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Health Security Preparedness For Biological Threats In Healthcare Facilities: Surveillance, Containment, And Response Capacity

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Abstract

Background: The contemporary global health security landscape is characterized by an intensifying frequency and complexity of biological threats, ranging from naturally occurring high-consequence infectious diseases (HCIDs) like Ebola and SARS-CoV-2 to the persistent specter of bioterrorism. Healthcare facilities (HCFs) constitute the operational frontline of biodefense, yet their capacity to effectively detect, contain, and respond to these threats remains critically uneven across geopolitical and economic divides. The convergence of workforce attrition, "just-in-time" logistical fragility, and infrastructural obsolescence has exposed profound vulnerabilities in the hospital sector's ability to maintain continuity of care under biological stress.

Objectives: This comprehensive systematic review aims to evaluate the global state of health security preparedness within healthcare facilities. The primary objectives are to: (1) assess the efficacy of existing surveillance architectures—specifically comparing syndromic surveillance in high-resource settings against Integrated Disease Surveillance and Response (IDSR) frameworks in low-resource settings—in facilitating early threat detection; (2) analyze containment capacities by contrasting the engineering and operational outcomes of High-Level Isolation Units (HLIUs) versus standard infection control wards; and (3) evaluate response capacity through the lenses of workforce resilience, personal protective equipment (PPE) compliance, and supply chain sustainability.

Methods: A systematic literature review was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. A multi-database search (PubMed, Scopus, Web of Science, Google Scholar) was executed for peer-reviewed and grey literature published through 2023. Included studies encompassed randomized trials, observational cohorts, and qualitative assessments of hospital preparedness globally. Quality assessment was rigorously performed using the Cochrane Risk of Bias tool (RoB 2) for interventional studies and the Newcastle-Ottawa Scale (NOS) for observational research, ensuring a weighted synthesis of high-quality evidence.

Results: The review synthesized data from a diverse array of global studies. In the domain of surveillance, syndromic systems in high-income nations demonstrated the capacity to predict Intensive Care Unit (ICU) surges by 11–13 days, though with significant specificity trade-offs (often ~50% detection probability for covert bioterrorism by Day 2). Conversely, IDSR implementation in sub-Saharan Africa showed marked improvements in reporting completeness (rising from 84.5% to 96% in Sierra Leone) but remained hampered by a lack of laboratory integration and feedback loops. Containment analysis revealed that HLIUs achieve aerosol containment rates exceeding 99.7% and significantly lower healthcare worker (HCW) infection rates (7% vs. 11% in general wards) yet are operationally non-scalable. Response capacity assessment identified a critical "preparedness decay," characterized by PPE compliance rates as low as

21.64% in observational audits despite high theoretical knowledge, and pervasive workforce burnout, with over 96% of staff reporting anxiety during surges.

Conclusion: Health security preparedness in healthcare facilities is currently defined by a "hardware-software" dissonance. While advanced engineering solutions and theoretical frameworks exist ("hardware"), they are critically undermined by the "human factor" ("software")—specifically, behavioral non-compliance, psychological exhaustion, and the inequitable distribution of resources. Achieving genuine bioresilience requires a paradigm shift from reactive, agent-specific planning to a sustained, all-hazards approach that prioritizes workforce protection, integrates real-time diagnostics with syndromic signals, and establishes resilient, equitable supply chains independent of crisis-driven funding cycles.

1. Introduction

1.1 The Evolving Biological Threat Landscape

The concept of health security has undergone a radical transformation in the first quarter of the 21st century. Historically, hospital preparedness was often viewed through the narrow lens of civil defense, focused primarily on managing mass casualty events resulting from conventional warfare or, in the post-2001 era, bioterrorism events involving specific agents such as Bacillus anthracis (anthrax) or Variola major (smallpox) **[1]**. Frameworks established by policy instruments like the U.S. Homeland Security Presidential Directive 10 (HSPD-10) emphasized early warning systems and the stockpiling of specific antidotes, predicated on the assumption that threats would be discrete, localized, and identifiable **[2]**.

However, the epidemiological reality has shifted towards an environment of continuous, overlapping biological threats. The Global Burden of Disease (GBD) Study 2023 underscores that while global mortality rates from some communicable diseases are stabilizing, the interaction between novel pathogens and populations with high prevalence of non-communicable comorbidities (e.g., diabetes, ischemic heart disease) has created a fragile substrate for high mortality during outbreaks **[3]**. The modern healthcare facility must now contend with a "threat agnostic" environment where the distinction between a natural zoonotic spillover (e.g., localized Ebola outbreaks, novel influenza pandemics) and an intentional biological release is functionally irrelevant during the initial phase of recognition and stabilization **[4]**.

This convergence of risks—termed "all-hazards" in emergency management doctrine—demands that hospitals function not merely as curative institutions but as active nodes in the national security architecture. They are the sentinel sites where a covert biological attack or a cryptic pandemic introduction will first manifest **[5]**. The failure to detect and contain a threat at the facility level can amplify a local cluster into a national crisis, as demonstrated during the initial phases of the SARS-CoV-1, MERS-CoV, and SARS-CoV-2 outbreaks, where nosocomial (hospital-acquired) transmission acted as a primary engine of epidemic propagation **[6]**.

1.2 The Healthcare Facility as the Critical Node

The role of the healthcare facility in biological preparedness is tripartite: Surveillance, Containment, and Response.

