

Advanced Biochemical Threats: The Role of Genetic Engineering in Bioterrorism and Countermeasures

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Abstract

Replace 'Bioterrorism remains a critical global security concern as advances in biotechnology and genetic engineering have expanded the potential to manipulate pathogens for hostile purposes. The deliberate modification of microorganisms through techniques such as recombinant DNA and CRISPR/Cas9 has raised new ethical and security challenges by enhancing virulence, drug resistance, and detection evasion. This study aimed to provide a comprehensive synthesis of current knowledge on the biochemical foundations of bioweapons, the influence of genetic engineering on their evolution, and the countermeasures necessary to mitigate related risks. A systematic review of peer-reviewed literature and credible reports from databases such as PubMed, Google Scholar, JSTOR, and Web of Science was conducted, focusing on the history, mechanisms, and biosecurity implications of genetically engineered pathogens. Key findings reveal that biological agents like Bacillus anthracis, Yersinia pestis, influenza viruses, and ricin toxins have historically served as potential bioweapons and that modern genetic tools significantly increase their lethality and resilience. The study also contextualizes the ongoing debate about the origins of SARS-CoV-2, noting that while some theories suggest laboratory manipulation, the prevailing scientific consensus supports a natural zoonotic origin. Furthermore, the review emphasizes that although global initiatives such as the Biological Weapons Convention have reduced overt bioweapon programs, gaps in surveillance and preparedness persist, particularly in developing regions such as Africa. Overall, the findings underscore that while genetic engineering offers immense benefits for science and medicine, it simultaneously amplifies bioterrorism risks, necessitating stronger international collaboration, bioethical governance, and technological safeguards to prevent misuse and ensure global health security.'

Keywords: Bioweapons, Covid-19, Bioterrorism, Genetic Engineering

1. Introduction

The rise of bioterrorism as a global threat has prompted increased scrutiny and research into the use of biological agents for hostile purposes. Bioweapons—biological agents such as bacteria, viruses, or toxins—are intentionally used to cause harm to humans, animals, or plants. These agents can spread rapidly, causing widespread disease and panic, and their use in warfare or terrorism poses significant risks to public health and safety [1,2]. Biological weapons are defined as pathogens or toxins deliberately deployed to inflict disease or death on a large scale. Historically, the use of biological agents dates back to ancient times when adversaries poisoned wells or spread diseases to weaken enemies [3]. In the 20th century, advances in microbiology and genetics transformed the field of bioweapons, making them more potent and difficult to detect [4,5]. Notable historical instances include the use of anthrax

and plague in warfare, and the development of sophisticated bioweapons programs during the Cold War [6-9].

In recent decades, the threat of bioterrorism has escalated due to advancements in genetic engineering and synthetic biology. The ability to manipulate genes and create novel pathogens has increased the potential for bioweapons to be used in both state and non-state actor scenarios [10]. For instance, the 2001 anthrax attacks in the United States demonstrated the potential for bioweapons to cause widespread fear and disruption, even though the attacks were relatively limited in scope [11,12]. Genetic engineering, particularly techniques such as CRISPR/Cas9, has revolutionized molecular biology and biotechnology. These advancements allow for precise modifications of the genomes of various organisms, including pathogens. While these technologies offer significant benefits for

medicine and agriculture, they also pose risks if misused [13]. The potential to create genetically engineered bioweapons with enhanced virulence, drug resistance, or novel properties underscores the need for stringent biosecurity measures and ethical oversight [10,14].

The outbreak of COVID-19, caused by the novel coronavirus SARS-CoV-2, has sparked debates about its origins and potential as a bioweapon. Theories range from natural zoonotic transmission to accidental release from a laboratory [15,16]. While most scientific evidence supports a natural origin, some speculative theories suggest the virus could be a product of genetic engineering [17,18]. The World Health Organization and various scientific studies have largely refuted the bioweapon theory, emphasizing the need for continued research to understand the virus's origins and mitigate future risk [19]. This study aimed to provide a comprehensive analysis of bioweapons, focusing on the history, current trends, and implications of genetic engineering. It also examined the COVID-19 pandemic in the context of bioweapon theories, evaluating the scientific evidence and implications for future biosecurity. By synthesizing current research and expert opinions, this review seeks to enhance understanding and inform strategies for preventing and mitigating bioterrorism.

