

โรคแอนแทรกซ์ในมนุษย์ในประเทศไทย : พยาธิกำเนิด การแพร่กระจาย การรักษา และการป้องกัน

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บทคัดย่อ

โรคแอนแทรกซ์เป็นโรคติดเชื้อเฉียบพลันที่เกิดจากเชื้อ *Bacillus anthracis* แม้ว่าการให้ยาปฏิชีวนะหลังสัมผัสเชื้อโรคตามแนวปฏิบัติ Post-Exposure Prophylaxis (PEP) และการให้วัคซีนจะมีประสิทธิภาพสูงในการยับยั้งการแพร่กระจายของโรค แต่การเฝ้าระวังอย่างต่อเนื่องยังคงมีความจำเป็นอย่างยิ่ง เนื่องจากสปอร์ของเชื้อแอนแทรกซ์มีความทนทานและอยู่ในสิ่งแวดล้อมหรือสัตว์รังโรคได้เป็นเวลายาวนาน ซึ่งเสี่ยงต่อการแพร่ระบาดซ้ำ อย่างไรก็ตามเอกสารทางวิชาการเกี่ยวกับโรคแอนแทรกซ์ในมนุษย์ของประเทศไทยยังมีอยู่อย่างจำกัด บทความวิชาการฉบับนี้จึงมีวัตถุประสงค์เพื่อสังเคราะห์รายงานและทบทวนวรรณกรรมที่เกี่ยวข้องกับการระบาดของโรคแอนแทรกซ์ในมนุษย์ในประเทศไทย เพื่อให้ได้ภาพรวมองค์ความรู้ที่ครอบคลุม ผ่านการสืบค้นข้อมูลจากฐานข้อมูล PubMed และ ThaiJO โดยใช้คำสำคัญ ได้แก่ Anthrax, Thailand, Epidemiology, Diagnosis, Treatment และ Therapy ผลการศึกษาพบว่า การระบาดของโรคแอนแทรกซ์ในประเทศไทยเกิดขึ้นส่วนใหญ่ในภาคเหนือและภาคตะวันออกเฉียงเหนือ ซึ่งมีพรมแดนติดต่อกับประเทศเพื่อนบ้าน เช่น ลาว และเมียนมา เป็นต้น แม้ว่าการพึ่งพาการรักษาด้วยยาปฏิชีวนะทำให้หน่วยงานสาธารณสุข สามารถจำกัดการแพร่กระจายของโรคได้ แต่ความเข้าใจเชิงลึกเกี่ยวกับโรคและแบบแผนทางระบาดวิทยาเป็นสิ่งสำคัญสำหรับการพัฒนากลยุทธ์ควบคุมและป้องกันโรคที่มีประสิทธิภาพ รวมไปถึงการรักษาและวัคซีนแบบมุ่งเป้าหมายที่ออกแบบให้เหมาะสมกับบริบทของเชื้อ *B. anthracis* ในประเทศไทย

คำสำคัญ : แอนแทรกซ์, บาซิลลัส แอนทราซิส, ประเทศไทย, การแพร่ระบาด

Human Anthrax in Thailand: Pathogenesis, Transmission, Treatment and Prevention

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Abstract

Anthrax is an acute infectious disease caused by *Bacillus anthracis*. Although Post-Exposure Prophylaxis (PEP) with antibiotics and vaccination are highly effective at suppressing the spread of the disease, continuous surveillance remains imperative. Due to the persistence and environmental resilience of anthrax spores, which can remain viable in environmental substrates and animal reservoirs for prolonged periods, there is an ongoing risk of recurrent outbreaks. Despite this, academic literature regarding human anthrax in Thailand remains limited. This review article aims to synthesize reports and summarize literature of human anthrax outbreaks within Thailand, providing a comprehensive knowledge review. Data were retrieved from PubMed and ThaiJO databases using keywords such as "Anthrax", "Thailand", "Epidemiology", "Diagnosis", "Treatment", and "Therapy". The findings indicate that outbreaks in Thailand occur predominantly in the Northern and Northeastern regions, particularly along the borders of neighboring countries like Laos and Myanmar. While the reliance on antibiotic treatment has enabled public health agencies to limit disease transmission, a deeper understanding of the disease and its epidemiological patterns is vital for a crucial development of effective control and prevention strategies, including treatment and targeted vaccines-specifically tailored to *B. anthracis* within the Thai context.

