemical and radiological hazards, which further complicate the safety protocols. Effective communication and interdisciplinary collaboration between biosafety officers, laboratory managers, and clinical staff are crucial to maintaining safety standards in these complex environments (Callihan et al., 2021).

The literature highlights the critical importance of biosafety in laboratory settings, particularly in tertiary hospitals where the volume and complexity of specimens increase the risk of exposure to infectious agents. Despite comprehensive guidelines from international and national bodies, there are significant challenges in ensuring consistent biosafety compliance, including resource constraints, training gaps, and infrastructure limitations. The COVID-19 pandemic has underscored the need for flexibility and preparedness in biosafety practices, while ongoing training and interdepartmental communication remain essential to maintaining safety standards in high-risk environments. Addressing these challenges is crucial to improving biosafety measures and ensuring the safety of laboratory personnel and healthcare workers.

Methodology

Study Design

This study employed a cross-sectional observational design to evaluate biosafety measures in the laboratories of a tertiary hospital. The research was conducted over a period of six months, from January to June 2024, across five different laboratories within the hospital, including microbiology, hematology, pathology, biochemistry, and molecular diagnostics. Each laboratory was selected based on its high volume of specimen processing and potential exposure to biohazards.

Study Setting

The study was conducted in a tertiary hospital, known for handling complex cases and a high volume of laboratory testing. The laboratories included in the study process a wide range of biological samples, including blood, tissue, and body fluids, many of which are classified as potentially infectious. These laboratories operate within Biosafety Level 2 (BSL-2) and Biosafety Level 3 (BSL-3) environments, adhering to national and international biosafety regulations.

Participants

The participants of the study were laboratory personnel working in the selected laboratories, including laboratory technologists, technicians, and support staff. A total of 100 laboratory workers were invited to participate, and 90 individuals provided informed consent and completed the survey. Participants were selected based on their direct involvement in laboratory procedures that require adherence to biosafety protocols.

Data Collection

1. Survey

A structured survey was administered to the laboratory staff to collect data on their perceptions of the

biosafety measures in place, their adherence to these measures, and the challenges they face in implementing them. The survey consisted of both closed-ended and open-ended questions and was divided into three sections:

- Section 1: Demographic information (age, years of experience, laboratory department).
- Section 2: Evaluation of current biosafety measures (e.g., use of personal protective equipment (PPE), waste disposal procedures, biological safety cabinet (BSC) usage).
- Section 3: Challenges and barriers to biosafety (e.g., shortages in PPE, insufficient training, inadequate infrastructure).

The survey responses were collected anonymously to encourage honest feedback and were conducted both online and through paper forms to accommodate different preferences.

2. Observational Checklist

In addition to the survey, an observational checklist was used to evaluate the biosafety practices in real-time. Trained research assistants conducted observations across all five laboratories during routine laboratory operations, focusing on key biosafety procedures:

- Proper use of PPE by staff members.
- Correct usage of biological safety cabinets (BSCs) during specimen processing.
- Adherence to waste disposal protocols for hazardous materials.
- Hand hygiene practices before and after handling samples.
- Emergency preparedness procedures (e.g., availability of spill kits and eyewash stations).

Observations were made during peak working hours to capture the full range of biosafety practices under realistic working conditions.

3. Document Review

Hospital biosafety protocols, incident reports, and audit reports from the past two years were reviewed to provide context for the study findings. The incident reports included any documented breaches of biosafety measures, laboratory accidents, or exposure events. Audit reports conducted by the hospital's safety department were analyzed to understand how frequently biosafety lapses were recorded and what corrective actions were taken.

Data Analysis

1. Survey Data Analysis

Quantitative data from the closed-ended survey questions were analyzed using descriptive statistics, including frequency distributions and percentages, to summarize the adherence levels to biosafety protocols. Responses from the open-ended questions were analyzed using thematic analysis to identify common challenges and barriers reported by the participants.

2. Observational Data Analysis

The data collected from the observational checklist were analyzed to calculate the compliance rate for each biosafety procedure. Compliance was defined as the correct execution of a given biosafety protocol at least 90% of the time. The compliance rates across different laboratories and biosafety levels were compared using chi-square tests to determine whether there were statistically significant differences between departments.