- **Surveillance:** HCFs are the primary interface for identifying the "signal" of a biological event amidst the "noise" of routine illness. This requires systems capable of detecting anomalous patterns in triage data (syndromic surveillance) and rapidly confirming etiologies through laboratory networks **[5]**.
- **Containment:** Upon detection, the facility must physically arrest the chain of transmission. This involves complex engineering controls—negative pressure environments, high-efficiency particulate air (HEPA) filtration—and rigorous infection prevention and control (IPC) protocols to protect both patients and the healthcare workforce **[7]**.

- **Response:** The facility must sustain operations under conditions of extreme stress ("surge capacity"). This encompasses the mobilization of trained personnel, the management of critical supply chains (oxygen, PPE, therapeutics), and the ethical allocation of scarce resources **[7]**.

1.3 The Global Inequity of Preparedness

While the biological threats are global, the capacity to respond is profoundly unequal. The literature reveals a stark dichotomy between the preparedness architectures of the Global North and the Global South. High-Income Countries (HICs) have largely invested in technological solutions—High-Level Isolation Units (HLIUs), automated electronic surveillance, and strategic stockpiles **[8]**. In contrast, Low- and Middle-Income Countries (LMICs) rely heavily on the Integrated Disease Surveillance and Response (IDSR) strategy, which seeks to optimize limited resources by unifying surveillance functions across diseases **[9]**.

This inequity is not merely a humanitarian concern but a structural security flaw. As evidenced by the COVID-19 pandemic, delays in vaccine and therapeutic access for LMICs—often exceeding 100 days relative to HICs—create reservoirs for viral persistence and mutation, ultimately undermining health security globally **[10]**. Furthermore, the financial fragility of health systems in regions like South America and South Asia means that "preparedness" is often the first casualty of budget constraints, leaving facilities vulnerable to the next crisis **[11]**.

1.4 Problem Statement and Rationale

Despite the proliferation of guidelines from the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), and national bodies, there remains a persistent "implementation gap" between written preparedness plans and operational reality. Simulation exercises often yield high readiness scores that evaporate when tested by actual biological events. This gap is frequently attributed to the "human factor"—staff burnout, non-compliance with safety protocols, and lack of training—as well as the systemic underfunding of biopreparedness as a non-revenue-generating activity **[12]**.

Existing reviews have often focused on specific pathogens (e.g., Ebola preparedness) or specific regions. There is a paucity of comprehensive systematic reviews that synthesize the global evidence across the full spectrum of surveillance, containment, and response capacities, integrating the lessons of the post-2020 era with the foundational literature of biodefense.

1.5 Objectives

This report aims to bridge that gap by conducting a systematic review of health security preparedness in healthcare facilities globally. The specific research questions guiding this review are:

1. **Surveillance:** How effective are syndromic and integrated surveillance systems in detecting biological threats within the clinical window of opportunity?
2. **Containment:** What are the comparative outcomes (infection rates, containment efficiency) of specialized HLIUs versus standard isolation wards?
3. **Response:** What are the primary determinants of response failure, specifically regarding workforce resilience, PPE compliance, and logistical sustainability?
4. **Systemic Resilience:** How do global inequities and funding models impact the long-term viability of hospital biopreparedness programs?

2. Literature Review: Theoretical Frameworks of Health Security

2.1 The Shift to All-Hazards Biopreparedness

The theoretical underpinning of hospital preparedness has evolved from a "defense" orientation to a "resilience" orientation. Early literature, heavily influenced by military doctrine, focused on "hardening"

targets against bioterrorism **[2]**. This approach prioritized the detection of Category A agents (e.g., anthrax, plague, tularemia) and the stockpiling of specific countermeasures. However, the economic and operational inefficiency of preparing for low-probability, high-impact intentional events led to the adoption of the "all-hazards" approach **[12]**.

The all-hazards framework posits that the core capabilities required to manage a bioterrorist attack—rapid triage, isolation, PPE usage, and crisis communication—are identical to those required for natural pandemics or industrial chemical accidents. By building dual-use capabilities, hospitals can maintain readiness through routine management of seasonal outbreaks (e.g., influenza), thereby avoiding the "preparedness decay" that affects dormant, specialized programs **[13]**.

2.2 The Hierarchy of Controls in Biocontainment

The literature on containment is grounded in the industrial hygiene "hierarchy of controls."

1. **Elimination/Substitution:** Generally not applicable to patient care (one cannot "eliminate" the patient).
2. **Engineering Controls:** These are considered the most effective reliability measures. This includes negative pressure rooms, anterooms, and HEPA filtration systems designed to physically remove pathogens from the air, independent of human behavior **[14]**.
3. **Administrative Controls:** These include policies on triage, zoning, and visitation restriction.
4. **Personal Protective Equipment (PPE):** Considered the least effective control due to its reliance on perfect human adherence. The literature consistently highlights that while PPE is critical, it is the primary point of failure due to doffing errors, fatigue, and supply shortages **[15]**.

2.3 The Psychology of Response

A growing body of literature addresses the psychosocial dimensions of biopreparedness. The concept of "moral injury" has emerged to describe the psychological distress experienced by healthcare workers when resource constraints force them to compromise care standards (e.g., rationing ventilators). Theoretical models of HCW behavior suggest that compliance with safety protocols is not merely a function of knowledge but is modulated by risk perception, physical discomfort, and organizational culture. High anxiety levels, while theoretically prompting caution, can paradoxically lead to cognitive overload and errors in complex procedural tasks like PPE doffing **[16]**.