Keywords: Anthrax, *Bacillus anthracis*, Thailand, Outbreak

Introduction

Anthrax is a zoonotic disease primarily transmitted through contact with infected animals or contaminated animal products. The disease is predominantly maintained within animal populations, with occasional transmission to humans; however, human-to-human transmission has not been documented (Ashique et al., 2024). Despite being largely preventable through effective livestock vaccination and improved animal husbandry practices, anthrax outbreaks continue to pose a significant public health risk (Hossain et al., 2026). Approximately 95% of human anthrax cases manifest as cutaneous anthrax, while inhalational anthrax (also known as Woolsorter's disease) and gastrointestinal anthrax account for the remaining cases (Subedi et al., 2024). Delayed healthcare seeking or initiation of treatment during the fulminant stage of disease has been associated with an increased risk of mortality (Thompson et al., 2022). However, the full clinical spectrum of anthrax infection, which ranges from subclinical disease to fatal outcomes, remains incompletely characterized (Sirisanthana & Brown, 2002).

In Thailand, anthrax cases were reported between 1999 and 2000, with an estimated incidence ranging from 0.02 to 0.17 cases per 100,000 population. Most outbreaks occurred in the northern and northeastern regions and were commonly associated with the importation and transport of infected livestock. These outbreaks were effectively contained through control measures implemented by the Ministry of Public Health. The most recent outbreak, reported in May 2025 (World Health Organization [WHO], 2025a), reignited public concern, particularly among rural communities near the affected areas. Despite these incidents, reports of anthrax outbreaks in Thailand are often presented in simplified formats, such as Thai Journals Online (ThaiJO), news and other public dissemination platforms in the Thai language. Comprehensive academic documentation and detailed outbreak reports, especially in Thailand, remain limited. Therefore, this narrative review aims to comprehensively synthesize existing evidence on human anthrax in Thailand, with a focus on epidemiology, pathogenesis, clinical manifestations, diagnosis, treatment, and prevention. A comprehensive understanding of the disease and its outbreaks is crucial for the development of effective control and preventive strategies, including therapeutics and vaccines targeting *Bacillus anthracis*.

The literature reviewed encompassed studies addressing the definition of the disease, the characteristics and pathogenesis of the pathogen, and the clinical pathology

categorized by routes of infection, diagnosis, treatment, and prevention. A structured search strategy was employed using the keywords such as "Anthrax", "Thailand", "Epidemiology", "Diagnosis", "Treatment", and "Therapy", covering publications from earlier works up to May 2025. The relevant findings were synthesized thematically, and the quality of the included studies was assessed using standardized evaluation frameworks to ensure the validity, reliability, and relevance of the review outcomes.

What is Anthrax?

Anthrax is a zoonotic infectious disease caused by *B. anthracis*. The term “anthrax” originates from the Greek word “anthrakis”, meaning “coal,” in reference to the characteristic black eschar that develops in the cutaneous form of the disease. Anthrax affects both domestic and wild animals, particularly herbivores such as cattle, sheep, and goats, which serve as primary reservoirs and sources of sporadic zoonotic transmission to humans. Infection is mediated by highly resilient endospores that persist in the environment for prolonged periods due to their resistance to desiccation, extreme temperatures, ultraviolet and gamma radiation, and many chemical disinfectants (Ashique et al., 2024).

