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Systemic and localized infections in humans caused by *Paenibacillus*: a case report and literature review

Shuwen Lu[1*], Haoyu Li[2], Chao Ma[3] and Xian Li[4]

Abstract

Background As opportunistic pathogens, *Paenibacillus* organisms rarely induce human infections. This research paper details the clinical manifestations, treatment, and prognosis of an intraocular infection caused by *Paenibacillus* in a 43-year-old male patient.

Case presentation In this case, the patient initially presented with persistent ocular redness and a sensation of foreign bodies following trauma surgery. Upon admission, we performed intraocular fluid metagenomic next generation sequencing (mNGS) testing and systemic blood sampling for infection-related assessments. The results revealed a localized ocular infection with *Paenibacillus* organisms. Consequently, the patient received daily levofloxacin injections (500 mg) and clindamycin (300 mg) for systemic anti-infective therapy, along with subconjunctival injections of gentamicin (2 WIU) and dexamethasone (5 mg) for topical application. The infection was effectively managed, and their ocular symptoms showed improvement during the treatment course.

Conclusions We conducted a comprehensive review of previously reported cases involving *Bacillus*-like organisms causing human infections, exploring mechanisms, diagnostic approaches, and treatment strategies.

Keywords *Paenibacillus*, Endophthalmitis, Opportunistic pathogen, Diagnosis, Therapeutic

Background

Endophthalmitis encompasses a range of severe intraocular inflammatory conditions, including vitritis, pus accumulation in the anterior chamber, and eye pain. These conditions can be triggered by intraocular infections, foreign bodies within the eye, necrotic tumors, severe non-infectious uveitis, and hypersensitivity to lens cortex materials [1]. Endophthalmitis manifests in various forms, often involving infections of the vitreous and aqueous humor, typically caused by bacteria or fungi. It is a condition that can lead to irreversible blindness in the infected eye [2]. The incidence of penetrating ocular trauma is estimated to be between 2 and 3.8 cases per 100,000 people. Post-traumatic endophthalmitis affects approximately 0.9–18% of adults and 5–54% of children

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following such injuries [3, 4]. Traumatic endophthalmitis can be induced by a variety of microorganisms, including coagulase-negative staphylococci, bacilli, streptococci, gram-negative bacilli, and coagulase-positive staphylococci [5]. While advances in diagnosis and treatment strategies have allowed some patients to regain near-normal vision, the majority still experience significant vision loss as a result of endophthalmitis [6]. Early diagnosis is critical to the successful treatment of endophthalmitis, emphasizing the imperative of rapid identification for effective management.

Saprophytic bacteria of the *Paenibacillus* type are commonly found in nature [7]. These *Paenibacillus* bacteria exhibit a rod-like structure, with motile flagella enveloping them [8]. The *Paenibacillus* bacteria exhibit both Gram-positive and Gram-negative characteristics, with the ability to thrive in anaerobic environments and form spores [9]. The genus *Paenibacillus* has expanded considerably since Ash, Priest, and Collin's division of *Bacillus* in 1993, now encompassing more than 260 identified species [10]. This includes 22 species isolated from human samples [11]. In general, *Paenibacillus* is not highly susceptible to causing infections in humans. However, human infections can occur if individuals come into contact with nutritive spores through ingestion, injection, injury, inhalation, or other means [12].

Paenibacillus lautus, a member of the *Paenibacillus* genus, is considered an opportunistic pathogen that is capable of causing infections when individuals are injured or immunocompromised [13]. Furthermore, the detection of *P. lautus* in ticks raises concerns about its potential transmission from tick bites to humans or other hosts, possibly leading to illness [14]. Of note, according to our records, cases of *P. lautus* eye infections have not previously been reported. However, continued monitoring and research in this area are vital to better comprehend the potential risks associated with this pathogen. In this study, we present a rare case of intraocular infection caused by *P. lautus* following traumatic surgery. Our objective is to provide a systematic and detailed exploration of the mechanism of action, diagnostic approaches, and therapeutic means for human infections attributed to *P. lautus*. To achieve this, we thoroughly reviewed prior reports documenting *P.lautus* infections in humans.