3. Document Analysis

The review of biosafety incident reports and audit records was used to identify patterns in biosafety lapses over time. Data from these reports were triangulated with survey and observational data to provide a comprehensive understanding of the gaps in biosafety practices.

Ethical Considerations

The study was approved by the ethics committee. All participants provided informed consent, and their anonymity and confidentiality were strictly maintained throughout the study. Participation was voluntary, and respondents were free to withdraw at any point without any consequences. Observational data were collected without direct interaction with staff, and all observational findings were reported in aggregate to avoid identifying specific individuals or departments.

Limitations

One limitation of the study is that it was conducted in a single tertiary hospital, which may limit the generalizability of the findings to other healthcare settings. Additionally, the study relied on self-reported data from the survey, which may introduce bias due to participants' desire to provide socially desirable responses. To mitigate this, anonymity was emphasized, and observational data were used to validate the self-reported practices.

This methodology provides a robust approach to evaluating the effectiveness of biosafety measures in a tertiary hospital setting while identifying areas for improvement.

Findings

1. Demographics of Participants

A total of 90 laboratory staff members participated in the study. The demographic distribution of participants is summarized in Table 1 below.

Demographic Variable	Number of Participants (n=90)	Percentage (%)
Gender		
Male	50	55.6
Female	40	44.4
Age Group		
20-30 years	28	31.1
31-40 years	40	44.4
41-50 years	18	20.0
51+ years	4	4.5
Years of Experience		
1-5 years	25	27.8
6-10 years	30	33.3
11-20 years	28	31.1
21+ years	7	7.8

Table 1: Demographic characteristics of participants

2. Compliance with Biosafety Measures

The survey and observational data indicated varying levels of compliance with different biosafety protocols. Overall, the majority of participants reported adhering to biosafety protocols, although compliance levels differed depending on the specific measure.

Table 2 presents the compliance rates for key biosafety practices as reported in the survey and confirmed through observations.

Biosafety Measure	Reported Compliance (%)	Observed Compliance (%)
Use of PPE (gloves, masks, lab coats)	92.2%	88.9%
Proper use of Biological Safety Cabinets	87.8%	85.0%
Safe handling and disposal of hazardous materials	89.0%	82.2%
Hand hygiene before and after specimen handling	80.0%	75.6%
Availability and use of spill kits	68.9%	60.0%
Participation in regular biosafety training programs	77.8%	N/A

Table 2: Compliance rates for key biosafety practices as reported by participants and observed during the study.

3. Challenges in Implementing Biosafety Measures

The survey and open-ended responses revealed several key challenges that laboratory staff face in maintaining biosafety standards. Table 3 summarizes the main challenges reported by participants.

Challenge	Number of Participants (n=90)	Percentage (%)
Shortage of Personal Protective Equipment (PPE)	30	33.3%
Insufficient training/refresher courses	25	27.8%
Overcrowded laboratory spaces	20	22.2%
Inadequate ventilation in some areas	15	16.7%
High workload pressure leading to protocol lapses	35	38.9%

Table 3: Challenges reported by laboratory staff in implementing biosafety measures

4. Incident Reports and Biosafety Breaches

Data from incident reports over the past two years were analyzed to identify the most common biosafety

breaches in the hospital's laboratories. Table 4 highlights the frequency of specific biosafety-related incidents.

Incident Type	Number of Incidents (Last 2 Years)	Percentage of Total Incidents (%)
Exposure to infectious agents due to improper PPE usage	10	22.7%
Spills of hazardous materials	15	34.1%
Incomplete decontamination of work surfaces	8	18.2%
Needle-stick injuries	6	13.6%
Equipment failure (e.g., biosafety cabinet malfunction)	5	11.4%

Table 4: Frequency of biosafety-related incidents recorded in the hospital's laboratories over the past two years.

5. Observational Findings on Biosafety Practices

The observational data revealed specific gaps in the application of biosafety protocols. For example, while the majority of staff members used PPE, compliance with hand hygiene protocols before and after specimen handling was significantly lower. Additionally, the availability and use of spill kits were found to be suboptimal, with many staff members relying on ad-hoc cleaning methods rather than following formal spill response procedures.