2. Methodology

2.1. Literature Search Strategy

A comprehensive literature search was conducted to gather relevant information on the use of bioweapons, genetic engineering, and the COVID-19 pandemic. The following databases were utilized: PubMed (for peer-reviewed biomedical and life sciences literature), Google Scholar (for grey literature and a broader search), JSTOR (for historical and theoretical perspectives), and Web of Science (for multidisciplinary research and citation tracking).

The search strategy included combinations of the following keywords: "bioterrorism," "bioweapons," "genetic engineering," "CRISPR/Cas9," "SARS-CoV-2," "COVID-19 origin," "bioweapon theory," and "biosecurity measures."

Inclusion Criteria:

- Peer-reviewed journal articles.
- Publications from the last two decades to ensure relevance.
- Articles in English or with English translations available.
- Studies providing empirical data, theoretical insights, or case studies relevant to bioweapons and genetic engineering.

Exclusion Criteria:

- Non-peer-reviewed articles and opinion pieces.
- Publications with insufficient data or methodological rigor.
- Articles not directly related to the core topics of the review.

2.2. Data Extraction and Analysis

Data were extracted from selected articles focusing on the use and

history of bioweapons, genetic engineering techniques and their applications, theories on the origin of COVID-19, including lab-based and natural origin theories. Opinions and evidence regarding COVID-19 as a potential bioweapon were also involved. Comparative tables were created to synthesize data on different origin theories of COVID-19 and opinions on its potential as a bioweapon. Trend analysis was utilized in identifying patterns and trends in bioweapon research, including advancements in genetic engineering and biosecurity measures. Critical evaluation was used to assess the credibility and relevance of the sources, noting any biases or limitations.

2.3. Case Studies and Real-World Examples

Case studies were reviewed to provide real-world context. Recent instances of bioterrorism and biosecurity breaches, historical and contemporary examples of bioweapons use, relevant incidents involving genetic engineering and its misuse were reviewed. The sources for case studies were reports from health organizations (e.g., WHO, CDC), government and intelligence agency publications, peer-reviewed case studies and reviews from credible journals.

2.4. Synthesis and Presentation

Information was synthesized to address key themes and questions such as the effectiveness and history of bioweapons, advances and potential risks of genetic engineering technologies, and the validity and implications of COVID-19 origin theories. Findings were organized into: Comparative tables summarizing evidence and opinions, and narrative summaries that contextualize findings within current scientific and geopolitical discussions.

3. Discussion

Table 1 shows that a wide range of biological agents, such as *Bacillus anthracis*, Influenza virus, and botulinum toxins, are widely acknowledged as potential bioweapons. These pathogens are highly lethal, rapidly transmissible, and can be delivered through multiple routes such as air, water, and food supplies. Additionally, the data reflects that genetically engineered pathogens—particularly through recombinant DNA technology—pose even greater threats due to their potential for enhanced drug resistance, evasion of immune responses, and improved stability in the environment.

Bacillus anthracis, with its three key toxins (Protective Antigen, Edema Factor, and Lethal Factor), is highlighted as a potent bioweapon. Its genetic modification for antibiotic resistance, as demonstrated in some historical examples, further enhances its danger, making it an ideal candidate for bioterrorism [20]. Influenza virus, the causative agent of Influenza, can be engineered to resist multiple antibiotics, making outbreaks difficult to contain. The historical data from Madagascar in 1995 illustrates how the introduction of multidrug-resistant plasmids into these pathogens significantly heightened their bioweapon potential [21,22].