Case presentation

Patient medical history

In February 2023, a 43-year-old male presented to the outpatient clinic due to a year-long history of vision loss following trauma to his right eye. The initial treatment involved suturing a laceration in the right eye, followed by the removal of the lens. Subsequently, a vitrectomy was performed, and an intraocular lens (IOL) was implanted in the right eye. Following the surgical procedures, the patient experienced recurring symptoms of eye redness and foreign body sensations, which were managed as uveitis. The patient's post-surgery vision varied, with periods of both good and poor vision. Throughout the one-year period, the patient did not exhibit any systemic symptoms such as fever, headaches, or a decreased appetite.

In the early stages of the disease, the patient received steroids hormonal therapy, although the specific medication used was not documented at the time. During the consultation, the examination of the patient's right eye revealed corneal haze with edema and concurrent corneal leukoplakia. Additionally, there were signs of inflammation in the anterior chamber with keratic precipitates (KP+), atrial flashes, a pupil diameter measuring 4.5 mm, the absence of a light reflex, and an intraocular pressure reading of T + 2. Conversely, the examination of the left eye did not reveal any apparent abnormalities (Fig. 1A).

Patient examination and preliminary diagnosis

Due to the patient's recurrent episodes of eye redness and the extended time elapsed since hospital admission, we conducted immune-related blood tests and intraocular fluid tests. The results of the immune-related blood tests were as follows:

- Routine blood and electrolyte tests did not reveal any significant abnormalities.
- In the liver function tests, alanine aminotransferase (ALT) levels were elevated at 105 U/L (normal range: 0–40 U/L), glutamine aminotransferase (AST) levels were elevated at 70 U/L (normal range: 0–40 U/L), aspartate aminotransferase isoenzyme levels were elevated at 25 U/L (normal range: 0–15 U/L), and glutamine transpeptidase was elevated at 63 U/L (normal range: 0–58 U/L).
- Renal function tests did not display any noticeable irregularities.
- Tuberculosis infection-related tests (including Mycobacterium tuberculosis T cells and tuberculosis antibodies) yielded negative results.
- Autoimmune-related antibodies were also negative.
- Viral tests indicated the presence of antibodies IgG to the Epstein-Barr virus (EBV), IgG to the measles virus, and IgG to cytomegalovirus. The remaining viral tests were negative.
- Blood culture results were negative for both bacterial and fungal infections.

Following the negative results from the systemic examination, the possibility of a localized ocular infection was considered. To confirm this suspicion, metagenomic next generation sequencing (mNGS) was conducted on the intraocular fluid. The mNGS analysis confirmed the