Bacillus anthracis: Bacterial Burden of Anthrax

B. anthracis is a Gram-positive, non-motile, rod-shaped bacterium belonging to the phylum Firmicutes, family Bacillaceae, and genus *Bacillus*, and is a member of the *B. cereus* group of closely related pathogenic species (Pilo & Frey, 2011). Historically, its study was pivotal in microbiology; the work of Robert Koch in 1876 demonstrated its spore-forming capacity and established *B. anthracis* as the first bacterium proven to cause disease, providing a foundation for the germ theory of disease (Zasada, 2020). The organism exists in two forms: a highly resistant dormant spore and a vegetative form that replicates within the host under aerobic or facultative anaerobic conditions (Ochai et al., 2024).

Pathogenesis of *B. anthracis*

After infection into a suitable host, bacterial spores are phagocytosed by macrophages and subsequently germinate into vegetative cells, initiating active infection. The spore formation and germination can be summarized as follows: Stage I - Initiation: Organization of DNA into an axial filament. Stage II - Septum formation: Onset of asymmetric

division between the mother cell and the forespore. Stage III - Engulfment: The forespore is completely engulfed by the mother cell. Stage IV - Cortex formation: Development of a protective cortex around the forespore. Stage V - Coat formation: Deposition of spore coat proteins, accumulation of dipicolinic acid (DPA), and uptake of calcium ions into the spore core. Stage VI - Maturation: Development of the characteristic refractile appearance of mature spores. Stage VII - Release: Lysis of the mother cell, releasing the mature spore into the environment (Figure 1) (Sangwan et al., 2025).

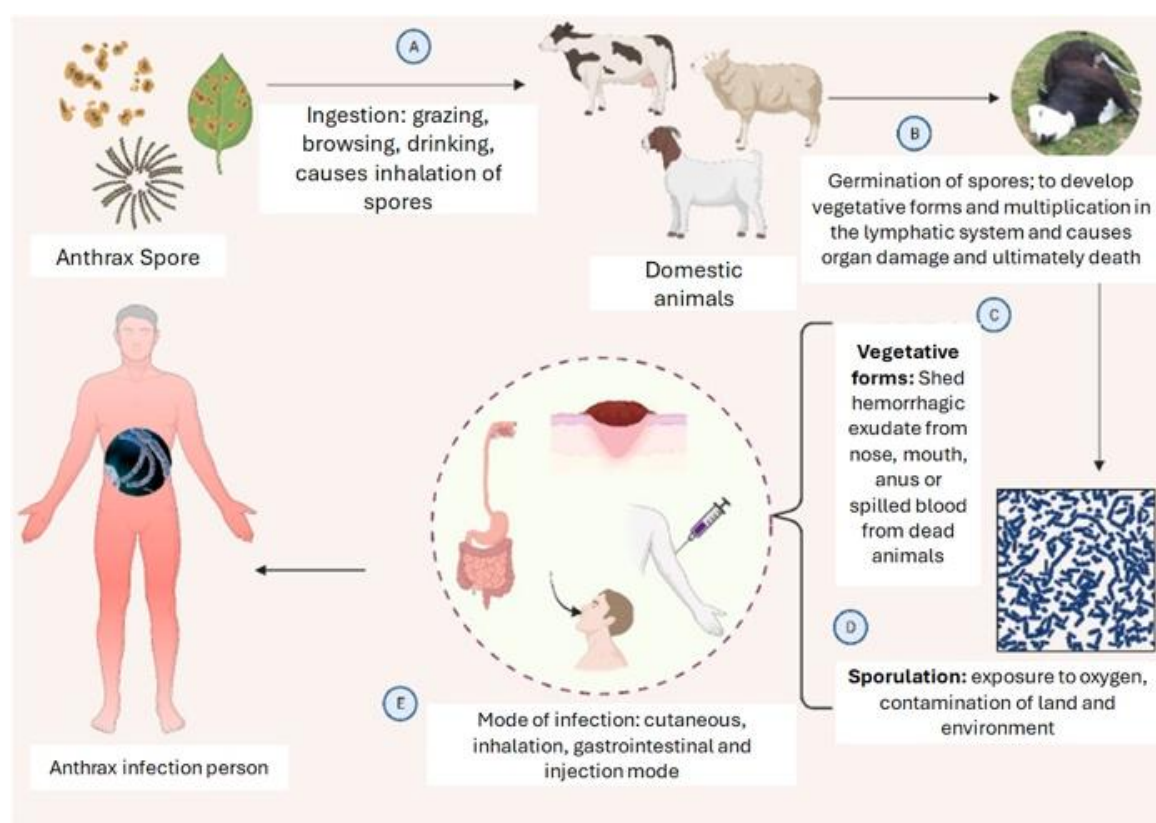


Figure 1 Pathogenesis of anthrax infection in humans and other host organisms caused by *B. anthracis* (Ashique et al., 2024).