Type of Bioweapon	Agent	Historical Examples	Impact	References
Bacteria	Bacillus anthracis	Anthrax used in World War I and the 2001 anthrax attacks	Severe infections, high mortality if untreated	Riedel, 2005; Inglesby et al., 2020
Viruses	Influenza virus	United States Bioweapons Program (1940s–1969) bioweapon development in USSR	Epidemics with high fatality rates	Davis & Singh, 2020; Alibek & Handelman, 1999
Toxins	Ricin	Used in assassinations during Cold War	Severe poisoning, high lethality in small doses	Tiwari et al., 2019; Choi & Lee, 2021

Table 1: Types of Bioweapons and Historical Use

Genetic engineering has played a pivotal role in enhancing the virulence and transmissibility of biological agents (Table 2). The analysis of genetically engineered pathogens indicates an alarming trend in the use of molecular techniques to increase the potency of these organisms. For instance, *Francisella tularensis*, the bacterium responsible for tularemia, was altered by inserting a gene encoding beta-endorphin to produce confusing symptoms in victims Borzenko et al., 1993. The manipulation of genes in this manner makes diagnosis more difficult, delaying treatment and contain-

ment. Such findings illustrate the sophisticated use of genetic engineering for offensive purposes.

Furthermore, the insertion of antibiotic resistance genes into bacteria like *Bacillus anthracis* and *Yersinia pestis* demonstrates how bioweapons can evade existing treatment protocols. This heightens the global risk of large-scale infections that may be uncontrollable due to the lack of effective antibiotics.

Technology	Application	Potential Bioweapon Use	Implications	References
CRISPR/Cas9	Gene editing	Creation of drug-resistant pathogens	Increased difficulty in treatment	Doudna & Charpentier, 2014;
Synthetic Biology	Construction of novel pathogens	Development of pathogens with novel properties	Unpredictable impacts, higher risk of outbreaks	Trump et al., 2021; Jefferson et al., 2021
Recombinant DNA	Genetic modification of existing organisms	Enhancing the pathogenicity of bacteria and viruses	More severe and resistant biological threats	Mahdizade et al., 2024; Khan et al., 2016

Table 2: Advances in Genetic Engineering and Potential Bioweapon Applications

The COVID-19 pandemic has brought renewed attention to bioweapon theories, including speculation about the origins of SARS-CoV-2 (Table 3). This study evaluated evidence regarding the natural versus laboratory origins of the virus and its implications for biosecurity. The majority of scientific evidence supports a zoonotic origin for SARS-CoV-2, with bats and other wildlife as

potential reservoirs. However, concerns about laboratory accidents and biosecurity breaches have been raised, particularly due to the virus’s rapid spread and severity [23,17]. Despite speculative theories, current research and expert consensus suggest that while the virus’s origins warrant further investigation, there is no substantial evidence to classify it as a bioweapon [18,24].

Theory	Evidence	Scientific Consensus	Implications	References
Natural Zoonotic Origin	Evidence of bat and wildlife reservoirs	Supported by majority of studies	Emphasizes the need for wildlife monitoring and pandemic preparedness	Ellwanger and JAB., 2020; Olival et al., 2020
Laboratory Accident	Speculative and unconfirmed	No conclusive evidence, but warrants further investigation	Highlights the importance of biosecurity in laboratories	V'kovski et al., 2020; World Health Organization, 2020

Table 3: COVID-19 Origin Theories and Evidence

This study has provided a comparative view of bioterrorism incidents globally and in Africa, highlighting the increasing use of biological weapons (Table 4). While documented cases of bioterrorism in Africa are sparse compared to other regions, there is significant concern over terrorist groups like Boko Haram and their potential access to bioweapons. The increasing sophistication of such groups and their international affiliations suggest that Africa could be at high risk if bioweapons are utilized. This geographical analysis shows that while Western nations have focused heavily on bioterrorism defense, the lack of preparedness in African countries may leave them vulnerable to devastating bioterrorism attacks. The review highlights the need for stronger defensive measures, including improved surveillance and biodefense infrastructure.

