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Biosafety Measures in Healthcare: A Historical Perspective on Laboratory-Acquired Infections for Mitigating Bioterrorism and Laboratory-Related Health Risks

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Abstract

Background: Laboratory-acquired infections (LAIs) pose significant risks to laboratory personnel and public health, with a historical incidence that reflects evolving biosafety practices. This study explores the timeline of LAIs, emphasizing key developments in safety protocols and their impact on infection rates.

Methods: A comprehensive literature review was conducted, analyzing historical data, documented cases of LAIs, and advancements in biosafety measures from the late 19th century to the present. Key milestones in laboratory safety and the evolution of biosafety regulations were identified and contextualized within the broader framework of public health.

Results: The findings reveal a substantial decline in LAIs due to improved biosafety measures, such as the implementation of Biological Safety Cabinets (BSCs) and the introduction of the Biosafety Level (BSL) classification system. Despite these advancements, notable outbreaks and incidents illustrate ongoing vulnerabilities, particularly related to human error, inadequate training, and the handling of emerging pathogens.

Conclusion: The historical evolution of LAIs underscores the critical importance of continuous improvement in biosafety practices and training within laboratory settings. As research advances, the introduction of novel pathogens necessitates an adaptive biosafety framework that addresses both existing

and emerging risks. Future studies should focus on enhancing awareness and training among laboratory personnel to mitigate the risks associated with LAIs.

Keywords: Laboratory-acquired infections, biosafety, public health, infection control, laboratory practices.

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1. Introduction

Laboratory staff have faced the possibility of pathogen infection since before to the advent of microbiology. The Centers for Disease Control and Prevention (CDC) characterizes a laboratory-acquired infection (LAI) as "an infection contracted by laboratory personnel during laboratory activities." Between 1949 and 1974, Sulkin and Pike documented over 4000 instances of LAIs, with a mortality rate of 4.1% during the 1950s and 1960s [1]. The relative risk of microbiologists contracting illnesses varies from 0.03 to 8000 in comparison to the general population. In 2018, researchers calculated that the yearly incidence rate of LAI in the United States was between one to five cases per 1,000 workers [2].

Long-acting injectables (LAIs) have long been overlooked, mostly owing to the lack of legislative mandates and data gathering procedures in several countries. Moreover, laboratory directors have expressed apprehension regarding potential culpability, while editors have shown hesitance to disseminate such reports [3]. In 1994, the United Kingdom enacted the "Reporting of Injuries, Diseases and Dangerous Occurrences Regulations," which required the reporting of LAIs; however, the gathered data was classified as confidential and not publicly accessible. In October 2016, the International Editorial Board of the American Biological Safety Association (ABSA) established an online searchable database for LAIs, significantly decreasing the time needed to discover pertinent biological threats [4]. The ongoing introduction of novel diseases and the continual advancement of information about established pathogens have made laboratory biosafety research more comprehensive. To enhance the enforcement of the Biosafety Law of the People's Republic of China, the National Health Commission of China has, in 2023, revised the Catalogue of Human Infectious Pathogenic Micro-organisms by incorporating international and domestic regulations and research findings.

The first documented LAI was a case of typhoid fever in 1885. Thirty years later, Kisskalt released an investigation, marking it as the inaugural documented report of LAI [5]. Beginning in the 1950s and 1960s, pioneers like Sulkin and Pike commenced systematic investigations of LAIs, with subsequent research conducted by Byers and Harding conducted many case studies and epidemiological assessments of LAIs. Certain studies have integrated policy research and sociological discourse to conceptualize LAIs as occupational diseases or as components of biosafety research. Nonetheless, there is a deficiency of research that integrates the historical examination of LAIs with practical case studies, as well as an analysis of the inherent connection between LAIs and the evaluation of biosafety risks. Based on real-world experiences as factual data, this study investigates the risk factors and categorization of LAIs from the viewpoint of biosafety research, exposing the historical development, major milestones, and biosafety features of LAIs. The study performs a comparative analysis of the historical origins of LAI risk factors and the scientific implications of laboratory biosafety, thereby illustrating the alignment between contemporary biosafety principles and the technological development trajectory and scientific justification throughout history.