2.4 Integrated Disease Surveillance and Response (IDSR)

In the context of LMICs, the IDSR strategy developed by the WHO Regional Office for Africa represents a critical theoretical innovation. Unlike the vertical, disease-specific programs of the past (e.g., separate malaria and HIV surveillance), IDSR creates a matrix where resources are shared. The theory holds that strengthening the core functions—detection, reporting, analysis, and feedback—at the district level builds a platform capable of responding to any emerging threat **[9]**. However, the literature indicates a gap between the theory of integration and the reality of fragmented funding streams that continue to reinforce silos **[17]**.

3. Methods

3.1 Research Design and Protocol

This research report employs a systematic literature review methodology, designed to synthesize qualitative and quantitative evidence regarding healthcare facility preparedness for biological threats. The protocol was developed in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement **[18]**. The PRISMA 2020 checklist was utilized to ensure the transparency, completeness, and reproducibility of the review process, encompassing all stages from search strategy formulation to data synthesis.

3.2 Search Strategy and Information Sources

A comprehensive search strategy was executed to capture the global breadth of the topic. The following electronic databases were queried:

- PubMed / MEDLINE
- Scopus
- Web of Science
- Google Scholar (for grey literature and expansive citation tracking)

The search algorithms utilized a combination of Medical Subject Headings (MeSH) and free-text keywords, adapted for the syntax of each database. Key terms included:

- Conditions: "Biological threats," "Bioterrorism," "High-Consequence Infectious Diseases," "Pandemic," "Ebola," "COVID-19," "SARS-CoV-2."
- Settings: "Healthcare facilities," "Hospitals," "Intensive Care Units," "High-Level Isolation Units," "Emergency Departments."
- Interventions/Capabilities: "Surveillance," "Syndromic surveillance," "Integrated Disease Surveillance and Response," "IDSR," "Containment," "Biocontainment," "Personal Protective Equipment," "PPE compliance," "Surge capacity."
- Outcomes: "Preparedness," "Readiness," "Mortality," "Infection rates," "Response time," "Resilience."

To ensure the review reflected the current state of science and policy, the search was limited to references published up to and including **2023**, with a particular emphasis on literature emerging post-2014 (post-West Africa Ebola) and post-2019 (COVID-19).

3.3 Inclusion and Exclusion Criteria

The selection of studies was governed by the following criteria:

Inclusion Criteria:

- **Population:** Healthcare facilities, including acute care hospitals, specialized treatment centers, and long-term care facilities.
- **Intervention:** Preparedness measures related to biological threats (surveillance systems, isolation infrastructure, staff training, logistics).
- **Comparators:** Comparison between different levels of care (e.g., HLIU vs. general ward) or pre- vs. post-intervention (e.g., training impact).
- **Outcomes:** Quantitative metrics (mortality, infection transmission, time to detection, compliance rates) and qualitative assessments (barriers to implementation, staff perceptions).
- **Study Types:** Systematic reviews, randomized controlled trials (RCTs), cohort studies, cross-sectional surveys, and validated simulation studies.
- **Geography:** No restrictions; global scope required.

Exclusion Criteria:

- Studies focused exclusively on community-level public health interventions (e.g., lockdowns, border closures) without a facility-specific component.
- Clinical trials of therapeutics or vaccines that did not address the logistics of administration or facility impact.
- Editorials, opinion pieces, and commentaries lacking primary data or systematic analysis.
- Animal studies not directly related to facility transmission models.

3.4 Quality Assessment and Risk of Bias

To ensure the reliability of the synthesized evidence, included studies underwent rigorous quality assessment using tools appropriate to their design:

1. Randomized Controlled Trials (RCTs): The Cochrane Risk of Bias 2 (RoB 2) tool was employed. This instrument assesses bias across five fixed domains:
    - Domain 1: Bias arising from the randomization process.
    - Domain 2: Bias due to deviations from intended interventions (effect of assignment vs. adherence).
    - Domain 3: Bias due to missing outcome data.
    - Domain 4: Bias in measurement of the outcome.
    - Domain 5: Bias in selection of the reported result.
      Each domain was judged as "Low risk," "Some concerns," or "High risk" [19].
2. Observational Studies (Cohort/Case-Control): The Newcastle-Ottawa Scale (NOS) was utilized. This scale awards "stars" based on three perspectives:
    - Selection: Representativeness of the exposed cohort and selection of the non-exposed.
    - Comparability: Design or analysis controls for confounders (e.g., age, severity of illness).
    - Outcome: Assessment method (independent/blinded vs. self-report) and adequacy of follow-up. Studies scoring 3-4 stars in Selection, 1-2 in Comparability, and 2-3 in Outcome were classified as "Good Quality." Studies with fewer than 5 stars total were flagged as high risk of bias [20].
3. Cross-Sectional Studies: An adapted version of the NOS or AHRQ standards was used, focusing on sample representativeness and non-response rates **[21]**.

3.5 Data Extraction and Synthesis

Data were extracted into a structured matrix capturing: study author/year, geographic setting, study design, specific intervention (Surveillance/Containment/Response), and key findings. Due to the heterogeneity of the included studies—ranging from engineering airflow studies to ethnographic surveys of healthcare workers—a meta-analysis was not feasible. Instead, a **narrative synthesis** approach was adopted. Evidence was grouped thematically into the three core domains (Surveillance, Containment, Response). Quantitative data points (e.g., "18.5% mortality," "99.7% containment efficiency") were tabulated to facilitate direct comparison, while qualitative findings were woven into the narrative to explain why certain interventions succeeded or failed.