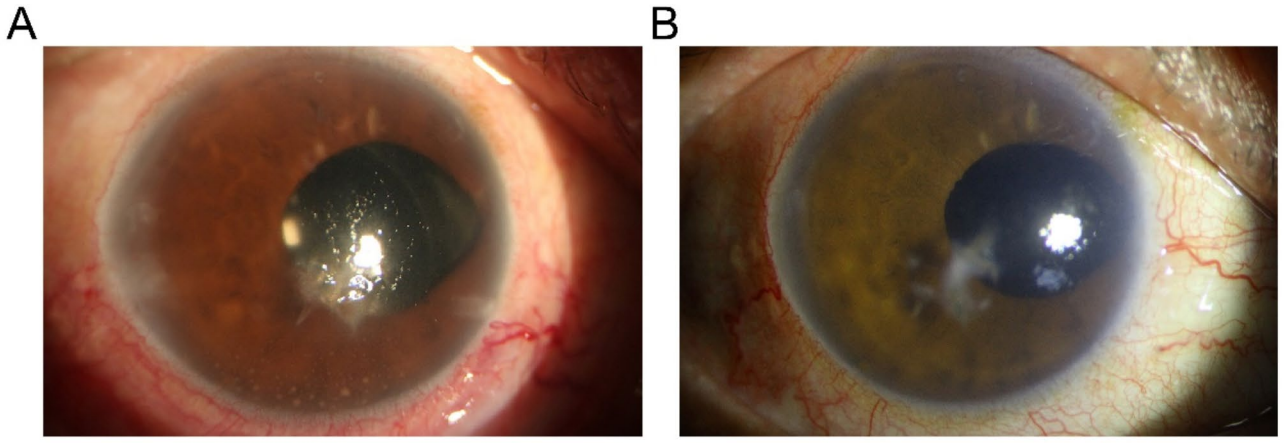

Fig. 1 (**A**) Anterior segment of the eye at admission: Digital photograph showing corneal haze edema, posterior corneal amniotic keratic precipitate attachment, and mild turbidity of the atrial fluid. (**B**) Anterior segment of the eye at discharge: Digital photograph illustrating a clear cornea, absence of apparent keratic precipitate attachment behind the cornea, and noticeably clearer atrial fluid compared to the initial presentation

presence of a *P. lautus* infection. Further, bacterial and fungal smears and cultures were performed on the intraocular fluid, and these tests yielded negative results, indicating the absence of other bacterial or fungal infections within the eye.

Treatment

Given the patient's unclear diagnosis upon admission, an initial approach of symptomatic treatment was administered. In response to the patient's elevated intraocular pressure (IOP) symptoms, we implemented several interventions:

1. Brinzolamide thimerosal and brimonidine tartrate eye drops were administered as an IOP-lowering treatment.
2. Intravenous mannitol was systemically administered to lower IOP. Additionally, anterior chamber puncture was performed to alleviate ocular pain and headache associated with high intraocular pressure.
3. Empirical systemic treatment with clindamycin (300 mg, twice daily) as an anti-infective infusion to address potential infections.
4. Local subconjunctival injections of gentamicin (2 WIU) and dexamethasone (5 mg) were administered to combat inflammation and infection within the anterior chamber.

Upon confirming the localized *P. lautus* infection in the eye based on the patient's systemic and ophthalmological test results, the therapeutic medication plan was adjusted to systemic administration of levofloxacin (500 mg once daily) and clindamycin (300 mg twice daily). The ongoing treatment of subconjunctival injections of gentamicin (2 WIU) with dexamethasone (5 mg) was continued to address both inflammation and infection. While hospitalized for anti-infective treatment, the patient received an intravitreal injection of vancomycin directly into the eye.

Follow-up and outcomes

After one month of topical and systemic medications, there was notable improvement in the patient's ocular condition. The presence of KP and atrial flashes in the anterior chamber decreased, and the IOP was controlled within the range of 25–28 mmHg (Fig. 1B). As a result of this progress, the patient was discharged from the hospital with symptoms of ocular distension and eye pain that were markedly improved compared to the initial presentation. After therapeutic intervention, the patient's eye condition improved, but the white scar in the center of the cornea remained.

Literature reviews

In our search on PubMed, we utilized the keyword "*Paenibacillus*" with the restriction of including only articles related to humans and written in English. This search yielded a total of 181 articles, all of which were reviewed to identify cases with a definitive diagnosis of *Paenibacillus* infections. From these articles, we selected and included 17 unique case reports or series in our analysis. The collective cohort of patients in these reports comprised 18 patients, of which 10 were males and 8 were females. The age of infection onset varied, ranging from 4 weeks to 80 years, with a median age of onset at 54 years. Additional data pertaining to the 18 patients are shown in Table 1.

Discussion

Current status and historical overview

Paenibacillus species were originally categorized within the *Bacillus* genus but now considered a separate genus