2. Preliminary Laboratory Safety Concerns and the Genesis of Antibiotics (1901–1947)

During the early 20th century, safety problems were widespread in biological labs. The apparatus was rudimentary, the environment was substandard, and insects were omnipresent. The personnel often exhibited a deficiency in understanding about safety protocols, and activities like smoking, eating, smelling cultures, and doing oral pipetting were deemed acceptable in the laboratory setting. Of the 23 documented cases of LAIs in 1915, 16 were associated with oral pipetting [5]. Despite the availability of the Pasteur pipette, the forerunner to the rubber bulb pipette, it was not until Heinrich Schnitger's invention of the micropipette in 1957 that the Carlsberg pipette, which required oral pipette, gained widespread use [6].

The advancement of antibacterial therapy began in 1928 with the discovery of penicillin by British bacteriologist Alexander Fleming, signifying the start of the "antibiotic era." An analysis of 25 instances of jungle typhus and murine typhus LAI from 1931 to 2000 revealed that all 8 deaths occurred before the use of antibiotics [7]. In the first four decades of the 20th century, certain laboratory-acquired illnesses (LAIs) were ascribed to pathologists and technicians conducting autopsies. Histopathologists and forensic pathologists remain intrinsically linked to clinical laboratory processes.

On April 3, 1901, in Dr. F.G. Novy's laboratory at the University of Michigan, a student analyzing the culture of animal tissues was diagnosed with pulmonary plague. The patient had not received vaccination but was given "protective serum" during the second week of illness [8]. Fortunately, care was administered promptly after exposure, and the patient received treatment despite the absence of specific drugs. Penicillin was ineffective against the plague, and antibacterial therapy began with sulfa medicines in 1937, prior to the discovery of streptomycin in 1943. In 1947, a laboratory technician in Johannesburg, South Africa, exhibiting symptoms, was handling a culture of plague-infected tissues. The physician prescribed a large dosage of streptomycin; however, the patient disregarded the recommendation and succumbed three days later. A postmortem investigation verified a standard plague illness. A 45-year-old lady had direct touch with this patient three days before the beginning of sickness. The lady began treatment with streptomycin, took sulfa medications, and was given two doses of plague microbe antiserum. She received penicillin therapy after a fever return and subsequently achieved complete recovery [8].

3. Initiating Awareness of Protection (1948–1972)

As LAI reports accumulate, experts have begun to formulate tailored preventative measures. In 1905, Robert Koch first introduced the concept of biological safety cabinets (BSCs) to safeguard workers against aerosol exposure. In 1919, Fricke released the first laboratory safety handbook in Germany, advocating for the use of long-sleeved protective clothes, prohibiting eating in the laboratory, and discouraging mouth pipetting. Nonetheless, the enhancement of the current circumstances is often behind the development of concepts. In 1943, Hubert Kaempf created the first-Class III Biological Safety Cabinet, subsequently enhanced by the use of high-efficiency particulate air (HEPA) filters. Nonetheless, the "aerosol era" is expected to conclude owing to the obligatory implementation of Biological Safety Cabinets (BSCs), exemplified by the EU's Council Directive on the Protection of Workers from Exposure to Biological Agents at Work, enacted in 1990 [9].

The handling of microbial suspensions in common laboratory instruments, such as centrifuges, pipettes, and stirrers, used for processing and studying infectious pathogens, may generate aerosols and possible sources of infection. Insect-borne diseases may also occur via aerosol transmission when germs are present in the respiratory secretions of sick people or animals. An examination of 66 studies from 1930 to 2008 on LAIs revealed that 84% of insect-transmitted viral infections were attributable to microbial aerosols. Infected persons often had either rudimentary personal protective equipment, such as masks, or lacked personal protective equipment entirely, and the respiratory protection afforded by masks was inadequate. Collins C.'s book "Laboratory-acquired infections: history, incidence, causes and prevention," published in 1988, designated the time from 1947 to 1966 as the "aerosol era" of laboratory-acquired infections (LAIs) [3], presenting a considerable danger of LAIs to researchers in biological labs [6].

In a 1940 instance of laboratory-acquired illness involving the Western equine encephalitis virus (WEEV), a researcher was exposed to a high quantity of chick embryo viral culture fluid and aerosols released due to a centrifuge accident, affecting the facial, oral, and nasal mucosa. At the time of the incident, the researcher was not using goggles or a protective face mask, resulting in his death from meningitis [10]. In 1924, American surgeon R.R. Spencer and colleagues converted this very deadly illness into a preventive, nonfatal variant. In 1941, a virologist inadvertently stabbed the tip of his ring finger with a needle and syringe carrying suspensions of Coxiella burnetii in egg yolk sacs in the laboratory. Subsequent to the use of iodine, he was given a vaccine for Rocky Mountain spotted fever (Lederle).