Virulence determinants are primarily mediated by two plasmids: pXO1 and pXO2. The pXO1 (182 kb) plasmid encodes the three key components of the anthrax toxin: lethal factor (LF), a zinc-dependent metalloprotease; edema factor (EF), a calmodulin-dependent adenylate cyclase; and protective antigen (PA), which facilitates the entry of LF and EF into host cells by suppress host cellular immune responses and cytokine production. The combination of PA with EF forms edema toxin, while PA with LF forms lethal toxin. These toxins act synergistically to disrupt host cellular signaling, induce tissue damage, and

ultimately cause the hallmark symptoms of the disease. The pXO2 plasmid (96 kb) encodes enzymes responsible for the biosynthesis of a poly-D-glutamic acid capsule, which enables the bacterium to evade phagocytosis and survive within macrophages—a critical step in the establishment and progression of disease. Both toxin and capsule are a key determinant of virulence and are primarily responsible for the characteristic clinical manifestations of anthrax. However, the loss of one or both plasmids results in a significant attenuation of *B. anthracis* virulence (Pilo & Frey, 2011; Zasada, 2020).

Clinical Presentations of Anthrax

Anthrax in human manifests in three classical clinical forms: cutaneous, gastrointestinal, and inhalational anthrax. The clinical severity depends on several factors, including the host's immune status, the infectious dose, and the bacterial virulence. Mortality is low with prompt administration of appropriate antibiotics. However, untreated or inadequately managed cases may progress to systemic infection, with complications including sepsis or meningoencephalitis due to hematogenous dissemination of the pathogen (Ashique et al., 2024; Doganay et al., 2023).

Cutaneous anthrax comprises over 95% of reported human cases, typically arising from direct contact with *B. anthracis* spores from infected animals or contaminated products (e.g., hides, wool, meat). Approximately four days post-infection, an initial papule progresses to a vesicle with surrounding erythema and edema, evolving into a painless black necrotic eschar, the disease's hallmark lesion. Prompt antimicrobial therapy yields mortality <2%, though untreated cases or those with systemic complications may reach 30% (Dhliwayo et al., 2022). Clinically, it mimics diverse dermatologic, infectious, and zoonotic conditions, including staphylococcal/streptococcal infections, erysipelas, orf virus, syphilitic chancre, cutaneous tuberculosis, ecthyma gangrenosum, tularemia, plague, glanders, rickettsial infections, and rat-bite fever. It requires meticulous differential diagnosis (Doganay et al., 2023).

Gastrointestinal anthrax typically results from the ingestion of food or beverages contaminated with *B. anthracis*, most commonly undercooked or raw meat from infected animals. Gastrointestinal anthrax manifests 1-7 days post-exposure along the tract, primarily as oropharyngeal or intestinal forms. Oropharyngeal anthrax features fever, sore throat, dysphagia, hoarseness, painful cervical lymphadenopathy, soft tissue edema, and neck swelling. Intestinal anthrax presents with fever, nausea, vomiting, anorexia, and

diarrhea, rapidly progressing to acute abdominal pain, hematemesis, bloody diarrhea, and massive ascites. These manifestations often culminate in toxemia, septic shock, and high mortality without prompt treatment; lesions predominantly affect the terminal ileum and cecal mucosa (Doganay et al., 2023). The outbreaks of gastrointestinal anthrax are often linked to the consumption of undercooked contaminated meat and have been reported in several regions, including Zimbabwe (December 2021 - February 2022) (Dhliwayo et al., 2022), Uganda (June - December 2023) (Tumusiime et al., 2025) and Thailand (Sirisanthana & Brown, 2002). While the reported mortality rate can reach approximately 74%, early diagnosis and timely administration of appropriate antibiotics substantially reduce the risk of fatal outcomes (Doganay et al., 2023).