4. Results

The systematic search and review process yielded a comprehensive dataset characterizing the state of global hospital biopreparedness. The results highlight a complex landscape where technological capabilities are often undercut by logistical and behavioral frailties.

4.1 Surveillance Capacity: The Early Warning Gap

The effectiveness of a healthcare facility's response is predicated on the speed of detection. The review identified a clear bifurcation in surveillance strategies based on resource settings.

4.1.1 Syndromic Surveillance in High-Resource Settings

In high-income nations, hospitals increasingly rely on automated syndromic surveillance systems that mine Emergency Department (ED) data for anomalous patterns (e.g., spikes in "fever + respiratory" triage codes).

- **Predictive Value:** Quantitative analysis confirms the utility of these systems in managing surges. One study demonstrated that ED syndromic surveillance could predict ICU bed occupancy surges with a lead time of 11–13 days during COVID-19 waves. This lead time is operationally critical, allowing

facilities to activate surge plans, cancel elective surgeries, and stockpile O2 before the critical mass of patients arrives **[22]**.

- **Sensitivity vs. Specificity Trade-offs:** However, these systems are not panaceas. A RAND Corporation evaluation highlighted a persistent trade-off: algorithms tuned for high sensitivity (to catch every possible bioterror event) generate unmanageable false-positive rates, leading to "alarm fatigue." The study found that for fast-spreading bioterror attacks, standard syndromic algorithms had only a ~50% probability of detecting the outbreak by Day 2 **[23]**. This implies that in a covert biological attack, half of the affected facilities would remain unaware for at least 48 hours, a window during which significant nosocomial transmission could occur.
- **Integration:** The literature emphasizes that "siloed" hospital data is of limited utility. The most effective systems were those integrated into regional public health networks, allowing for the detection of multi-site clusters that would be invisible to a single facility **[23]**.

4.1.2 Integrated Disease Surveillance and Response (IDSR) in Low-Resource Settings

In the WHO African Region and parts of South Asia, the IDSR framework is the standard for facility-based surveillance.

- **Successes in Reporting:** Significant progress has been made in formalizing reporting structures. In Sierra Leone, following the 2014 Ebola epidemic, targeted investments in training and supervision raised the completeness of IDSR reporting from 84.5% in 2016 to 96% in 2021 [24]. This indicates that the "administrative" backbone of surveillance can be strengthened even in resource-constrained environments.
- **The "Last Mile" Problem:** Despite improved reporting, the functional utility of IDSR is often compromised by the "support functions." A systematic review of IDSR performance in sub-Saharan Africa found that while data collection improved, data analysis and laboratory confirmation remained weak links **[17]**. Facilities often lack the "job aids" (standardized case definition posters) and rapid diagnostic tests required to convert clinical suspicion into confirmed public health data **[9]**.
- **Technological Lag:** Most IDSR systems remain heavily paper-based or reliant on basic SMS reporting, lacking the big data integration seen in HICs. This manual latency delays the recognition of outbreaks, allowing pathogens like Ebola or Marburg to circulate cryptically in the community before hospital-based signals trigger a response **[17]**.

Table 1: Comparative Efficacy of Surveillance Models

Feature	**Syndromic Surveillance (High-Resource)**	**IDSR (Low-Resource)**
Data Source	Electronic Health Records (EHR), Triage Vitals	Paper forms, SMS, aggregate tally sheets
Lead Time	11–13 days (predictive of ICU surge) **[22]**	Reactive (often post-cluster identification)
Sensitivity	High (often prone to false positives)	Variable (dependent on HCW training/suspicion)
Detection Probability	~50% by Day 2 for covert attacks **[23]**	Low for novel pathogens without case definitions

Primary Barrier	Alarm fatigue, lack of regional integration	Laboratory capacity, feedback loops, funding **[9]**

4.2 Containment Capacity: Engineering vs. Reality

Once a threat enters the facility, the priority shifts to containment. The review examined the spectrum of isolation capabilities, from elite biocontainment units to ad-hoc isolation in general wards.

4.2.1 High-Level Isolation Units (HLIUs)

HLIUs represent the pinnacle of containment engineering, designed for HCIDs like Ebola and Lassa fever.

- **Engineering Efficacy:** These units utilize negative pressure exceeding standard requirements, typically with 12 or more Air Changes Per Hour (ACH) and HEPA filtration on exhaust. Engineering studies on expedient isolation units (portable anterooms/tents) have shown aerosol containment efficiencies generally exceeding 99.7% **[14]**.
- **Healthcare Worker Safety:** The strict engineering and zoning protocols in HLIUs translate to superior staff safety. During the COVID-19 pandemic, HCWs in designated isolation wards (mimicking HLIU protocols) had significantly lower infection rates (**7%**) compared to staff in general wards (**11%**) during comparable periods. The risk was highest for staff in "non-COVID" wards who were exposed to undiagnosed patients, highlighting that known risk in a contained environment is safer than unknown risk in an open environment **[25]**.
- **Clinical Outcomes:** The level of care provided in HLIUs directly impacts patient survival. A stark disparity was observed in Ebola mortality rates: patients treated in West African general settings faced 40–50% mortality, whereas those evacuated to HLIUs in Europe and the US, receiving aggressive supportive care (dialysis, advanced monitoring), had a mortality rate of only 18.5% **[26]**. This confirms that HLIUs are not just containment vessels but superior therapeutic environments.