Numerous instances of LAI transpired in the 1940s during World War II, characterized by major endeavors to create scrub typhus vaccines aimed at diminishing infection rates among the Allied soldiers

in the Asian theater of conflict [11]. In April 1943, an Australian microbiologist developed a scrub typhus vaccine at the Walter and Eliza Hall Institute of Medical Research in Melbourne. The microbiologist's obituary said that they were among numerous staff members at the institution afflicted with murine typhus, offering compelling evidence for the absence of cross-immunity between murine typhus and scrub typhus [12]. In 1951, Smadel highlighted the perils associated with rickettsial research. He observed that "arguably the most crucial strategy in preventing and managing laboratory infections is to enhance awareness of the hazards among laboratory staff and to ensure they understand that reducing the risk of infection through the implementation of appropriate techniques is attainable" [13].

Symptoms may not manifest immediately after exposure to infectious agents; hence, pathogenic microbiology labs often conduct health assessments. Following the shift to the BCG department at the Danish National Serum Institute, a researcher was required to have a pulmonary examination every three months as stipulated by the agreement established with the chest outpatient department. Nonetheless, the researcher failed to comply with this strategy. In 1966, infiltration was first identified in his lungs; however, no anti-tuberculosis therapy was provided. Two weeks later, the pulmonary lesions significantly diminished. Thereafter, the researcher received a diagnosis of pulmonary tuberculosis [14].

In August 1967, laboratory personnel in Marburg documented a rapid emergence of elevated fever, diarrhea, emesis, significant hemorrhaging, shock, and circulatory failure. This disease, eventually identified as Marburg hemorrhagic fever, was subsequently seen in Frankfurt and Belgrade, resulting in a total of 31 cases, including 7 fatalities. Of the 31 individuals, 25 contracted the Marburg virus via direct contact with infected monkeys in the laboratory. The other six secondary infections included two doctors, a nurse, an autopsy assistant, and the wife of a veterinarian, all of whom had close contact with the original victims. The doctors contracted the virus when drawing blood from infected individuals. Three months later, German experts identified the illness as a unique and perilous virus characterized by a filamentous, rod-like form, originating from monkeys in Uganda. These monkeys were originally used for poliomyelitis vaccine testing and were conveyed to facilities in Marburg, Frankfurt, and Belgrade.

On March 1, 1972, a 56-year-old veterinarian succumbed to rabies illness. During his tenure in a commercial laboratory focused on the production of antiviral vaccines, he used a domestic blender to homogenize the brains of 11 rabid goats. An investigation revealed that the patient may have been removing his mask and positioning his face directly above the blender for many minutes while transferring equal quantities of contaminated homogenate into several containers [15].

4. Intricate Risks and Human Errors in Laboratory Operations (1973–2000)

During the 1970s, the prevalence of smallpox outbreaks in the UK and incidents involving healthcare personnel and LAIs related to renal dialysis, particularly hepatitis, increased societal awareness of LAIs. In 1970, 32 laboratories documented 127 cases of hepatitis within a single year, mostly affecting technicians specializing in biochemistry or hematology [16]. The probability of infection among biochemical technicians decreased from the last research conducted in 1970–1972, indicating an improvement in safety standards within this discipline [17]. Vaccination is the primary method for pre-exposure prophylaxis. Despite rigorous compliance with biosafety protocols from 1971 to 1976, aerosols containing infectious rickettsiae led to nine laboratory-acquired cases of Rocky Mountain spotted fever (RMSF) in individuals who had received both primary and booster doses of the RMSF vaccine. Newcomers to the laboratory post-1971 lacked immunity to RMSF, unlike their older counterparts, due to the cessation of the immunization program for low-risk workers [18].