Inhalation anthrax results from the inhalation of aerosolized spores and has historically been associated with occupational exposure during the processing of contaminated wool, hides, or hair, hence the term “Woolsorter’s disease.” It represents the most severe form of anthrax and has also been implicated in industrial accidents and bioterrorism events. The incubation period is typically up to 7 days, with initial nonspecific influenza-like symptoms, followed by rapid progression to a fulminant phase characterized by severe respiratory distress, toxemia, and mediastinal widening due to hemorrhagic lymphadenitis. Without prompt treatment, the disease rapidly advances to septic shock and death, with mortality exceeding 80% in untreated cases (Bower et al., 2022; Doganay et al., 2023). Experimental models estimate the inhalational LD₅₀ at approximately 8.1×10^3 CFU, highlighting its high virulence (Taft et al., 2020).

Injectional anthrax is a recently recognized clinical form, primarily reported among intravenous drug users. It resembles cutaneous anthrax but involves deeper soft tissues, resulting in extensive necrosis and a high risk of systemic dissemination. Clinical manifestations often include severe soft tissue infections (e.g., necrotizing fasciitis, gas gangrene, or cellulitis), toxemia, and sepsis (Doganay et al., 2023). Reported mortality is approximately 25%, with higher case-fatality rates observed during outbreaks, such as among heroin users in Europe between 2000 and 2012 (Hanczaruk et al., 2014). Although no outbreaks of injectional anthrax have been reported in Thailand to date, the severity of the disease necessitates precise diagnostic protocols to confirm suspected cases and facilitate the implementation of targeted therapeutic interventions.

Transmission of Anthrax in Thailand

Globally, approximately 1.83 billion people and 1.1 billion livestock inhabit regions at risk for anthrax infection. Sporadic epizootics among livestock and wild ungulates are reported across the world, with an estimated 20,000 to 100,000 human cases of anthrax, predominantly affecting rural populations in East and South Asia where livestock vaccination coverage remains limited, and anthrax control strategies are often reactive rather than preventive, contributing to ongoing disease transmission and periodic outbreaks (Wassie et al., 2022). Therefore, livestock vaccination and control strategies are important for preventing outbreaks.

In Thailand, the incidence of human anthrax was estimated at 0.17 cases per 100,000 population, with the majority of reported cases occurring in the northern and northeastern regions, bordering the Lao People's Democratic Republic and Myanmar (Nagachinda, 1990). Human anthrax cases in Thailand have been documented from 1983 to 2025 (Table 1).

Table 1 Timeline of Human Anthrax Cases in Thailand, 1983-2025

Years/Area	Outcomes	References
First recorded outbreak 1983; Phayao Province	Cutaneous anthrax: 5 Males patients had participated in the slaughter of water buffaloes. Symptoms are bruising on the fingers, fever, headache, and localized pruritus. All patients recovered following appropriate medical intervention. Epidemiological investigations indicated that the infected buffalo had been imported from Dok Khamtai District, although the exact origin of the animal could not be conclusively verified.	Division of Epidemiology (2025)
1984; Kanchanaburi Province	Between 1984 and 1989, 84 cases of cutaneous anthrax were reported in Kanchanaburi Province, with 83.3% of cases occurring in males.	Nagachinda (1990)
1985; Kanchanaburi Province	Nine individuals were exposed to infected cattle. Among them, seven developed cutaneous anthrax, presenting with inflamed skin and characteristic black eschars, while two developed gastrointestinal anthrax, characterized by fever, headache, severe abdominal pain, and bloody diarrhoea. All patients recovered following appropriate medical intervention.	Epidemiologist, Kanchanaburi Public Health Office (1985)

Table 1 Timeline of Human Anthrax Cases in Thailand, 1983-2025 (Continued)