In Ethiopia, historical instances of bioweapon use are minimal, with most references relating to natural outbreaks rather than deliberate acts. However, ongoing internal conflicts and limited surveillance capacities create a potential vulnerability to bioterrorism, especially in volatile regions where state control is weak. Although infrastructural and technical capabilities for bioweapon development are limited, regional instability could create opportunities for non-state actors to exploit biological agents, particularly through rudimentary or externally sourced methods. Ethiopia has initiated regional biosecurity and emergency response plans, yet these efforts are often underfunded and dependent on international support.

Nigeria faces a more pronounced threat. The presence of organized extremist groups such as Boko Haram and ISWAP (Islamic State West Africa Province), combined with ongoing internal conflict, elevates the risk profile. These groups may theoretically consider biological agents as terror tools due to their potential for mass dis-

ruption. However, their current tactics focus more on conventional methods—bombings, kidnappings, and armed assaults—largely due to lower cost, accessibility, and reliability compared to bioweapons. The development or use of bioweapons requires scientific expertise, access to pathogens, laboratory infrastructure, and knowledge of safe handling procedures—all of which are likely beyond the current capacities of such groups. Nevertheless, Nigeria’s high population density and limited public health infrastructure heighten the potential impact of a biological attack, making improved surveillance and international cooperation crucial components of its prevention strategy.

South Africa, despite having no significant history of bioweapon use, possesses advanced industrial and scientific infrastructure that could, in theory, be repurposed for biological weapons production. The country’s developed economy and technological base make it more susceptible to internal misuse or cyber-biothreats, particularly if rogue actors gain access to research facilities. However, South Africa maintains strict biosecurity protocols and regulatory oversight, which serve as strong deterrents. Its historical engagement with global non-proliferation agreements further reinforces its commitment to preventing misuse of biological materials. Addressing the feasibility of bioterrorism in these contexts, it is essential to note that the development and deployment of biological agents is not only technically complex but also risky for the perpetrators. Improper handling can lead to self-infection or uncontrollable spread, posing a threat to both users and unintended populations. Moreover, terrorist groups may often find conventional methods of attack more accessible, cost-effective, and symbolically powerful than biological alternatives.

Country	Historical Instances	Current Threats	Preventive Measures
Ethiopia	Limited historical use, mainly natural outbreaks	Potential for bioterrorism in conflict areas	Enhanced regional biosecurity and response plans
Nigeria	Potential use in conflicts (e.g., Boko Haram)	High risk due to ongoing conflicts and instability	Improved surveillance and international cooperation
South Africa	No significant historical bioweapon use	Risk of bioterrorism due to industrial capabilities	Strict biosecurity protocols

Table 4: Comparative Analysis of Bioweapon Threats in Africa

Table 5 outlines five key defensive measures against bioweapons—Decontamination, Detection, Prevention, Protection, and Treatment—each contributing to a layered approach to mitigating the risk and impact of bioterrorism. Decontamination involves methods used to neutralize or remove biological agents from contaminated environments. Common techniques include the use of chemical disinfectants (e.g., bleach solutions), thermal deactivation through high heat, and ultraviolet (UV) radiation. These strat-

egies are crucial for long-term safety, especially after a confirmed biological incident. For example, following the 2001 anthrax attacks in the United States, extensive chemical decontamination of affected mailrooms and offices was required. However, the effectiveness of decontamination depends heavily on timely application and environmental factors.

Detection systems are essential for the rapid identification of bio-

weapon exposure, enabling timely responses. Notable examples include:

- SMART (Sensitive Membrane Antigen Rapid Test), which detects specific pathogens quickly in field conditions,
- JBPDS (Joint Biological Point Detection System), used by the U.S. military for real-time biological monitoring,
- BIDS (Biological Integrated Detection System), a vehicle-mounted system for broader environmental surveillance.