4.2.2 The Scalability Challenge

The primary limitation of HLIUs is capacity. Most units contain only 2–10 beds. In a mass casualty bioterrorism event or a pandemic surge, these units are instantly overwhelmed.

- **General Ward Adaptation:** Facilities are forced to adapt general wards, often relying on "administrative" isolation (zoning, signage) rather than engineering controls. The review found that particle escape from isolation areas increases statistically with provider traffic **[14]**, suggesting that without physical anterooms, the movement of staff in and out of makeshift isolation rooms inevitably breaches containment.
- **Isolation Distress:** While effective for safety, strict isolation imposes a psychological burden on patients. Studies note the negative impact on patient well-being due to reduced human contact, necessitating a "patient-centered" approach even in high-security settings **[27]**.

4.3 Response Capacity: The Fragility of the "Human Factor"

The most extensive findings of the review relate to response capacity. The literature consistently identifies the workforce and supply chain as the points of failure, rather than the physical building.

4.3.1 Personal Protective Equipment (PPE) Compliance

Despite the critical importance of PPE, compliance remains alarmingly low.

- **The Knowledge-Behavior Gap:** A study on PPE usage found a profound disconnect: while staff demonstrated high theoretical knowledge of PPE policies, **only 21.64%** correctly performed donning and doffing procedures during observational audits **[28]**.
- **Determinants of Non-Compliance:** Qualitative data reveals that non-compliance is rarely malicious.

It is driven by physical discomfort (heat stress, restricted movement), fogging of vision (impairing clinical tasks), and cognitive overload during emergencies. The complexity of doffing protocols (which can involve 20+ steps) creates multiple opportunities for self-contamination **[15]**.

- **Resource Scarcity:** In Brazil, a cross-sectional study during COVID-19 revealed that 54.8% of anesthesiologists reported PPE scarcity, with 16% forced to use makeshift equipment like 3D-printed face shields or homemade masks. This scarcity directly correlates with increased anxiety and infection risk **[29]**.

4.3.2 Workforce Resilience and Mental Health

The human component of response is degrading.

- **Anxiety and Burnout:** A survey of ICU staff in isolation units found that **96.5%** reported being "scared" or "bothered," with over half meeting criteria for generalized anxiety disorder **[16]**. This level of psychological distress constitutes a functional impairment, reducing the cognitive bandwidth available for adhering to complex safety protocols.
- **Staffing Models:** The review compared "mandatory" vs. "volunteer" staffing for high-risk units. Volunteer models (typical in HLIUs) generally result in higher motivation and better adherence. Mandatory assignment (often necessary during surges) leads to lower morale and higher rates of "moral injury" when staff feel unprotected or untrained **[30]**.

4.3.3 Logistics and Supply Chain

- **Preparedness Decay:** The "boom and bust" cycle of funding leads to preparedness decay. Hospitals stockpile supplies after a scare (e.g., Ebola 2014) but allow them to expire or be depleted during quiet periods to save costs **[30]**.
- **Global Inequity:** The review highlights a massive logistical divide. HICs secured over **50% of COVID-19 vaccine doses** early in the pandemic, while LICs waited months. This inequity extends to therapeutics and basic supplies like oxygen, creating a two-tier global health security system where HCFs in the Global South are systematically deprived of the tools to respond **[31]**.

Table 2: Key Response Indicators by Region/Setting

Metric	High-Resource / HLIU Setting	Low-Resource / General Ward Setting
PPE Availability	Generally high (post-surge)	Scarcity common (54.8% reported shortages in Brazil study **[29]**)
PPE Compliance	Higher (supervised doffing)	Low (~21% correct usage in audits [25])
Mortality (Ebola)	~18.5% **[31]**	~40–50% **[32]**
Staff Anxiety	High (managed with support)	Extreme (96.5% "scared/bothered" **[16]**)
Vaccine Access Delay	Minimal	>100 days lag **[31]**

5. Discussion

5.1 The Hardware-Software Dissonance

The central insight emerging from this review is the dissonance between the "hardware" of biopreparedness

(facilities, stockpiles, plans) and the "software" (people, behavior, resilience). Much of the global investment in health security has focused on hardware: building negative pressure rooms, purchasing ventilators, and drafting response algorithms. However, the data indicates that failures largely occur in the software.

- **Interpretation:** A negative pressure room with 99.7% containment efficiency is rendered ineffective if the healthcare worker entering it fails to doff their PPE correctly (a 78% probability based on audit data) **[28, 33]**. Security is not a product of engineering alone; it is a product of culture and behavior. The low compliance rates are not evidence of incompetence but of system design failure—protocols that are too complex for exhausted humans to follow under stress.
- **Implication:** Future preparedness efforts must prioritize "human-factors engineering." This involves simplifying protocols, designing PPE that is more comfortable and intuitive, and implementing "buddy systems" where staff supervise each other's safety procedures to catch errors in real-time.