Years/Area	Outcomes	References
1985; Ratchaburi Province	Seven cases of cutaneous anthrax. Lesions initially appeared as papules on the hands and subsequently progressed to necrotic eschars. In response, local authorities implemented preventive measures, including the suspension of dead animal product imports and the enforcement of carcass disposal protocols such as burial and incineration.	Epidemiologist, Ratchaburi Provincial Public Health Office & Bureau of Epidemiology, Ratchaburi (2025)
1990 Northeastern	Fourteen individuals who were infected after handling or consuming meat from water buffaloes. The outbreak occurred in two villages, with an incubation period ranging from 2 to 11 days. Among the affected individuals, one patient succumbed to gastrointestinal anthrax following the onset of hematemesis, while the remaining cases predominantly cutaneous anthrax responded favourably to penicillin therapy. Notably, one patient developed the characteristic black eschar lesions associated with cutaneous infection.	Kunanusont et al. (1990)
Recent Outbreak 2025; Mukdahan Province	Three male patients, one of whom succumbed to the infection. Clinical manifestations included darkening eschars on the hands, lymphadenopathy, and seizures. Epidemiological investigation identified a total of 638 individuals at risk: 36 worked in a slaughterhouse, 472 had consumed potentially contaminated meat, and 130 had contact with slaughterhouse workers. As a preventive measure, doxycycline prophylaxis was administered for seven days and extended up to 60 days for high-risk contacts, under the supervision of local health authorities.	WATCH Team, Department of Disease Control (2025a)
2025; Amnat Charoen Province and Northern	10 individuals were suspected of anthrax infection, including two from Amnat Charoen Province and others from northern provinces. All affected individuals had a history of consuming raw meat, working on farms, or direct contact with infected animals, with ages ranging from 29 to 73.	WATCH Team, Department of Disease Control (2025b)

Diagnosis of Anthrax

Following the clinical manifestations described above, laboratory confirmation is essential for the definitive diagnosis of anthrax. The diagnosis is initially guided by clinical suspicion, supported by a detailed assessment of patient history and risk factors in accordance with WHO guidelines, including recent travel to endemic areas, occupational exposure to livestock or animal products, and contact with infected or deceased animals. Confirmation is established using a combination of microbiological, immunological, and molecular methods (Ashique et al., 2024).

In clinical laboratories, the initial diagnostic approach for suspected anthrax typically involves microscopic examination of stained blood smears to screen as large, square-ended, encapsulated, Gram-positive rods by staining techniques such as Gram, Giemsa, or polychrome methylene blue. The suspected specimens should be referred to a reference laboratory for confirmatory testing and biosafety-level-appropriate handling (Ochai et al., 2024).

At the reference laboratory level, culture method is performed on blood agar, where colonies appear non-hemolytic, gray-white, and display a characteristic ground-glass or “Medusa head” appearance. Additional confirmatory phenotypic features include susceptibility to ϕ -phage, sensitivity to penicillin, and distinct colony morphology. To enhance isolation efficiency, selective media such as PLET (Polymyxin-lysozyme-EDTA-thallos acetate) agar and TSPBA (Tryptic Soy Polymyxin Blood Agar) have demonstrated superior performance compared to conventional blood agar (Ashique et al., 2024).

Serological and immunological assays play a crucial role in detecting host antibody responses or bacterial toxin components associated with *B. anthracis* infection. The enzyme-linked immunosorbent assay (ELISA) remains one of the most widely employed techniques for identifying antibodies directed against the surface antigens; however, cross-reactivity with closely related species, particularly *B. cereus*, may limit its specificity. A unique tetra-saccharide surface antigen, known as anthrose, which is exclusively present in *B. anthracis*, has been proposed as a species-specific diagnostic marker (Ashique et al., 2024). Complementary approaches such as Western blot analysis and commercial antigen detection kits have been developed and validated for the detection of antibodies against the principal toxin components, PA, EF, and LF (Schwarz et al., 2017). Among these, the BioThreat Alert™ lateral flow assay demonstrates

excellent diagnostic performance, with a sensitivity of 100%, specificity of 98.77%, and overall accuracy of 98.97% (Pillai et al., 2019). Similarly, the Active Anthrax Detect (AAD) rapid test exhibits 98% sensitivity and 82% specificity, supporting its use as a rapid screening tool in field or outbreak settings (Kolton et al., 2019).