In 1974, the CDC and the National Institutes of Health (NIH) established the Biosafety Level (BSL) classification system, which categorizes labs according to the pathogenicity of the microorganisms they manage and the necessary protective measures. The system consists of four tiers: BSL-1 for non-pathogenic microorganisms; BSL-2 for moderately hazardous pathogens that necessitate biosafety cabinets; BSL-3 for severe respiratory pathogens that require rigorous air containment; and BSL-4 for high-risk, lethal pathogens that demand entirely sealed laboratories and the utmost protective equipment. This approach provides clear rules for ensuring laboratory safety. In 1975, the National Institutes of Health (NIH) in the

United States established the first comprehensive paper on biosafety, entitled the “NIH Guidelines for Laboratory Operations.” The first edition of "Biosafety in Microbiological and Biomedical Laboratories" (BMBL) was released in 1984 under the auspices of the CDC and NIH. Since 1976, the incidence rate of LAIs has declined due to improved identification of exposure sources, heightened awareness of biosafety principles among laboratory personnel, enhanced regulatory capabilities, prompt and accurate reporting, and advancements in medical treatment [19]. In 1978, Pike documented 258 laboratory-acquired cases of typhoid fever, resulting in 20 fatalities. Nonetheless, 97% of these occurrences and all fatalities were documented before 1955 [20]. Figure 1 presents a concise history of LAI research and administration.

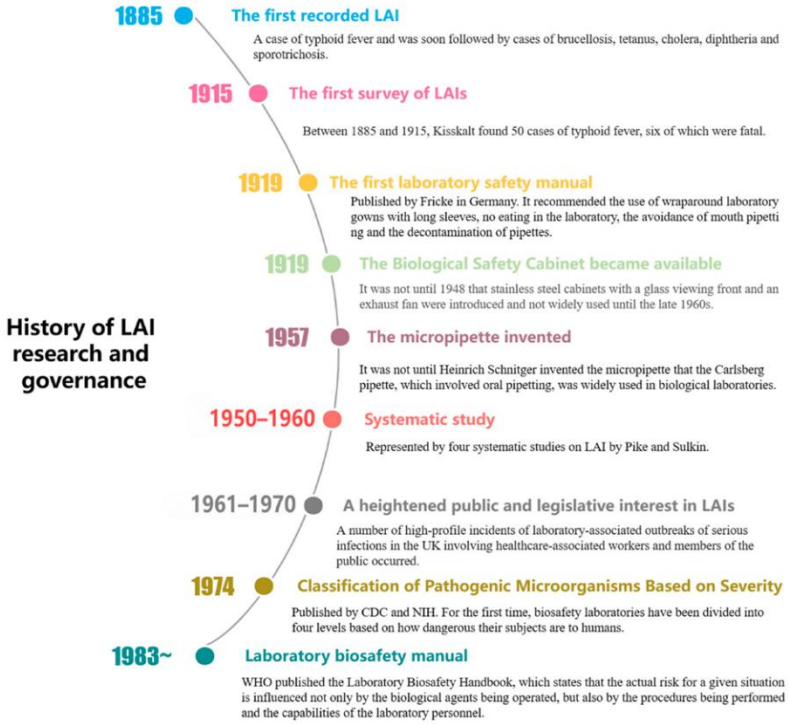

Figure 1. A succinct summary of the historical evolution of LAI research and its administration.

The pathogenicity of numerous viruses that infect humans has been validated solely through the examination of LAIs, and insufficient comprehension of these pathogens is a primary factor contributing to challenges in prevention and treatment [21]. In 1978, a 26-year-old female scientist at the German Virus Research Institute was the inaugural documented case of human infection and mortality due to the Semliki Forest virus (SFV) strain [22].

Salmonella typhi is the etiological agent of typhoid fever, with the capacity to cause fatal infections. Typhi in clinical or educational laboratories may not have been completely acknowledged. From 1977 to 1980, there was a notable surge in laboratory-acquired typhoid fever in the United States, with 31 documented cases. A minimum of 24 of those cases were ascribed to educational purposes. This study prompted researchers to recommend that students be exposed to analogous micro-organisms in a clinical laboratory environment [23].