While these systems represent technological advancements, their effectiveness varies. Some offer rapid results but are limited in pathogen range or sensitivity, while others are more comprehensive but slower, highlighting the need for continued development.

Prevention refers to proactive strategies aimed at reducing the likelihood of bioweapon development or deployment. This includes international legal frameworks such as:

- The Biological Weapons Convention (BWC) of 1972, which prohibits the development, production, and stockpiling of biological weapons,
- The United Nations Security Council Resolution 1540 (2004), which obligates member states to prevent non-state actors from acquiring WMDs, including bioweapons,
- Ongoing intelligence and biosurveillance efforts led by agencies

like the WHO and Interpol.

While these treaties and initiatives contribute to global norms against bioweapons, enforcement and compliance remain challenges, especially in politically unstable regions. Protection mechanisms aim to shield individuals and communities during a biological event. This includes personal protective equipment (PPE) such as gas masks, biosafety suits, and filtration systems. These measures are particularly valuable for first responders and medical personnel, providing immediate, albeit temporary, protection against airborne or contact-spread agents. However, their effectiveness is contingent on correct usage, maintenance, and availability during emergencies.

Treatment encompasses medical interventions such as vaccines, antiviral medications, and antibiotics. For example, the anthrax vaccine and ciprofloxacin (an antibiotic) were used effectively during the 2001 anthrax incidents. Timely diagnosis and access to appropriate countermeasures are critical for treatment success. In some cases, stockpiles like those maintained by the U.S. Strategic National Stockpile (SNS) offer rapid deployment of medical supplies during outbreaks, though such infrastructure is unevenly distributed globally.

Category	Description	Examples	Effectiveness
Decontamination	Methods to clean contaminated environments	Chemicals, heat, UV rays	Important for long-term safety and cleanup
Detection	Systems to identify bioweapon exposure	SMART, JBPDS, BIDS	Varies; some systems offer rapid detection
Prevention	Strategies to prevent the development or use of bioweapons	International treaties, intelligence monitoring	Effective in reducing the likelihood of use
Protection	Measures to protect individuals and communities	Protective suits, gas masks	Provides immediate, though limited, protection
Treatment	Medical interventions for exposure	Vaccines, antibiotics	Effective if administered promptly

Table 5: Defensive Measures against Bioweapons

The potential use of biological agents in bioterrorism presents significant risks to global health, security, and stability. This study has examined various aspects of bioterrorism, focusing on the biochemistry of potential bioweapons, genetic engineering implications, recent cases, and the ongoing debate about the origins of COVID-19.

3.1. Biochemical Mechanisms and Genetic Engineering

Bioweapons, including bacteria, viruses, and toxins, exploit biological mechanisms to inflict harm. *Bacillus anthracis*, the causative agent of anthrax, secretes three key proteins—protective

antigen (PA), edema factor (EF), and lethal factor (LF)—that collectively contribute to its virulence [7,25-26]. The genetic engineering of *B. anthracis*, particularly with drug-resistant properties, poses a severe threat due to the potential for untreatable infections [11,22,27-28]. Similarly, *Yersinia pestis*, the pathogen responsible for plague, has been genetically modified to resist multiple antibiotics, further complicating treatment and control measures [29].

The advent of recombinant DNA technology has significantly advanced the capabilities of bioweapons. Genetic engineering can enhance the virulence, transmissibility, and resistance of patho-

gens, making them more formidable threats [10,30]. For instance, the modification of ricin toxin to increase its potency and resistance underscores the potential dangers associated with biotechnological advancements [31-33].

3.2. Recent Cases of Bioterrorism

Recent global and regional incidents highlight the persistent threat of bioterrorism. Although there have been no confirmed bioterrorist attacks in Nigeria, the country remains vulnerable to such threats due to its geopolitical instability and the activities of militant groups like Boko Haram (James et al., 2022). The potential for bioterrorism in Nigeria is exacerbated by the ongoing conflict and limited resources for bioterrorism prevention and response [34,35]. Globally, incidents such as the 2001 anthrax attacks in the United States demonstrate the real and present danger of bioweapon utilization Hughes and Gerberding., 2002. These attacks not only caused widespread fear but also exposed vulnerabilities in public health preparedness and response systems.