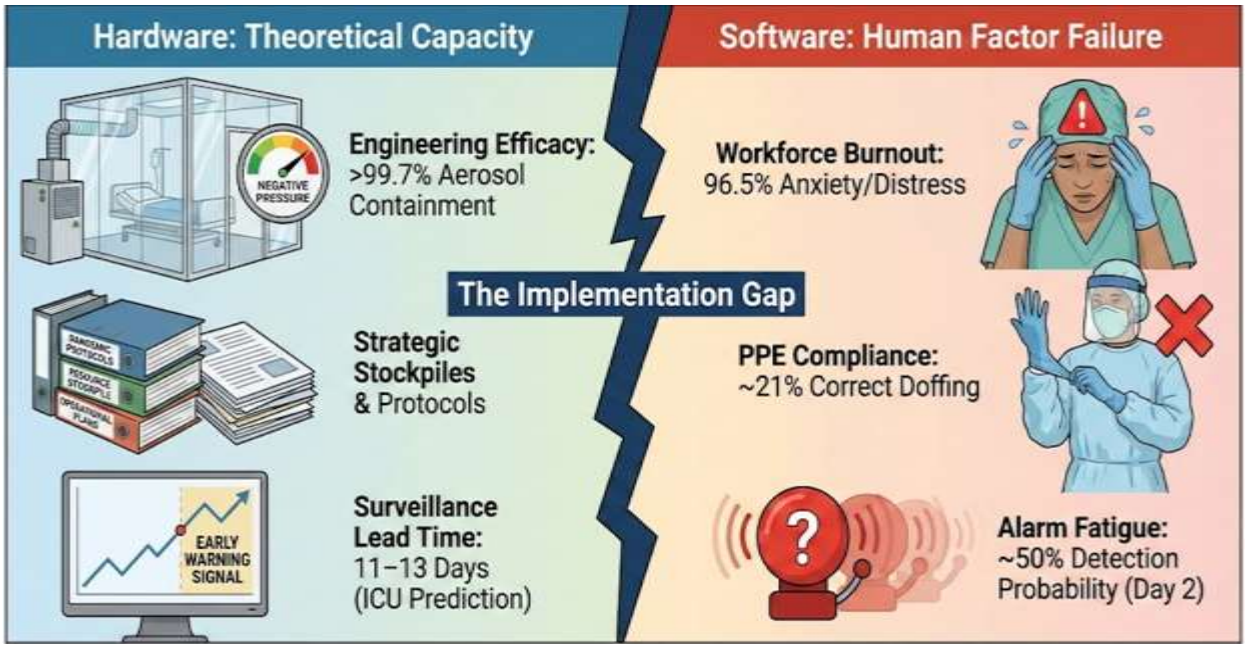

Figure 1. The Hardware-Software Dissonance.

5.2 The Economic Paradox of Preparedness

Hospital administrators operate in a market environment that prioritizes efficiency—lean staffing, just-in-time inventory, and high bed occupancy. Biopreparedness requires the opposite: redundancy, stockpiles, and empty surge capacity.

- **Cost vs. Value:** Preparedness is often viewed as a "cost center" without revenue. However, the economic impact of not being prepared—hospital shutdowns, staff quarantines, and massive liability—far outweighs the investment costs. The literature suggests that viewing preparedness as an "insurance policy" is the only viable economic model **[28]**.
- **Funding Models:** The reliance on grant funding (e.g., the U.S. Hospital Preparedness Program or international donor funds for IDSR) creates instability. When the immediate threat fades, funding is cut, leading to the "decay" of capabilities. Sustainable preparedness requires integrating these costs into the baseline operational budgets of healthcare systems, mandated by accreditation standards **[34]**.

5.3 Inequity as a Systemic Threat

The review starkly illuminates that health security is indivisible. The inability of an HCF in a low-income

country to detect and contain a pathogen due to lack of laboratory support **[9]** or PPE **[31]** poses a direct threat to the global community.

- **The Variant Factory:** Delayed access to MCMs in the Global South allows pathogens to circulate longer, increasing the probability of variants emerging that can evade the vaccines hoarded by the Global North **[31]**. Thus, the inequity detailed in the Results section is not just a moral failing but a strategic error. Strengthening the IDSR framework and laboratory capacity in Africa and Asia is a high-yield investment for global biosecurity.

5.4 The "Flex" Capacity Imperative

The failure of HLIUs to scale suggests that the future of hospital design lies in "flexibility" rather than "specialization."

- **Architectural Shifts:** Instead of building expensive, empty biocontainment units, hospitals should design general wards with "switchable" HVAC systems that can convert entire floors to negative pressure during a pandemic **[31]**.
- **Expedient Solutions:** The success of temporary isolation structures validates the use of low-cost, rapidly deployable containment solutions. Hospitals should stockpile the materials for these "pop-up" units (tents, portable HEPA scrubbers) to create instant surge capacity in lobbies or parking structures **[14]**.

6. Conclusion

This systematic review of health security preparedness in healthcare facilities reveals a global system that is technically capable but operationally fragile. The "implementation gap" between policy and practice is the defining characteristic of the current landscape.

Key Findings:

1. Surveillance: High-income nations possess predictive power (11–13 days lead time) but suffer from specificity issues. Low-income nations have improved administrative reporting (IDSR) but lack the laboratory capacity to make that data actionable in real-time.
2. Containment: The engineering of containment is solved (HLIUs work), but the capacity is missing. The vast majority of biological care will happen in general wards, where containment is heavily reliant on fallible human behavior.
3. Response: The workforce is the primary point of failure. Low PPE compliance (~21%) and extreme burnout (>96% anxiety) indicate that the human infrastructure of healthcare is degrading.
4. Inequity: A two-tier system of biosecurity exists, where resource-poor settings are left vulnerable to becoming reservoirs for global threats due to supply chain exclusion.