Table 1 Summary of 18 patients with *Paenibacillus* infection

Reference	Patient sex	Age (years)	Previous illnesses and treatment	Diagnosis	Systemic symptoms	Laboratory examination		Therapeutic method	Treatment cycle	Treatment outcome
Ko et al. [14].	M	75	N/A	*Paenibacillus konsidensis*	Fever, hematemesis, and hypotension	Blood culture: gram-positive rod	16 S rRNA	N/A	N/A	N/A
Ouyang et al. [15].	M	80	Hemodialysis	*Paenibacillus thiaminolyticus*	Pain in the left anterior chest wall at the catheter site	Blood culture: gram-variable rods	16 S rRNA	Vancomycin, gentamicin, levofloxacin, and amikacin	1 month	Asymptomatic
Roux et al. [16].	F	36	N/A	*Paenibacillus urinalis*	Emaciation, chronic cough, dysphagia, sweats, inflammatory syndrome, and pulmonary nodules	Urine culture: gram-negative staining bacillus	16 S rRNA	N/A	N/A	N/A
Roux et al. [16].	M	54	Cerebellar syndrome and diarrhea episodes	*Paenibacillus provencensis*	N/A	Cerebrospinal fluid culture: negative	16 S rRNA	N/A	N/A	N/A
Leão et al. [17].	M	25	Cystic fibrosis	*Paenibacillus cineris*	Thick sputum and digital clubbing	Sputum culture: positive for gram-negative rod	16 S rRNA	Amoxicillin clavulanate and levofloxacin dexamethasone	1 week	Asymptomatic
Kim et al. [18].	M	60	Pulmonary diseases	*Paenibacillus sputi*	N/A	Sputum culture: positive	16 S rRNA -	N/A	N/A	N/A
Anikpeh et al. [19].	M	79	Coronary heart disease	*Paenibacillus pasadenensis*	Fever, fatigue, elevated inflammatory markers, and sternal pain	Interstitial fluid culture: negative	16 S rRNA -	Vancomycin, ciprofloxacin, and clindamycin	1 month	Asymptomatic
Ferrand et al. [20].	W	65	Type 2 diabetes, atrioventricular block	*Paenibacillus glucanolyticus*	Skin fistula and purulent discharge at the implantation site of the pacemaker	Blood culture: gram-negative rod	16 S rRNA	Ceftriaxone	6 weeks	Asymptomatic
Padhi et al. [21].	M	60	Chronic kidney disease	*Paenibacillus alvei*	Dysuria and fever	Urine culture: gram-positive bacilli	Standard biochemical reactions	Cefotaxime	1 week	Asymptomatic
Wenzler et al. [22].	F	36	Splenectomy	*Paenibacillus amylolyticus*, *Lysinibacillus sphaericus*, *and Lysinibacillus fusiformis*	Fever, chills, vomiting, muscle pain, runny nose, and cough	Blood culture: gram-variable rods	16 S rRNA	Ampicillin/sulbactam	1 week	Asymptomatic
Marchese et al. [23].	F	54	Post-breast implementation	*Paenibacillus residui*	Mastitis	Interstitial fluid culture: gram-negative rod	16 S rRNA	N/A	N/A	N/A
DeLeon et al. [24].	F	4 weeks	N/A	*Paenibacillus alvei*	Drowsiness	Blood and cerebrospinal fluid culture: gram-positive rod	-	Vancomycin and ampicillin	3 weeks	Deceased

Table 1 (continued)

Reference	Patient sex	Age (years)	Previous illnesses and treatment	Diagnosis	Systemic symptoms	Laboratory examination		Therapeutic method	Treatment cycle	Treatment outcome
Pinho-Gomes et al. [25].	F	70	Aortic stenosis	*Paenibacillus provencensis*	Non-ST segment elevation myocardial infarction	Culture of the tissue specimen	-	Vancomycin, meropenem, and daptomycin	6 weeks	Asymptomatic
Zhang et al. [26].	M	44	Tuberculosis	*Paenibacillus assamensis*	Left knee swelling and pain	Detection of gram-negative bacilli in tuberculosis joint fluid	16 S rRNA	N/A	N/A	N/A
Salazar et al. [27].	M	37	Hypertension and neurofibromatosis type 1	*Paenibacillus timonensis*	Serous secretions appear after surgery	Secretion culture: gram-positive rod	16 S rRNA	Vancomycin, trimethoprim/sulfamethoxazole	1 month	Asymptomatic
Micco et al. [7]	F	33	Post-abdominal lipoplasty	*Paenibacillus thiaminolyticus*	Fever, abdominal wall mass pain	Blood culture: negative	MALDI-TOF	Amoxicillin/clavulanate	2 weeks	Asymptomatic
Kehayov et al. [3].	M	30	N/A	*Paenibacillus lactis*	Headache and left ear pain, epilepsy	MALDI-TOF	-	Meropenem and vancomycin	1 month	Asymptomatic
Tabarani et al. [28].	F	5 weeks	N/A	*Paenibacillus dendritiformis*	Fever and seizure	Cerebrospinal fluid culture: positive for *Paenibacillus*	16 S rRNA	Ampicillin	6 weeks	Complications relating to hydrocephalus