The prevalence of mental disorders among researchers undoubtedly heightens the risk of LAIs due to their erratic behavior. On 24 February 1982, a 52-year-old female technical specialist engaged in veterinary vaccine production contracted brucellosis. Her laboratory experienced two outbreaks of brucellosis, and she declined to undergo testing for the disease. She had a three-year history of personality disorder and urinary incontinence, accompanied by a diagnosis of depression. Although it cannot be entirely dismissed that brucellosis was deliberately induced or self-administered, it is more probable that the infection resulted from airborne transmission, considering the recorded outbreaks in her laboratory [24]. The disparity in experience results in differing risk levels for laboratory personnel, thus it is imperative for laboratories to emphasize training and evaluation of their staff. In 1986, six neonatal calves

were infected with mouse-derived Cryptosporidium oocysts. A researcher recruited five veterinary students, inexperienced in clinical research and without a background in cow husbandry, leading to an infection event [25].

Consequently, due to the increasing incidence of a particular LAI, laboratory staff frequently establish standard post-exposure prevention protocols; however, this agreement may not be the most effective option. In 1988, a laboratory technician, after an accidental inoculation incident, promptly received an intramuscular penicillin injection in accordance with the established post-exposure prophylaxis protocol. Nevertheless, they still acquired leptospirosis. Another technician had the same scenario and got a doxycycline injection, resulting in neither sickness nor seroconversion. Thus, a post-incident report advocated for the administration of doxycycline for chemoprophylaxis after exposure, as it demonstrated superior efficacy in preventing leptospirosis [26].

Following the introduction of a novel technology or pathogen into the laboratory, researchers may inadequately recognize the associated risks, leading to potentially unsuitable experimental methodologies. Culture media tailored for non-surface growth and optimal bacterial dispersion may enable micro-organisms to exist in minuscule droplets, potentially infiltrating the lungs and resulting in infection [27]. The utilization of syringes and pipettes may produce aerosols due to the risk of splashing and spilling [28].

In 1988, the incidence rate of acquired *Mycobacterium tuberculosis* infection in 77 tuberculosis laboratories across Germany, Austria, and Switzerland was 2.63 cases per 100 person-years, representing a rate 100 times greater than that of the general population. The risk is associated with the number of positive samples isolated by technical staff each year and the lab's shift system. Some laboratories have implemented broth culture methods for diagnosing tuberculosis, leading to an increased infection rate of 6.74 cases per 100 person-years [29].

In 1994, an individual who had never traveled to Asia and had studied mycology at the Pasteur Institute's teaching building was infected with the Penicillium marneffei fungus. Since 1956, over 150 cases of infection caused by this fungus have been reported in individuals with human immunodeficiency virus (HIV) infection. Even a small inoculum, such as a few fungal spores, could lead to symptomatic infection in individuals with underlying immune defects [30]. Immunocompromised laboratory personnel need to exercise extra caution when handling pathogenic micro-organisms, as this not only increases the likelihood of infection among the personnel but also restricts the application of commonly used interventions [31]. In 1997, a 30-year-old female laboratory technician accidentally acquired cutaneous leishmaniasis caused by the amastigote form of the Leishmania mexicana parasite through percutaneous inoculation. This occurred 8 months prior to the onset of systemic lupus erythematosus (SLE), which subsequently required immunosuppressive treatment [32].

In a review of exposure incidents from 1989 to 2002, only five cases of infection were attributed to bioagent exposure. Vaccination (such as anthrax and yellow fever vaccinations) authorized by the Food and Drug Administration (FDA) have led to a reduction in LAIs caused by these diseases. Since 1990, several labs have also installed safer needle systems, resulting in a low yearly occurrence of needlestick injuries. The number of LAIs has continuously fallen since 1965. UK-based research indicated that the yearly incidence of infections declined from 82.7 cases per 100,000 persons in 1988–1989 to 16.2 cases per 100,000 people in 1994–1995 [33]. This reflects the greater knowledge of laboratory safety among staff, the deployment of higher-level laboratory biosafety management, and the enhanced effectiveness of vaccinations, which have steadily decreased some of the causes that previously contributed to LAIs. However, the complexity of experimental techniques and study subjects has also generated new hidden hazards, with human mistakes being the leading cause of present-day LAIs.

Between 1971 and 2000, laboratory staff were infected with diseases such as Rocky Mountain spotted fever, typhoid fever, Semliki Forest virus, brucellosis, cryptosporidiosis, Creutzfeldt–Jakob disease, leptospirosis, Mycobacterium tuberculosis, Penicillium infection, and leishmaniasis. These occurrences underlined the necessity of immunization, employing attenuated strains, treating the mental health of

laboratory staff, giving professional training, analyzing possible hazards, chemoprophylaxis, and minimizing the exposure of immunocompromised patients [34-37].

