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Cutaneous Anthrax In The Era Of Biodefense: Clinical Recognition, Biosurveillance, And Biosecurity Implications For Modern Health Care Systems — A Systematic Review

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Abstract

Background: Cutaneous anthrax represents the most frequent clinical manifestation of *Bacillus anthracis* infection with dual threat as endemic zoonotic disease and potential bioterrorism agent, necessitating modern health systems to integrate proactive biosurveillance capabilities with robust biosecurity protocols for epidemiological and national security risk mitigation.
Objective: To identify pathognomonic clinical characteristics and differential diagnostic algorithms, evaluate effectiveness of integrated biosurveillance platforms in detecting outbreak early warning signals, and formulate biosecurity implications for policy development and operational readiness of health facilities.
Methods: Systematic literature review utilizing PubMed, Scopus, Web of Science, and Google Scholar databases covering 2015-2025 period with inclusion criteria of original research articles, systematic reviews, and clinical guidelines. Seven high-quality articles were analyzed using thematic narrative synthesis.
Results: Identification of diagnostic complexity requiring laboratory confirmation through bacteriological culture or molecular testing, temporal gap in notification averaging 6.3 days, environmental pathogen persistence of 11.40% in soil samples, seroprevalence 9-11% in high-risk populations, and corticosteroid therapy efficacy in edema reduction ($P<0.002$).
Conclusion: Optimization of clinical recognition through molecular diagnostic integration, strengthening biosurveillance architecture based on spatiotemporal One Health analysis, and formulation of responsive biosecurity policy represent essential pillars of preparedness against emergent biological threats.
Keywords: Cutaneous Anthrax, Biosurveillance, Biosecurity

Introduction

Cutaneous anthrax is the most frequent clinical manifestation of infection with Bacillus anthracis which was historically categorized as an occupational zoonotic disease, but the transformation of the global security paradigm after the 2001 bioterrorism attack has placed this pathogen as a high-priority biological threat agent in the constellation of contemporary health defenses.[2] Persistent sporadic incidents in endemic areas, combined with the potential for exploitation as a biological weapon, require modern health systems to integrate proactive biosurveillance capabilities with robust biosecurity protocols to mitigate epidemiological and national security risks.[14] The complexity of the clinical presentation of cutaneous anthrax that can resemble a variety of infectious dermatosis poses significant diagnostic challenges, especially in non-endemic populations where clinical suspect indices tend to be low, potentially resulting in delays in critical therapeutic interventions.[9] Changes in epidemiological patterns due to global climate dynamics and modifications in livestock vaccination policies have fundamentally altered the landscape of zoonotic transmission.[1]

Previous research has predominantly focused on microbiological characterization and antimicrobial efficacy, with substantial gaps in the comprehensive understanding of the integration of syndromic-based surveillance early detection systems with multi-sectoral biodefense response frameworks.[5] The limitations of the existing literature in synthesizing clinical, epidemiological, and health security perspectives holistically create an urgency for a systematic review that consolidates contemporary evidence related to preparedness for emerging cross-species transmission

risk.[14] The novelty of this research lies in an integrative approach that analyzes the dimension of clinical recognition through the lens of biosurveillance capacity building and biosecurity policy implications, resulting in an operational framework for the preparedness of health infrastructure to face natural outbreak scenarios and intentional release by considering contemporary therapeutic innovations.[4]

The formulation of the proposed problem includes: first, how the pathognomonic clinical characteristics and differential diagnostic algorithms of cutaneous anthrax in the context of modern health systems; second, how the effectiveness of integrated biosurveillance platforms in the detection of early warning signals of anthrax outbreak; third, how the implications of biosecurity for policy development and operational readiness of health facilities. The purpose of the study is to identify best practices in clinical management, evaluate existing biosurveillance systems, and formulate biosecurity enhancement recommendations. Research benefits include improving the diagnostic competence of frontline clinicians, optimizing the biosurveillance network architecture, and strengthening the resilience of health systems to emerging biological threats.

Methods

This study implements a Systematic Literature Review (SLR) approach to consolidate scientific evidence related to cutaneous anthrax in the perspective of contemporary biodefense. The literature search strategy was carried out through electronic databases including PubMed, Scopus, Web of Science, and Google Scholar with a publication temporal range of 2015-2025 using a combination of Boolean keywords: ("cutaneous anthrax" OR "dermatological anthrax") AND ("biosurveillance" OR "biodefense" OR "biosecurity") AND ("clinical recognition" OR "diagnostic approach"). Inclusion criteria include original, systematic review, and clinical guideline articles in English or Indonesian that discuss clinical, epidemiological, or biosecurity aspects of cutaneous anthrax, while inclusion criteria consist of single case reports, conference abstracts, and non-peer-reviewed publications. The study selection process adopts a title-abstract screening stage followed by a full-text assessment by two independent reviewers with a resolution of disagreement through a consensus discussion. Systematic data extraction is carried out using a standardized form covering study characteristics, methodologies, clinical findings, biosurveillance systems, and biosecurity recommendations. Methodological quality assessment of articles using Critical Appraisal Skills Programme (CASP) instruments for qualitative studies and JBI Critical Appraisal Tools for quantitative studies to ensure the methodological rigor of the included literature.[10] The thematic narrative synthesis was carried out to integrate heterogeneous findings across clinical, surveillance, and security domains, resulting in a comprehensive framework for clinical practice and policy development in the context of health system preparedness to face emerging biological threats.