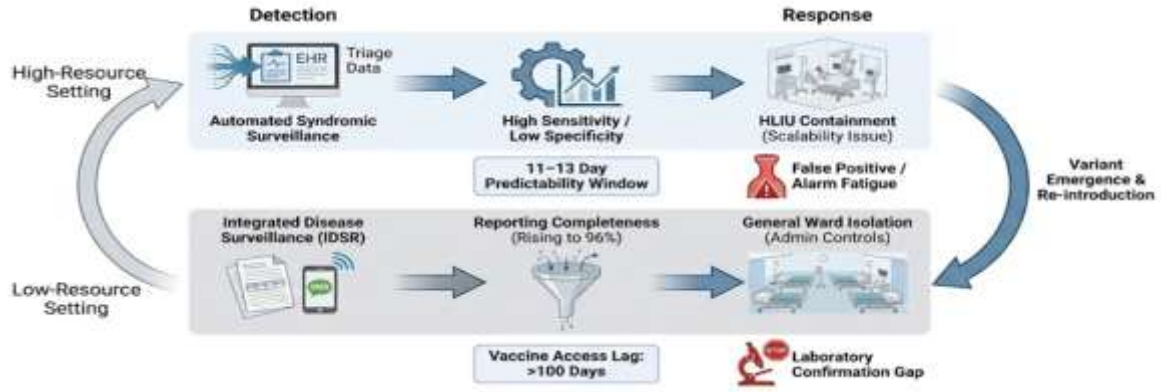

Figure 2. Global Surveillance and Response Inequity.

Recommendations:

- For Hospital Leadership: Institutionalize "human-factors" training. Move beyond annual lectures to frequent, low-stakes simulation drills that build muscle memory for PPE and isolation protocols. Invest in mental health support as a critical component of response capacity.
- For Policymakers: Shift funding from reactive "emergency supplementals" to sustained, baseline funding for biopreparedness. Mandate "pandemic-resilient" architectural standards for all new hospital construction (e.g., flexible HVAC).
- For the Global Community: Operationalize the "One Health" approach by financing the laboratory and surveillance networks of the Global South. The strengthening of IDSR is a global public good that requires stable international investment.

Current health security preparedness is fragmented. To withstand the biological threats of the coming decade, the healthcare sector must transition from a posture of "responding to the last war" (bioterrorism) to building a resilient, equitable, and human-centered defense against the inevitable "next war" (pandemic/all-hazards).

References

[1] Li, T., Zhang, Y., Yao, L., Bai, S., Li, N., and Ren, S., Knowledge, attitudes, and practices associated with bioterrorism preparedness in healthcare workers: a systematic review. Frontiers in Public Health, 11. 1272738 (2023).

[2] Atakro, C.A., Addo, S.B., Aboagye, J.S., Blay, A.A., Amoa-Gyarteng, K.G., Menlah, A., Garti, I., Agyare, D.F., Junior, K.K., and Sarpong, L., Nurses' and medical officers' knowledge, attitude, and preparedness toward potential bioterrorism attacks. SAGE open nursing, 5. 2377960819844378 (2019).

[3] Murray, C.J., The global burden of disease study at 30 years. Nature medicine, 28(10). 2019-2026 (2022).

[4] Sharififar, S., Jahangiri, K., Zareiyan, A., and Khoshvaghti, A., Factors affecting hospital response in biological disasters: A qualitative study. Medical journal of the Islamic Republic of Iran, 34. 21 (2020).

[5] Hope, K., Durrheim, D.N., d'Espaignet, E.T., and Dalton, C., Syndromic surveillance: is it a useful tool for local outbreak detection? 2006, BMJ Publishing Group Ltd.

[6] Coli, E., Difficile, C., Pylori, H., and HAI, H.A.I., Evolving and Emerging Challenges in Biopreparedness. Contagion, 8(2). 8 (2023).

[7] Mikulska, M., Carreras, E., Dufour, C., Mohty, M., and Kröger, N., Infection control and isolation procedures. The EBMT handbook-Hematopoietic Stem Cell Transplantation and Cellular Therapies. 189 (2019).

[8] Lukowski, J., Vasa, A., Arguinchona, C., ElRayes, W., Frank, M.G., Galdys, A.L., Garcia, M.C., Garland, J.A., Kline, S., Persson, C., Ruby, D., Sauer, L.M., Vasistha, S., Carrasco, S., and Herstein, J.J., A narrative review of high-level isolation unit operational and infrastructure features. BMJ Glob Health, 8(7) (2023).

[9] Phalkey, R.K., Yamamoto, S., Awate, P., and Marx, M., Challenges with the implementation of an Integrated Disease Surveillance and Response (IDSR) system: systematic review of the lessons learned. Health policy and planning, 30(1). 131-143 (2015).

[10] Liu, B.F., Quinn, S.C., Egnoto, M., Freimuth, V., and Boonchaisri, N., Public understanding of medical countermeasures. Health security, 15(2). 194-206 (2017).

[11] Baikmohammadi, S., Amirheidari, B., Dehesh, T., Moghadam, M.N., Yazdi-Feyzabadi, V., Hassani, E., and Habibzadeh, H., A qualitative study on barriers and strategies to hospital preparedness against chemical, biological, radiological, and nuclear incidents. J Educ Health Promot, 13. 3 (2024).