5. Periods of LAIs' Historical Evolution

This study largely separates the historical history of LAIs into four distinct eras, each defined by distinctive elements, including laboratory environment, researcher awareness, methods employed, protective and therapeutic measures, and study participants. The timetable of LAI historical eras is illustrated in Figure 2.

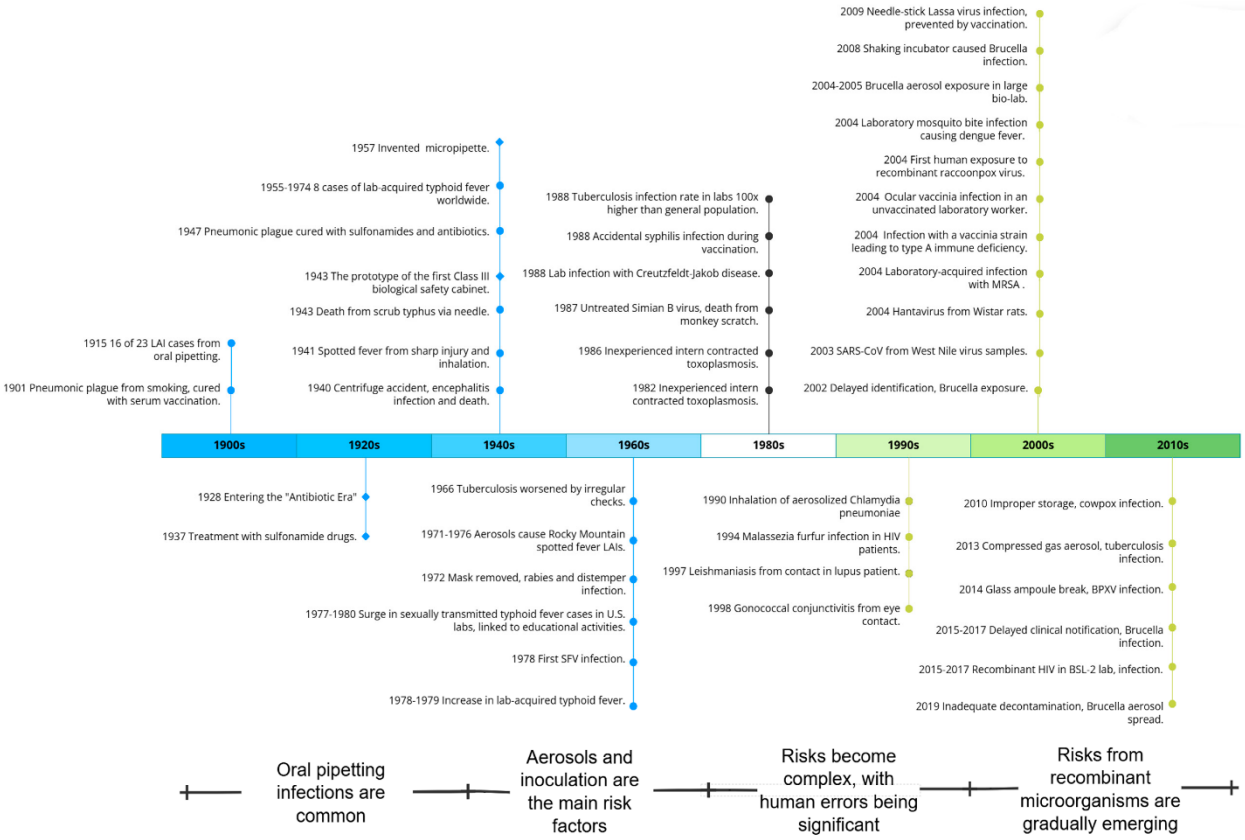

Figure 2. LAI historical era schedule.

During the earliest time of LAIs, laboratory activities were in their early phases and there was a lack of understanding and treatment methods for protection. Cases of infection from oral intake were prevalent. The lab was inadequately equipped for a long period, with no protective equipment. Practices such as eating, smoking, and oral pipetting resulted to considerable exposure [38,39]. The paucity of therapeutic medications and immunizations causes obstacles, although quick treatment may heal certain serious illnesses. For example, some plague sufferers survived after getting injections of a protective serum. Over time, self-protection methods such as face masks, pipettes, and bio-security cabinets have been steadily refined and promoted.