MALDI-TOF: Matrix-assisted laser desorption/ionization time of flight mass spectrometry

of *Bacillus*-like organisms, which are generally not commonly associated with causing diseases in clinical practice [15]. While *Paenibacillus* is not typically pathogenic to humans, there have been instances of isolated species causing infections in various parts of the world. Most of these infections are benign and do not harm the host [8], but in some cases, *Paenibacillus* can exhibit pathogenicity, particularly in individuals with weakened immune systems due to immune deficiencies. The diseases and syndromes associated with *Paenibacillus* infections, shown in Fig. 2, include chronic kidney disease, sickle cell disease, prematurity, Whipple's disease, hydrocephalus, skin cancer, chronic interstitial nephropathy, acute lymphoblastic leukemia, among others [16–19]. The relationship between *Paenibacillus* infections and the resulting diseases is not always clear, and it may not be simply casual. Previous literature reviews (Table 1) suggest that most human infections caused by *Paenibacillus* isolates are observed in elderly, pediatric, and infant patients who have compromised immune systems, making them more susceptible to opportunistic infections by these organisms.

Pathogenesis

The spores produced by *Paenibacillus* sp. exhibit remarkable resistance to environmental factors such as heat, cold, and common disinfectants. This resilience allows them to persist on surfaces for extended periods, and it is not uncommon for even healthy individuals to carry *Paenibacillus* spores on their skin [20]. In a hospital setting, *Paenibacillus* organisms can often be isolated from the skin surfaces of most hospitalized patients, but there have been limited effective methods to reduce the levels of these skin spores among hospitalized individuals [21]. In terms of their potential to infect humans, *Paenibacillus* organisms possess certain virulence properties that could enable them to act as pathogens or opportunistic pathogens, particularly in individuals with compromised immune systems [22]. One mechanism that might contribute to their virulence is the production of thiol-activated cytolysins [18]. It is hypothesized that as opportunistic pathogens, *Paenibacillus* organisms can persist on the body's surface for extended periods as bacillus spore. Under conditions of reduced immunity or compromised bodily barriers, which may arise from various circumstances, these organisms can potentially enter the human body. Once inside, they may utilize their virulence properties to infect and cause harm to host cells, leading to infection and tissue damage (Fig. 3).

In the research paper, we hypothesize that the patient may have acquired the infection subsequent to sustaining an injury. The primary preventive measure for ocular infections is the avoidance of trauma, given that patients possess an intact immune system and *P. lautus* is not a