[12] Seyedin, H., Moslehi, S., Dowlati, M., and Ehsanzadeh, S.J., Hospital management model for biological hazards: A qualitative content analysis study. Journal of Emergency Management, 20(5). 407-422 (2022).
[13] Popescu S, Making the case for biopreparedness in frontline hospitals: a Phoenix case study. (
[14] Johnson, D.L., Lynch, R.A., and Mead, K.R., Containment effectiveness of expedient patient isolation units. American journal of infection control, 37(2). 94-100 (2009).
[15] Alzamzami, A., Ibrahim, M., Nemer, F., Ghallab, Z., Alsulami, A., Alghamdi, A., Samm, H., Alasmari, N., Alshamrani, A., Aljohani, S., and Altalibi, N., Personal protective equipment usage and compliance among healthcare workers. International Journal Of Community Medicine And Public Health, (2025).
[16] Choudhary, A., Saurabh, K., Kumar, A., and Arun, N., A Cross-Sectional Survey to Assess the Preparedness of Healthcare Workers of Isolation Intensive Care Units for Anticipated Another Wave of the COVID-19 Pandemic in a Tertiary Care Center. Cureus, 16(2). e54949 (2024).
[17] Mremi, I.R., George, J., Rumisha, S.F., Sindato, C., Kimera, S.I., and Mboera, L.E.G., Twenty years of integrated disease surveillance and response in Sub-Saharan Africa: challenges and opportunities for effective management of infectious disease epidemics. One Health Outlook, 3(1). 22 (2021).
[18] Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., and Brennan, S.E., The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj, 372 (2021).
[19] Sterne, J.A., Savović, J., Page, M.J., Elbers, R.G., Blencowe, N.S., Boutron, I., Cates, C.J., Cheng, H.-Y., Corbett, M.S., and Eldridge, S.M., RoB 2: a revised tool for assessing risk of bias in randomised trials. bmj, 366 (2019).
[20] Stang, A., Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. European journal of epidemiology, 25(9). 603-605 (2010).
[21] Hartling, L., Milne, A., Hamm, M.P., Vandermeer, B., Ansari, M., Tsertsvadze, A., and Dryden, D.M., Testing the Newcastle Ottawa Scale showed low reliability between individual reviewers. Journal of clinical epidemiology, 66(9). 982-993 (2013).
[22] Ageron, F.-X., Hugli, O., Dami, F., Caillet-Bois, D., Pittet, V., Eckert, P., Beysard, N., and Carron, P.-N., Lessons from COVID-19 syndromic surveillance through emergency department activity: a prospective time series study from western Switzerland. BMJ open, 12(5). e054504 (2022).
[23] Stoto, M.A., Mariano, L.T., and Schonlau, M., Syndromic Surveillance: An Effective Tool for Detecting Bioterrorism? (2004).
[24] Njuguna, C., Vandi, M., Squire, J.S., Kanu, J.S., Gachari, W., Liyosi, E., Githuku, J., Chimbaru, A., Njeru, I., Caulker, V., Mugagga, M., Sesay, S., Yahaya, A.A., Talisuna, A., Yoti, Z., and Fall, I.S., Innovative approach to monitor performance of integrated disease surveillance and response after the Ebola outbreak in Sierra Leone: lessons from the field. BMC Health Serv Res, 22(1). 1270 (2022).
[25] Jung, J., Kim, S.K., Lee, Y., Park, S., Lim, Y.J., Kim, E.O., and Kim, S.H., Rates of COVID-19 Infection Among Healthcare Workers in Designated COVID-19 Wards and General Wards. J Korean Med Sci, 37(43). e308 (2022).
[26] Marshall Lyon, G., Mehta, A.K., and Ribner, B.S., Clinical Management of Patients with Ebola Virus Disease in High-Resource Settings. Curr Top Microbiol Immunol, 411. 115-137 (2017).
[27] Jankowski, J., Kubińska, M., and Zduńczyk, Z., Nutritional and immunomodulatory function of methionine in poultry diets–a review. Annals of Animal Science, 14(1). 17-32 (2014).
[28] Hagert, B. and Krummel, N., PPE compliance and knowledge among healthcare staff. (2020).
[29] Quintão, V.C., Simões, C.M., Munoz, G.E.H., Barach, P., and Carmona, M.J.C., A Brazilian national preparedness survey of anesthesiologists during the coronavirus pandemic. Braz J Anesthesiol, 71(2). 184-187 (2021).

[30] Herstein, J.J., Stern, K., Flinn, J., Garland, J.A., Lowe, A.E., and Sauer, L.M. Challenges and approaches to high-level isolation unit staffing and just-in-time training: a meeting report. in Open Forum Infectious Diseases. 2023. Oxford University Press US.
[31] Sharma, K., Syeda, S., Shah, S.M., Kori, S.A., Shetty, P., Kazi, S., Khaiterpal, A., Choudhary, A., Pathak, S., and Ahmed, S., Overcoming barriers to medical countermeasures: Strengthening global biosecurity. Hum Vaccin Immunother, 21(1). 2483043 (2025).
[32] Organization, W.H., WHO: Ebola situation report. (2016).
[33] Johnson, D., Lynch, R., and Mead, K., Containment effectiveness of expedient patient isolation units. American Journal of Infection Control, 37: 94-100. American journal of infection control, 37. 94-100 (2008).
[34] Gribben, K., Sayles, H., Roy, S., Shope, R.J., Ringel, J.S., and Medcalf, S., The crosscutting benefits of hospital emergency preparedness investments to daily operations: a hospital senior leadership perspective. Health security, 18(5). 409-417 (2020).