The second stage of LAIs started with the creation and implementation of experimental instruments and equipment, such as high-speed centrifuges. Researchers are starting to create an early knowledge of protection, with aerosols and injections being the primary danger factors. Aerosol exposure has led to instances of infection with diseases such as TB and Rocky Mountain spotted fever, and even rabies. However, the treatment of pathogen infections in humans has entered the antibiotic age, with numerous vaccines being created, and much enhanced post-exposure prophylactic capabilities [40-43].

In the third era of LAIs, the experimental activities grew more diversified, the dangers more complicated, and there are major human mistakes. Since 1978, LAIs have reduced dramatically owing to

better laboratory rules, increasing awareness of conservation, and equipment optimization. However, as laboratory and staff numbers rise, work intensities increase, current technologies are deployed, and research issues become more complicated, laboratory workers confront more complex dangers, including major human aspects. Many untrained persons, those at risk of host-specific immunity, and even those with mental illnesses participate in pathogen-related employment, leading to instances of previously undiscovered pathogens such as hantaviruses and Epstein–Barr virus infections. Some laboratories have halted prophylactic vaccines for illnesses such as cowpox and *Salmonella typhi*, leading in a subsequent rise in LAIs from specific infections [44,45].

In the fourth era of LAIs, laboratory safety protection and intervention continue to be enhanced, with the danger from recombinant micro-organisms rising. In the 21st century, research has indicated a considerable reduction in LAIs owing to better equipment and technology. However, with breakthroughs in recombinant micro-organism technology and synthetic biology, LAIs produced by natural infections such as recombinant raccoonpox virus and recombinant HIV-1 clones have been identified. Cases of the mishandling of sample handling and culture of distinct viruses have been recorded owing to the development of laboratory scales and the variety of individuals [46].

6. The scientific basis for the evaluation of biosafety risks

Key risk factors from the historical development of LAIs in the technical field are now considered essential criteria for risk assessment in contemporary laboratory biosafety systems. The "Laboratory Biosafety Manual" (LBM) published by the WHO, the Biosafety in Microbiological and Biomedical Laboratories (BMBL), and the Biosecurity Law of the People's Republic of China (BLPRC) all emphasize the need to enhance biosafety management in laboratories dealing with hazardous microorganisms. The fourth iteration of the 2020 LBM comprehensively addresses the 13 principal risk factors that contribute to overall risk in biological labs. These characteristics are associated with the scientific context and development of LAI's historical narrative [47]. The considerations encompass the attributes of the micro-organisms being managed, including the concentration and volume of potentially infectious materials, the infectious dose of biological agents, their transmissibility, the severity of infections, the stability of these agents in laboratory and external settings, and the local prevalence of these agents within the population. Furthermore, the handbook delineates potential hazards associated with operating procedures and employee behavior [8, 14, 24, 30, 32, 42, 43, 48, 49].

This research appropriately reflects the hazards associated with laboratory activities at various phases of LAI development. Laboratory staff are often exposed to activities such as pipetting, centrifugation, and the handling of sharp instruments. With technological advancement, several danger issues have arisen. Aerosols may be produced by the manual compression of a gas coolant to aid with pathological slicing, whereas advanced cryogenic procedures need more sophisticated glass apparatus. The proficiency of the individuals executing the activity is a critical concern that emerges promptly, as infractions and non-adherence to medical treatment directives may lead to postponed treatment and perhaps fatal outcomes. Issues with sample handling, viral culture, and human mistakes emerged as significant problems with the expansion of the laboratory scale. The growth of laboratory scales has resulted in heightened participation of high-risk persons in laboratory work, whose sensitivity must be regarded as a significant individual risk factor. Consider the first human SFV infection and the instance of an HIV patient infected with Malassezia furfur as instructive examples. The absence of cross-immunity to a source pathogen in persons previously exposed to a specific pathogen underscores the need of investigating the host range of biological agents, including possible zoonotic illnesses. Moreover, since laboratory biosafety increasingly depends on equipment and infrastructure, the failure to enforce these safeguards may lead to extensive exposures that might impact the adjacent population and environment.