6. Training and Education Gaps

Although most participants indicated that they had undergone initial biosafety training, a notable proportion (27.8%) reported that they had not participated in any refresher training programs in the past year. This lack of ongoing education was also reflected in the observational data, where inconsistencies in the application of certain biosafety practices were observed, particularly among less experienced staff.

Discussion

The findings from this study provide valuable insights into the biosafety practices, challenges, and compliance rates in laboratory settings within a tertiary hospital. While the majority of laboratory staff reported high adherence to biosafety protocols, significant challenges remain that affect the consistent implementation of these measures. The results indicate areas where improvements are necessary, particularly in addressing resource limitations, enhancing training, and optimizing infrastructure to ensure safer working conditions.

Compliance with Biosafety Measures

The compliance rates observed in this study demonstrate a generally high level of adherence to key biosafety protocols, particularly in the use of personal protective equipment (PPE) and biological safety

cabinets (BSCs). The reported compliance rates for PPE usage (92.2%) and BSC usage (87.8%) align with previous studies that highlight these measures as essential for protecting laboratory workers from hazardous exposures (Callihan et al., 2021; Cornish et al., 2021). However, the lower observed compliance rates (88.9% for PPE and 85.0% for BSCs) suggest that while staff are knowledgeable about the requirements, practical challenges and workload pressures may lead to lapses in following these protocols consistently.

One notable area of concern is the lower compliance rate for hand hygiene practices, which was reported at 80.0% but observed to be only 75.6%. This gap is significant, as hand hygiene is a critical component of preventing cross-contamination and the spread of infections in laboratory environments (Homer et al., 2013). This finding suggests the need for stronger emphasis on hand hygiene training and frequent reminders to ensure consistent compliance, especially in high-stress environments.

Challenges in Implementing Biosafety Protocols

The study identified several key challenges that contribute to lapses in biosafety practices. Resource limitations, particularly shortages in PPE, were reported by 33.3% of participants, reflecting global trends where laboratories, especially in tertiary care settings, struggle to maintain sufficient stocks of biosafety equipment (Cornish et al., 2021). This challenge was exacerbated during the COVID-19 pandemic, where PPE shortages were widespread and further strained by increased demand (Callihan et al., 2021).

Overcrowded laboratory spaces (22.2%) and inadequate ventilation (16.7%) were also identified as barriers to effective biosafety practices. These infrastructure issues create an environment where adhering to biosafety protocols, particularly those involving spatial separation and ventilation for containment, becomes difficult. Similar findings have been reported in other studies, where space and resource limitations have compromised the effectiveness of containment measures in laboratory settings (Mtafya et al., 2023).

Another critical challenge was the high workload pressure experienced by laboratory staff, with 38.9% of participants reporting that this contributed to lapses in biosafety protocols. High workloads often lead to shortcuts in safety practices, as staff prioritize speed over safety, increasing the risk of exposure to hazardous materials (Long et al., 2022). This finding underscores the importance of balancing productivity demands with safety, ensuring that biosafety protocols are not compromised during peak workloads.

Biosafety Training and Education

The study's findings also highlight the need for continuous biosafety education and training. While 77.8% of participants reported having undergone initial biosafety training, nearly 28% indicated that they had not participated in any refresher courses in the past year. This lack of ongoing training may contribute to the observed lapses in compliance, particularly among less experienced staff. Previous research has shown that regular, updated training is essential for maintaining high biosafety standards, especially as new hazards and protocols emerge (Wilson and Chosewood, 2009; Homer et al., 2013).

The absence of routine refresher training is particularly concerning given the fast-paced nature of medical laboratories, where the introduction of new technologies and procedures necessitates regular updates to safety practices. Therefore, implementing more frequent and mandatory training programs, including simulations of emergency situations, could help reinforce the importance of biosafety compliance and reduce the risk of accidents.