Molecular diagnostic techniques, particularly polymerase chain reaction (PCR) and real-time PCR, have become the cornerstone for the rapid and definitive identification of *B. anthracis* DNA, include *pagA* (protective antigen gene on plasmid pXO1), *capA* and *capB* (capsule biosynthesis genes on plasmid pXO2), and *Ba813* (a chromosomal marker). These assays exhibit high specificity and sensitivity, enabling reliable confirmation of anthrax in both clinical specimens and environmental samples (Ashique et al., 2024).

Recent developments in isothermal DNA amplification technologies have introduced rapid, field-deployable diagnostic platforms that eliminate the need for thermocycling equipment. Among these, Loop-mediated Isothermal Amplification (LAMP), Helicase-dependent Amplification (HDA), and Recombinase Polymerase Amplification (RPA) have demonstrated substantial diagnostic potential. These methods are particularly advantageous in cases where prior antibiotic administration may suppress bacterial growth and compromise culture-based detection.

Beyond nucleic acid-based assays, several advanced immunodiagnostic platforms have emerged for the detection of anthrax antigens or antibodies. These include flow cytometry using fluorescently labeled antibodies, Förster Resonance Energy Transfer (FRET) assays, Luminex multiplex immunoassays, Magnetic Particle Fluorogenic Immunoassays (MPFIA), and Antibody Immuno Column for Analytical Processes (ABICAP) systems. Although antibody-based lateral flow devices have demonstrated practical utility for environmental surveillance and field screening, they currently lack the sensitivity and specificity required for clinical diagnostic applications (Doganay et al., 2023).

Treatment of Anthrax

According to WHO guidelines, the use of personal protective equipment (PPE) is essential when managing suspected or confirmed anthrax cases. Treatment depends on disease severity: uncomplicated cases are typically managed with monotherapy, whereas severe or systemic forms require combination therapy with at least two antimicrobial

agents. First-line agents include ciprofloxacin, doxycycline, ampicillin, or penicillin G, selected based on local susceptibility patterns. Adjunctive agents such as clindamycin, rifampicin, or gentamicin are recommended for severe manifestations, including inhalational, gastrointestinal, or complicated cutaneous anthrax. Post-exposure prophylaxis (PEP) consists of oral antibiotics administered for approximately 42 to 60 days following suspected exposure. Antimicrobial therapy remains the cornerstone of anthrax management; however, the potential emergence of antimicrobial resistance remains a concern (WHO, 2025b).

Recently, in addition to antimicrobial agents, several antitoxin therapies have been approved by the U.S. Food and Drug Administration (FDA) for the treatment of anthrax, particularly in cases associated with systemic toxemia. Raxibacumab, a fully human IgG1 λ monoclonal antibody that binds specifically to PA, thereby blocking the cellular entry of LF and EF. Anthrax Immune Globulin Intravenous (AIGIV), a purified human polyclonal IgG preparation containing antibodies directed against PA, which enhances host immune defense mechanisms. ETI-204, a monoclonal antibody designed to neutralize the PA, preventing toxin internalization and mitigating disease progression (Couse et al., 2021). These immunotherapeutic agents serve as critical adjuncts to antibiotic therapy, particularly in severe or systemic cases, where early administration significantly improves clinical outcomes.

A comprehensive review by Maxson et al. (2022), revealed that *B. anthracis* isolates collected in USA between 1947 and 2019, remain highly effective for both therapeutic use and PEP to fluoroquinolones, tetracyclines, and β -lactams. Moreover, the efficacy of orally administered amoxicillin in combination with amoxicillin/clavulanate in monkeys after *B. anthracis* exposure revealed that the treated animals survived beyond 60 days. This study underscores the potential utility of these combinations for human post-exposure therapy (Slay et al., 2022).