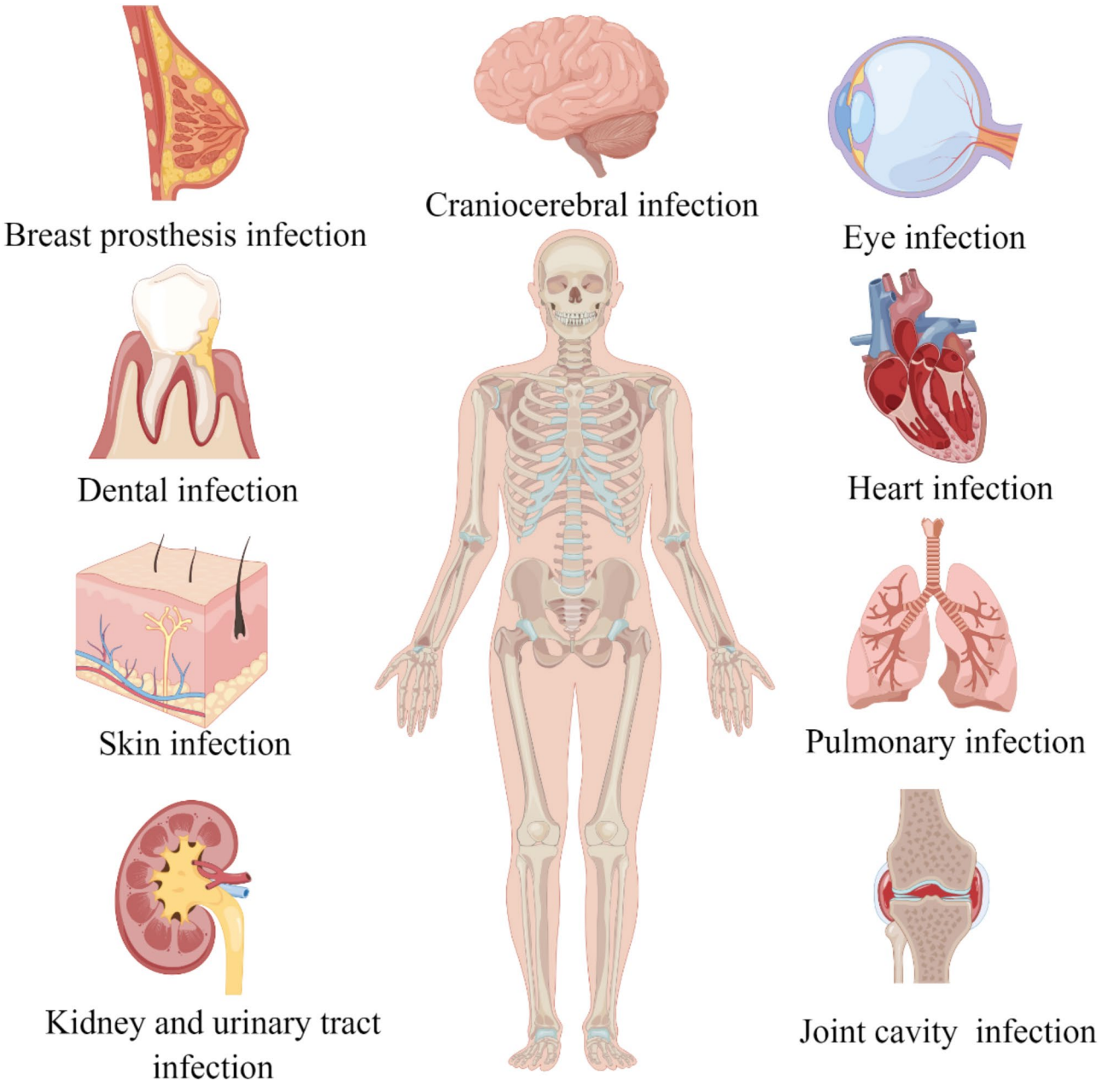

Fig. 2 *Paenibacillus* have been identified as culprits behind both systemic and localized infections in humans (image created by Figdraw)

highly virulent microorganism. Consequently, the initial symptoms could be attributed to this bacterium. However, following therapeutic intervention, the patient's ocular condition showed improvement, while the symptoms of ocular damage persisted over an extended period.

Clinical manifestation

Infections caused by *Paenibacillus* can present varying clinical manifestations depending on the specific tissues or organs affected. Generally, inflammation is observed in infected tissues, but the symptoms are not uniform across all types of infections. For instance, infections involving vital organs like the heart, brain, or blood (hematological infections) may present with systemic symptoms such as generalized fever and elevated inflammatory markers. In contrast, localized infections like those affecting the skin or joints tend to present with localized redness, swelling, and fluctuating sensations in the affected area [23, 24]. Consequently, it can be difficult to directly attribute clinical symptoms to *Bacillus*-like infections based solely on clinical presentation or patient history.