3.3. COVID-19 and Bioterrorism Debate

The debate over the origins of SARS-CoV-2, the virus responsible for COVID-19, continues to be a topic of significant interest. While the World Health Organization (WHO) has largely dismissed the theory that COVID-19 is a bioweapon, the possibility of laboratory manipulation remains under investigation [36,18]. Genetic analysis of SARS-CoV-2 has revealed similarities with other coronaviruses, leading some to speculate about potential engineering or recombination events [37-39]. However, evidence supporting deliberate genetic modification is currently insufficient, and the prevailing view is that SARS-CoV-2 emerged from natural processes.

3.4. Defensive Measures and Future Directions

Effective defensive measures against bioweapons require a multi-faceted approach, including prevention, protection, detection, treatment, and decontamination. International treaties and disarmament efforts play a crucial role in mitigating the risk of bioweapons proliferation [40]. Enhanced surveillance systems, improved healthcare infrastructure, and advanced research in vaccine and therapeutic development are essential for combating potential bioterrorism threats [41]. Moving forward, there is a need for greater international collaboration and investment in bioterrorism defense. Governments and scientific communities must work together to strengthen regulations, improve detection technologies, and ensure transparency in biodefense programs [42]. The potential for misuse of biotechnology underscores the importance of maintaining stringent oversight and fostering global cooperation to safeguard against the proliferation of bioweapons.

4. Conclusion

While all bioweapon types pose significant threats, their strategic use has varied according to context, intent, and technological capability. Bacterial and viral agents are suited to mass-casualty scenarios, while toxins offer precision lethality. Understanding

historical applications aids in anticipating future threats and guiding preparedness efforts. While each the multi-tiered defensive frameworks against bioterrorism offers value, their success hinges on the integration of technology, international cooperation, public health readiness, and robust policy enforcement. A more nuanced understanding of these tools—alongside investments in education, infrastructure, and interagency coordination—is essential for strengthening global biodefense capabilities. Bioterrorism poses varied levels of threat across African countries but these risks are shaped by local factors such as political stability, access to technology, public health infrastructure, and the presence of violent non-state actors. Current preventive measures show promising direction but require enhanced investment, regional collaboration, and sustained international engagement to effectively mitigate these evolving threats.

• Funding

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• Data availability

All data generated or analyzed during this study are included in this article

• Ethics Declarations

• Ethics approval and consent to participate

This study does not require ethical approval.

• Consent for publication

Not applicable.

• Clinical Trial Number

Not Applicable

• Competing interests

The author declares no competing interest.

References

1. Tucker, J. B., & Hooper, C. (2006). Protein engineering: Security implications: The increasing ability to manipulate protein toxins for hostile purposes has prompted calls for regulation. *EMBO reports*, 7(S1), S14-S17.
2. Long, C. (2019). Biosecurity and biodefense. In *The Palgrave Encyclopedia of Global Security Studies* (pp. 1-8). Palgrave Macmillan, Cham.
3. Rathish, B., Pillay, R., Wilson, A., et al. (2023). Comprehensive review of bioterrorism. In *StatPearls* [Internet]. StatPearls Publishing.
4. Trump, B. D., Florin, M. V., Perkins, E., & Linkov, I. (2021). Biosecurity for synthetic biology and emerging biotechnologies: Critical challenges for governance. *Emerging Threats of Synthetic Biology and Biotechnology: Addressing Security and Resilience Issues*, 1-12.
5. Jefferson, C., Lentzos, F., & Marris, C. (2014). Synthetic biology and biosecurity: challenging the “myths”. *Frontiers in public health*, 2, 115.
6. Alibek, K. (1998). Terrorist and intelligence operations: potential impact on the US economy. *testimony provided before the Joint Economic Committee*, 20.
7. Alibek, K., & Handelman, S. (1999). Biohazard Random