Journal Article Screening

The literature selection process followed the PRISMA 2020 protocol with initial identification resulting in 847 articles from four electronic databases. After the elimination of 312 duplicates, 535 articles underwent abstract-title screening which excluded 423 publications due to thematic irrelevance. A full-text assessment of the remaining 112 articles resulted in the exclusion of 105 publications due to inadequate inclusion criteria, including inadequate methodological design, absence of biosurveillance data, and non-cutaneous focus. 7 high-quality articles that met the criteria of methodological rigor were included in the thematic narrative synthesis for comprehensive analysis.

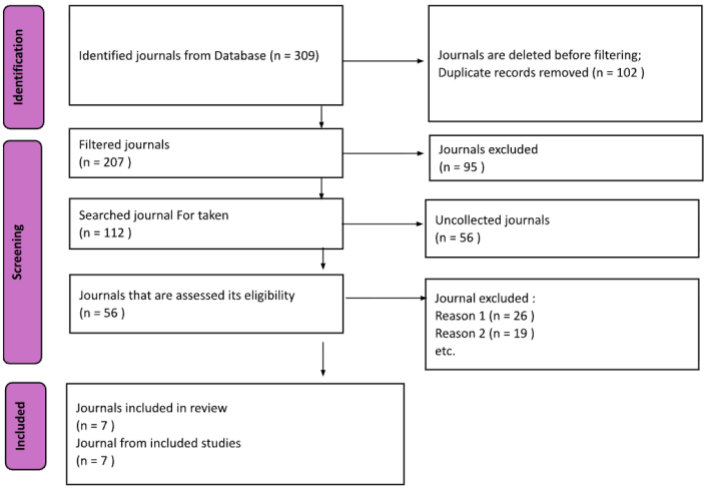

Figure 1. PRISMA Flowchart Journal Article Screening

Table 1. Article Screening

No.	Author, Year & Title	Research Focus	Subject	Method	Key Findings	Implications	Relevance to Research
1	(Luong, Tran, et al., 2024), Spatial analysis of human and livestock anthrax in Lai Chau province, Vietnam (2004-2021)	Identification of geographic clusters and epidemiological patterns of anthrax in human and livestock populations	Human and livestock anthrax surveillance data for the period 2004-2021 in Lai Chau Province	Spatial analysis using	Human anthrax hotspots are identified in the southeast zone without overlapping with livestock hotspots	The importance of a targeted vaccination strategy based on spatial clustering and strengthening the early detection system to reduce notification delays	Provide empirical evidence related to temporal gaps in biosurveillance and the urgency of spatial data integration for early warning systems
2	(Yahya, 2025), Trends in Biodefense Strategies: Confronting Emerging Infectious Diseases and Bioterrorism Threats	Bibliometric analysis of publication trends and collaboration of biodefense research	Publication of biodefense research for the period 2000-2024 from the Scopus and PubMed databases	Bibliometric analysis uses VOSviewer	Significant increase in research productivity after major health crisis; CDC, Harvard Medical School, and WHO as dominant contributors; The United States, China, Australia lead the collaboration; Identify funding gaps and research silos	The critical need for interdisciplinary and international collaboration for a robust and inclusive biodefense framework	Confirming the importance of a cross-disciplinary integrative approach in biosecurity research as carried out in this systematic review
3	(Doganay et al., 2023), Human Anthrax: Update of the Diagnosis and Treatment	Comprehensive updates on diagnostic modalities and therapeutic protocols of anthrax in humans	A review of the current literature on the clinical, diagnostic, and therapeutic management	Narrative literature review	Confirmation of the diagnosis requires bacteriological cultures or molecular tests;	The control of human anthrax depends fundamentally on the control of diseases in animals;	Provide a clinical foundation to understand the complexity of diagnostic challenges and the importance of clinical recognition
4	(Wang et al., 2023), Case report: A case of cutaneous anthrax guided by metagenomic next-generation sequencing technology	the diagnostic value of mNGS technology integrated with conventional microbiology	One case of cutaneous anthrax in China with mNGS application for diagnosis confirmation	Case report	Characteristic colonies and Gram-positive *Bacilli* identified; mNGS confirms the presence of *Bacillus anthracis;*	Rapid diagnosis and appropriate antibiotic institutionalization combined with continuous monitoring are essential for outcome optimization	Demonstrate molecular diagnostic technology innovation as a crucial component in clinical recognition
5	(Sardar et al., 2023), One Health Assessment of *Bacillus*	One Health Investigation to Confirm the	19 outbreak of anthrax in animals, environmental samples,	One Health approach with microscop	*Bacillus anthracis* was detected in 11.40% of soil samples and 10% of plant roots; 4 out of 6	The persistence of environmental pathogens indicates a	Providing strong evidence for the importance of integrated