Incident Reports and Biosafety Breaches

The analysis of biosafety incidents over the past two years revealed several areas where improvements are needed. The most common incidents were spills of hazardous materials (34.1%) and exposure to infectious agents due to improper PPE usage (22.7%). These findings are consistent with global trends in laboratory safety breaches, where PPE-related incidents are frequently reported as a leading cause of laboratory-acquired infections (Callihan et al., 2021; Callihan et al., 2021).

The frequency of spills highlights the need for better spill response protocols and the availability of spill kits. The observed compliance rate for spill kit usage (60.0%) was notably low, suggesting that staff may be relying on inadequate cleaning methods in the event of spills. This gap could be addressed through more rigorous training on spill management and ensuring that all laboratories are fully equipped with the necessary tools to handle hazardous material spills.

Recommendations for Improvement

Based on the findings, several recommendations can be made to improve biosafety practices in the hospital's laboratories. First, addressing the shortage of PPE and other biosafety equipment is essential for maintaining high compliance rates. The hospital administration should prioritize resource allocation for PPE and ensure that laboratories have sufficient stocks to handle high-volume specimen processing, especially during peak periods such as pandemics.

Second, ongoing biosafety training should be made mandatory for all laboratory staff, with an emphasis on refresher courses and practical simulations. Regular audits and feedback sessions could also be implemented to monitor compliance and identify areas for improvement. Third, infrastructure upgrades, such as improved ventilation systems and the expansion of laboratory spaces, are critical for creating a safer working environment. These upgrades would not only enhance biosafety compliance but also reduce the stress on staff working in overcrowded and under-ventilated conditions.

Finally, better integration of biosafety protocols into daily workflows is necessary to reduce the impact of workload pressure on compliance. This could include staggered work shifts, additional staff support during peak hours, and the use of automation to reduce manual handling of hazardous specimens.

The study provides a comprehensive evaluation of biosafety practices in a tertiary hospital laboratory setting, identifying both strengths and areas for improvement. While compliance with key biosafety protocols was generally high, significant challenges remain, particularly in addressing resource limitations, infrastructure constraints, and the need for continuous training. By implementing the recommended improvements, the hospital can enhance its biosafety practices, reduce the risk of laboratory-acquired infections, and create a safer environment for both staff and patients.

References:

1. Callihan, D. R., Downing, M., Meyer, E., Ochoa, L. A., Petuch, B., Tranchell, P., & White, D. (2021). Considerations for laboratory biosafety and biosecurity during the coronavirus disease 2019 pandemic: applying the ISO 35001: 2019 standard and high-reliability organizations principles. *Applied Biosafety*, 26(3), 113-122.
2. Cornish, N. E., Anderson, N. L., Arambula, D. G., Arduino, M. J., Bryan, A., Burton, N. C., ... & Campbell, S. (2021). Clinical laboratory biosafety gaps: lessons learned from past outbreaks reveal a path to a safer future. *Clinical microbiology reviews*, 34(3), 10-1128.

3. Homer, L. C., Alderman, T. S., Blair, H. A., Brocard, A. S., Broussard, E. E., Ellis, R. P., ... & Barkley, E. (2013). Guidelines for biosafety training programs for workers assigned to BSL-3 research laboratories. *Biosecurity and bioterrorism: biodefense strategy, practice, and science*, 11(1), 10-19.
4. Long, Y., Chang, F., Yang, F., Hou, Y., Mo, Z., & Diao, Q. (2022). Biosafety risk assessment and risk control of clinical laboratory in designated hospitals for treating COVID-19 in Chongqing, China. *American Journal of Infection Control*, 50(9), 999-1005.
5. Mtafya, B., Qwaray, P., John, J., Sichone, E., Shoo, A., Gillespie, S. H., ... & Sabiiti, W. (2023). A practical approach to render tuberculosis samples safe for application of tuberculosis molecular bacterial load assay in clinical settings without a biosafety level 3 laboratory. *Tuberculosis*, 138, 102275.
6. Wilson, D. E., & Chosewood, L. C. (2009). Biosafety in microbiological and biomedical laboratories. *Center for Disease Control and Prevention (CDC) publication*, (21-1112).
7. World Health Organization. (2020). *Laboratory biosafety manual*. World Health Organization.