- House. *New York*, 29-38.
8. Frischknecht, F. (2003). The history of biological warfare: Human experimentation, modern nightmares and lone madmen in the twentieth century. *EMBO reports*, 4(S1), S47-S52.
 9. Riedel, S. (2004, October). Biological warfare and bioterrorism: a historical review. In *Baylor University Medical Center Proceedings* (Vol. 17, No. 4, pp. 400-406). Taylor & Francis.
 10. Doudna, J. A., & Charpentier, E. (2014). The new frontier of genome engineering with CRISPR-Cas9. *Science*, 346(6213), 1258096.
 11. Riedel, S. (2005, July). Anthrax: a continuing concern in the era of bioterrorism. In *Baylor University Medical Center Proceedings* (Vol. 18, No. 3, pp. 234-243). Taylor & Francis.
 12. Bush, L. M., & Perez, M. T. (2012). The anthrax attacks 10 years later. *Annals of internal medicine*, 156(1_Part_1), 41-44.
 13. Mahdizade Ari, M., Dadgar, L., Elahi, Z., Ghanavati, R., & Taheri, B. (2024). Genetically engineered microorganisms and their impact on human health. *International Journal of Clinical Practice*, 2024(1), 6638269.
 14. Ledford, H. (2016). CRISPR: gene editing is just the beginning. *Nature*, 531(7593), 156-159.
 15. Ellwanger, J. H., & Chies, J. A. B. (2021). Zoonotic spillover: Understanding basic aspects for better prevention. *Genetics and molecular biology*, 44(1 Suppl 1), e20200355.
 16. Olival, K. J., Cryan, P. M., Amman, B. R., Baric, R. S., Blehert, D. S., Brook, C. E., ... & Wang, L. F. (2020). Possibility for reverse zoonotic transmission of SARS-CoV-2 to free-ranging wildlife: A case study of bats. *PLoS pathogens*, 16(9), e1008758.
 17. V'kovski, P., Kratzel, A., Steiner, S., Stalder, H., & Thiel, V. (2021). Coronavirus biology and replication: implications for SARS-CoV-2. *Nature Reviews Microbiology*, 19(3), 155-170.
 18. World Health Organization. (2020). *Origins of the SARS-CoV-2 virus*.
 19. Knight, D. (2021). COVID-19 pandemic origins: bioweapons and the history of laboratory leaks. *Southern medical journal*, 114(8), 465.
 20. Liu, S., Moayeri, M., & Leppla, S. H. (2014). Anthrax lethal and edema toxins in anthrax pathogenesis. *Trends in microbiology*, 22(6), 317-325.
 21. Lister, I. M., Meccas, J., & Levy, S. B. (2010). Effect of MarA-like proteins on antibiotic resistance and virulence in *Yersinia pestis*. *Infection and immunity*, 78(1), 364-371.
 22. Inglesby, T. V., Henderson, D. A., Bartlett, J. G., Ascher, M. S., Eitzen, E., Friedlander, A. M., ... & Working Group on Civilian Biodefense. (1999). Anthrax as a biological weapon: medical and public health management. *Jama*, 281(18), 1735-1745.
 23. Jo, W. K., de Oliveira-Filho, E. F., Rasche, A., Greenwood, A. D., Osterrieder, K., & Drexler, J. F. (2021). Potential zoonotic sources of SARS-CoV-2 infections. *Transboundary and emerging diseases*, 68(4), 1824-1834.
 24. Holmes, E. C., Goldstein, S. A., Rasmussen, A. L., Robertson, D. L., Crits-Christoph, A., Wertheim, J. O., ... & Rambaut, A. (2021). The origins of SARS-CoV-2: A critical review. *Cell*, 184(19), 4848-4856.
 25. Froude 2nd, J. W., Thullier, P., & Pelat, T. (2011). Antibodies against anthrax: mechanisms of action and clinical applications. *Toxins*, 3(11), 1433-1452.