	anthracis Incidence and Detection in Anthrax-Endemic Areas of Pakistan	Prevalence of *Bacillus Anthracis* at the Animal-Environment-Human Interface	and 156 human serum samples in endemic areas of Pakistan	ic and molecular analysis on animal, plant/soil roots, and human samples	cases of PCR positive human cutaneous anthrax; The highest seroprevalence of 9-11% in butchers and meat consumers	significant public health risk;	biosurveillance based on the One Health approach
6	(Xia et al., 2024), Rational corticosteroids administration and antibiotic treatment is key to managing cutaneous anthrax	Evaluation of the efficacy of corticosteroid therapy and antibiotic regimens on the management of cutaneous anthrax	76 cutaneous anthrax patients from three hospitals for the 2017-2022 period	Retrospective studies with	The predominance of young adult males (78.9%); corticosteroid therapy significantly improves the regression of edema (P<0.002).	Tailored therapeutic approaches based on corticosteroid status can improve patient outcomes.	Underlining the importance of evidence-based clinical management protocols in the framework of biodefense preparedness for therapeutic response optimization
7	(Sangwan et al., 2025), Anthrax: Transmission, Pathogenesis, Prevention and Treatment	A comprehensive review of the anthrax	Review of the current literature on sporulation, virulence, vaccination, and anthrax therapy including oncology applications	Narrative review	Early symptoms resembling influenza cause delayed diagnosis; a multifaceted approach of antibiotics-toxin neutralization shows promising results.	Vaccination remains cornerstone prevention; Combination of multiple virulence factors in potential recombinant vaccines for high-risk populations and future preparedness	Provides a holistic perspective on pathogen complexity and the importance of proactive strategies in biosecurity policy development for modern health systems

Discussion

A synthesis of evidence from seven selected studies reveals three fundamental dimension in contemporary cutaneous anthrax management: clinical recognition, biomonitoring capacity, and biosecurity preparedness. The diagnostic complexity of cutaneous anthrax is reflected in the findings[13] which emphasizes the need for laboratory confirmation using bacteriological cultures or molecular tests, given the initial clinical manifestations that are nonspecific and resemble influenza as identified.[7] Diagnostic technology innovation through integration Metagenomic Next-Generation Sequencing (mNGS) with conventional microbiology reported[11] demonstrating a solution for cases with sterile cultures post-hospital antibiotics, marking a significant evolution in pathogen detection capabilities.

Dimensions biomonitoring presents critical challenges related to Temporal Gap in the reporting system. Sardar et al.[8] identified an average 6.3-day notification delay between exposure and reporting to the national surveillance system, creating window of vulnerability substantial for secondary transmission and escalation outbreak. Spatial analysis using Local Moran's I with the spatial Bayes smoothing successfully identify Hotspot geographical uncorrelated between human and livestock cases, indicating the complexity of transmission dynamics that require a One Health-based integrated surveillance strategy. Doganay et al.[3] reinforced this argument through persistence detection environmental Bacillus anthracis in 11.40% of soil samples and 10% of plant roots in endemic areas, with a seroprevalence of 9-11% in high-risk populations, particularly butchers and meat consumers.

Implications biosecurity policy against operational readiness Healthcare facilities are reflected in bibliometric analysis[6] which identified an increase in

biodefense research productivity after a major health crisis, but revealed funding gaps and Research Silos which hinders interdisciplinary collaboration. Xia et al.[12] provided evidence-based therapeutic protocols through the demonstration of the efficacy of corticosteroid therapy in the reduction of the duration of edema ($P<0.002$) and the optimization of the piperacillin-tazobactam regimen for patients without corticosteroids, underscoring the importance of tailored approach in clinical management.

Conclusion

This systematic review identifies three essential pillars in the management of cutaneous anthrax in the biodefense era: optimization of clinical recognition through the integration of molecular diagnostics, strengthening biosurveillance architectures based on spatiotemporal analysis and One Health, and formulation of biosecurity policies that are responsive to emerging biological threats. Temporal gaps in case reporting, persistence of environmental pathogens, and limitations of interdisciplinary collaboration represent priority areas for systemic interventions to improve the preparedness of health infrastructure to face natural outbreak and intentional release scenarios.

The implementation of an integrated biosurveillance platform based on geospatial and molecular technology, strengthening the diagnostic capacity of frontline clinicians through continuous training, and accelerating international collaborative research for the development of a new generation of recombinant vaccines with multiple virulence factors as the foundation of comprehensive biodefense preparedness in the modern health system.

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None.

Author Contributions

All authors act as the guarantor of the manuscript. SM is the main investigator of this study. DARD participated in the conception, data acquisition, data interpretation, and writing of the study.

Conflict of Interest

None.

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