Furthermore, documents such the LBM, the Biosafety Management Level (BMBL), and the Biosecurity Law of the People's Republic of China underscore variables that provide prospective dangers of LAIs, even if they have not yet emerged. LBM references the evaluation of innovative biological agents. The Canadian Biosafety Handbook (2nd Edition) addresses biotechnology, which entails the development of transgenic

organisms by the insertion, deletion, replacement, or modification of genes or gene fragments. This approach may be used to generate novel pathogenic organisms or augment the virulence of pre-existing ones. In cell lines and cultures, growth conditions (including pH, temperature, and culture media supplements) can induce variations in oncogene expression, latent virus activation, interactions among recombinant genomic fragments, or modifications in cell surface protein expression, thereby presenting additional risks. The Biosecurity legislation of the People's Republic of China stipulates that relevant State Council agencies must monitor and assess biotechnology application activities in compliance with the legislation.

7. Summary

This study adopts a historical perspective, including contextual background, comprehensive accounts of actual instances, and synthesizing similarities across notable examples throughout several developmental phases. It delineates the four developmental phases and their primary features by examining the scientific and conceptual dangers linked to LAIs. The evolution of LAIs has been linked to advancements in biological experimental methodologies, concepts, and safety protocols, as well as being shaped by social influences and healthcare norms. An examination of the technical history of LAIs uncovers standard instances and the progression of risk factors in laboratory biosafety, illustrating its transformation into a novel theory for developing a contemporary framework for risk assessment in this domain. The growth of LAI exemplifies the dual nature of technology, whereby mankind navigates the unknown, encounters dangers, achieves achievements, and confronts new obstacles. In reaction to the increasing complexity and danger of LAI accidents, more efficient response strategies have been developed. Behind the current conventional theoretical understanding is the experience acquired via the diligent efforts of prior researchers. Consequently, the evolutionary history of LAIs is scientifically significant and warrants more exploration.

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التدابير البيولوجية في الرعاية الصحية: منظور تاريخي حول العدوى المكتسبة في المختبر للحد من الإرهاب البيولوجي ومخاطر الصحة المختبرية

الملخص

الخلفية :تشكل العدوى المكتسبة في المختبر (LAIs) مخاطر كبيرة على العاملين في المختبرات والصحة العامة، حيث يعكس تاريخ حدوثها تطور ممارسات السلامة البيولوجية. يستكشف هذا البحث تطور العدوى المكتسبة في المختبر عبر الزمن، مع التركيز على التطورات الرئيسية في بروتوكولات السلامة وتأثيرها على معدلات العدوى.

المنهجيات :تم إجراء مراجعة شاملة للأدبيات لتحليل البيانات التاريخية، والحالات الموثقة للعدوى المكتسبة في المختبر، والتطورات في التدابير البيولوجية منذ أواخر القرن التاسع عشر وحتى الوقت الحاضر. تم تحديد المعالم الرئيسية في سلامة المختبرات وتطور اللوائح البيولوجية ضمن إطار الصحة العامة الأوسع.

النتائج :كشفت النتائج عن انخفاض كبير في العدوى المكتسبة في المختبر نتيجة لتحسين التدابير البيولوجية، مثل تطبيق خزانات السلامة البيولوجية (BSCs)وتقديم نظام تصنيف مستويات السلامة البيولوجية .(BSL) ومع ذلك، فإن الفاشيات والحوادث البارزة تشير إلى ثغرات مستمرة، لا سيما تلك المتعلقة بالأخطاء البشرية، والتدريب غير الكافي، والتعامل مع مسببات الأمراض الناشئة.

الخلاصة :يبرز التطور التاريخي للعدوى المكتسبة في المختبر الأهمية الحاسمة للتحسين المستمر في ممارسات السلامة البيولوجية والتدريب داخل بيئات المختبرات. ومع تقدم البحث، يستدعي إدخال مسببات الأمراض الجديدة وضع إطار بيولوجي متكيف يعالج المخاطر الحالية والناشئة. ينبغي أن تركز الدراسات المستقبلية على تعزيز الوعي والتدريب بين العاملين في المختبرات للتخفيف من المخاطر المرتبطة بالعدوى المكتسبة في المختبر.

الكلمات المفتاحية :العدوى المكتسبة في المختبر، السلامة البيولوجية، الصحة العامة، مكافحة العدوى، ممارسات المختبرات.