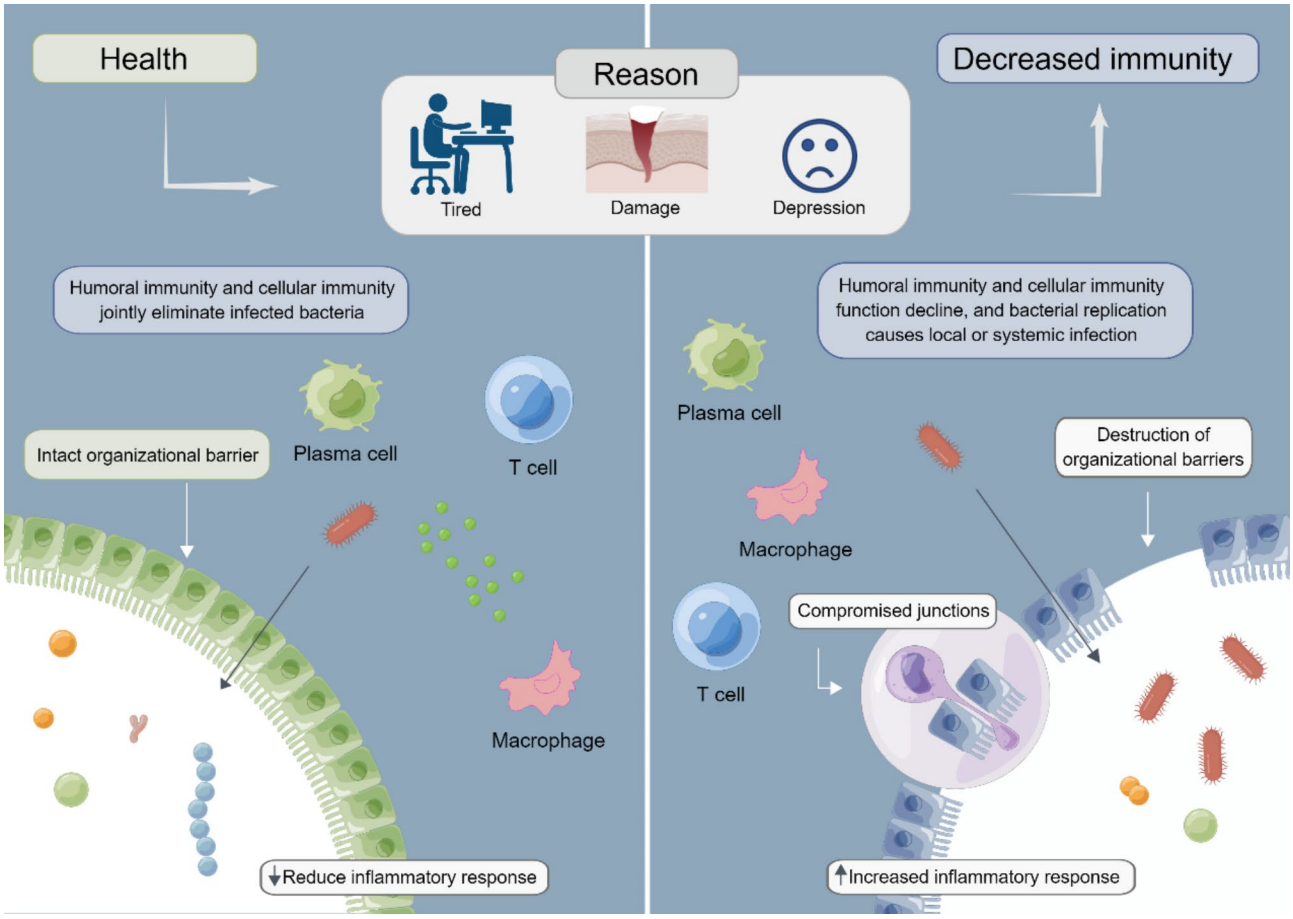

Fig. 3 As an opportunistic pathogen, *Paenibacillus* may cause infections in individuals who are fatigued, injured, or experiencing depression (image created by Figdraw)