 26. Bhatnagar, R., & Batra, S. (2001). Anthrax toxin. *Critical reviews in microbiology*, 27(3), 167-200.
 27. Dassanayake, M. K., Khoo, T. J., & An, J. (2021). Antibiotic resistance modifying ability of phytoextracts in anthrax biological agent *Bacillus anthracis* and emerging superbugs: a review of synergistic mechanisms. *Annals of clinical microbiology and antimicrobials*, 20(1), 79.
 28. Muteeb, G., Rehman, M. T., Shahwan, M., & Aatif, M. (2023). Origin of antibiotics and antibiotic resistance, and their impacts on drug development: A narrative review. *Pharmaceuticals*, 16(11), 1615.
 29. Lei, C., & Kumar, S. (2022). *Yersinia pestis* antibiotic resistance: a systematic review. *Osong Public Health and Research Perspectives*, 13(1), 24.
 30. Khalil, A. M. (2020). The genome editing revolution. *Journal of genetic engineering and biotechnology*, 18(1), 68.
 31. Vitetta, E. S., & Yen, N. (1990). Expression and functional properties of genetically engineered ricin B chain lacking galactose-binding activity. *Biochimica et Biophysica Acta (BBA)-Gene Structure and Expression*, 1049(2), 151-157.
 32. Leshin, J., Danielsen, M., Credle, J. J., Weeks, A., O'Connell, K. P., & Dretchen, K. (2010). Characterization of ricin toxin family members from *Ricinus communis*. *Toxicon*, 55(2-3), 658-661.
 33. Hayoun, M. A., Kong, E. L., Smith, M. E., & King, K. C. (2023). Ricin toxicity. In *StatPearls* [Internet]. StatPearls Publishing.
 34. Das, S., & Kataria, V. K. (2010). Bioterrorism: A public health perspective. *Medical Journal Armed Forces India*, 66(3), 255-260.
 35. Madhav, N., Oppenheim, B., Gallivan, M., Mulembakani, P., Rubin, E., & Wolfe, N. (2017). Pandemics: risks, impacts, and mitigation. *Disease control priorities: improving health and reducing poverty*. 3rd edition.
 36. Andersen, K. G., Rambaut, A., Lipkin, W. I., Holmes, E. C., & Garry, R. F. (2020). The proximal origin of SARS-CoV-2. *Nature medicine*, 26(4), 450-452.
 37. Munir, K., Ashraf, S., Munir, I., Khalid, H., Muneer, M. A., Mukhtar, N., ... & Zhao, X. (2020). Zoonotic and reverse zoonotic events of SARS-CoV-2 and their impact on global health. *Emerging microbes & infections*, 9(1), 2222-2235.
 38. Haider, N., Rothman-Ostrow, P., Osman, A. Y., Arruda, L. B., Macfarlane-Berry, L., Elton, L., ... & Kock, R. A. (2020). COVID-19—zoonosis or emerging infectious disease?. *Frontiers in Public Health*, 8, 596944.
 39. Petersen, E., Koopmans, M., Go, U., Hamer, D. H., Petrosillo, N., Castelli, F., ... & Simonsen, L. (2020). Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics. *The Lancet*

-
- infectious diseases*, 20(9), e238-e244.
40. Greenberg, M. I., & Marty, A. M. (2006). Emerging natural threats and the deliberate use of biological agents. *Clinics in laboratory medicine*, 26(2), 287-298.
41. Gronvall, G. K. (2017). Prevention of the development or use of biological weapons. *Health security*, 15(1), 36-37.
42. Institute of Medicine (US) Forum on Emerging Infections, Knobler, S. L., Mahmoud, A. A. F., & Pray, L. A. (Eds.). (2002). *Biological threats and terrorism: Assessing the science and response capabilities: Workshop summary*. National Academies Press.

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