In the outbreaks in Thailand, empirical antibiotic therapy should be initiated upon clinical suspicion, with regimens tailored to disease presentation, severity, and local resource availability. For suspected gastrointestinal exposure, a 60-day course of oral prophylaxis may be considered. PEP should be administered promptly, with doxycycline or ciprofloxacin as first-line agents (WATCH Team, Department of Disease Control, 2025; WHO, 2025a).

However, the management of anthrax differs from that of typical bacterial infections due to its toxin-mediated pathogenesis, the potential for antimicrobial resistance, and the relatively high risk of associated meningitis.

Prevention of Anthrax

Effective anthrax prevention relies on early intervention and risk mitigation, particularly among populations with a high likelihood of exposure. For high-risk groups, the use of PPE, including gloves, masks, protective clothing, and boots, is essential to minimize exposure to spores. In addition, PEP, comprising antimicrobial therapy and vaccination, represents a critical component of prevention strategies (Sidwa et al., 2020; WHO, 2025b).

Several vaccines have been developed to target distinct stages of the pathogen's virulence and host-pathogen interaction mechanisms. The Anthrax Vaccine Adsorbed (AVA; BioThrax), developed in the USA, is a cell-free filtrate of the *B. anthracis* V770-NP1-R strain, containing the PA as the primary immunogen. It is administered intramuscularly as a multi-dose primary series, followed by periodic booster doses to maintain long-term protective immunity. BioThrax remains the most widely used anthrax vaccine in Thailand (Tangsathapornpong, n.d.). The Anthrax Vaccine Precipitated (AVP), used primarily in the United Kingdom, is produced from a cell-free culture filtrate of the *B. anthracis* Sterne 34F2 strain. It contains PA, LF, and trace amounts of EF, thereby eliciting a broader immune response compared with PA-based vaccines alone. Similar to AVA, AVP requires a series of primary doses followed by booster injections to ensure sustained protection. The Live Anthrax Vaccine (LAV), developed in Russia, consists of non-encapsulated live spores from *B. anthracis* STI-1 and No. 3 strains. The vaccine is administered cutaneously or subcutaneously and requires annual booster doses. Owing to its live, attenuated composition, its use is restricted to endemic regions and occupational groups at persistent risk of exposure (Sangwan et al., 2025).

Therefore, an integrated anthrax prevention strategy should combine public education, livestock vaccination, safe carcass disposal, and targeted immunization of high-risk personnel. Strengthening surveillance systems, enhancing laboratory diagnostic capacity, and fostering regional cooperation in transboundary disease control are also vital to reducing the public health and economic burden of anthrax.

Conclusion

Anthrax is an acute zoonotic disease caused by *B. anthracis*. In Thailand, human and animal cases have historically been concentrated in the northern and northeastern regions, frequently associated with the importation of infected livestock. Although large-scale outbreaks have been uncommon since 1983, the emergence of new cases in Mukdahan Province in 2025 highlights the persistent risk of re-emergence and the necessity for continuous surveillance and effective control measures. The cornerstone of anthrax treatment remains the prompt administration of appropriate antimicrobial agents, with therapeutic regimens adjusted according to the clinical form and severity of infection. Effective prevention and control require an integrated, multisectoral strategy encompassing public health education, routine livestock vaccination, safe carcass disposal practices, and vaccination of high-risk occupational groups. The BioThrax formulation is the primary vaccine approved and administered in Thailand. The understanding of the disease and its epidemiology is crucial for the development of effective control and preventive strategies, including therapeutics and vaccines targeting *B. anthracis* in Thailand.

Therefore, an integrated strategy for anthrax prevention must weave together public awareness campaigns, livestock vaccination programs, and rigorous protocols for carcass disposal, while ensuring high-risk workers receive targeted immunizations. To effectively mitigate the disease's medical and economic impact, it is equally essential to bolster surveillance networks, upgrade laboratory diagnostic capacity, and maintain cross-border partnerships to manage transboundary transmission.

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