Diagnostic methods

The accurate identification of *Paenibacillus* in clinical settings has historically been challenging due to the absence of clear and distinguishable phenotypic features. Traditional assays have relied on isolating the target strain and then referring to known characteristics of the isolate in question for identification [25]. Therefore, accurate identification without a reference strain has been difficult to achieve. Further, *Paenibacillus* organisms can be challenging to grow in petri dishes, and biochemical testing often has a low positive rate. To achieve accurate identification, modern molecular biology methods such as 16 S rRNA gene sequencing are often necessary [26]. This approach entails clustering analysis based on the similarity of PCR-amplified 16 S sequences. Despite its convenience and power, this method has its limitations. It relies on certain assumptions, such as considering > 95% identity as belonging to the same genus and > 97% identity as belonging to the same species. Additionally, this method requires a known target for bacterial detection and cannot be used directly as a screening method for bacteria, fungi, or parasites [27]. In clinical settings, when detecting *Paenibacillus* organisms, both positive and negative organisms are typically detected, and the 16s rRNA is used to identify the type of organism. Consequently, the use of the 16s rRNA method in clinical diagnostics can result in longer turnaround times for diagnosis, potentially increasing the risk of misdiagnosis, and contributing to higher diagnostic testing costs for patients.

In an investigation into neonatal sepsis attributed to the Paenibacillus genus, Ericson et al. [28] utilized genus- or species-specific quantitative polymerase chain reaction (qPCR) assays on blood and cerebrospinal fluid specimens from afflicted neonates. Consequently, from a clinical standpoint, the qPCR detection threshold warrants reevaluation, given that very low copy numbers could stem from contamination during sample collection or laboratory processing. Alternatively, these low copy numbers might suggest that Paenibacillus acts as a commensal organism rather than a pathogenic agent.

Matrix-assisted laser desorption ionization-time of flight mass spectrometry (MALDI-TOF-MS) is a relatively recent advancement in organic mass spectrometry

[29]. This targeted approach minimizes the influence of external factors such as culture medium, incubation time, and other cultivation conditions, resulting in excellent stability and reproducibility [29]. Therefore, MALDI-TOF-MS is considered one of the most valuable methods currently available for detecting infections caused by *Paenibacillus* organisms. Similar to the 16 S rRNA technique, the successful identification of unknown bacteria using MALDI-TOF-MS relies on comparing the spectrum of the unknown strain with a library containing a sufficient number of known strains to achieve the best match. This approach yields realistic and reliable strain identification results but is primarily designed for identifying the target strain and not intended for broader screening or correlation purposes.

mNGS is capable of detecting a wide range of pathogens in clinical samples within a short timeframe, making it a rapid diagnostic tool. It is recognized as an unbiased and versatile high-throughput technology [30], meaning it does not rely on prior knowledge of the suspected pathogen and can screen a wide range of bacteria, fungi, and viruses, with high efficiency in clinical applications [31]. In addition, a key strength is its ability to provide information on antibiotic resistance by comparing sequenced genes in microorganisms with antibiotic resistance databases. In ophthalmic clinical applications, mNGS carries the advantage of requiring only a small volume (approximately 0.2 mL) of intraocular fluid, either aqueous or vitreous, for testing. In clinical scenarios where the nature of the infection is uncertain, such as not knowing whether it is viral, bacterial or parasitic, mNGS is a valuable and reliable method for the detection of pathogens, including *Paenibacillus* organisms, especially as it offers the advantage of comprehensive testing in a single assay.

Antibiotic resistance and treatment options

Paenibacillus isolates commonly exhibit high levels of penicillin resistance [22]. While certain antibiotics, such as cefotaxime, gentamicin, rifampicin, and vancomycin, are generally effective against *Paenibacillus*, there is variability in susceptibility to erythromycin [11]. Further, metronidazole has shown efficacy in treating *Paenibacillus lactis* [9]. However, *P. lautus* has demonstrated potential resistance to ampicillin, penicillin, clindamycin, chloramphenicol, rifampicin, and sulfamethoxazole based on drug susceptibility testing [14]. Studies have identified several antibiotics, including cefotaxime, ceftriaxone, amikacin, and levofloxacin, as effective treatments for *Paenibacillus* infections in individuals [32]. Nevertheless, reports have indicated that ampicillin, vancomycin, tetracycline, and clindamycin may not effectively combat *Paenibacillus* due to resistance issues [11, 16]. Hence, antimicrobial susceptibility testing remains imperative in clinical practice, even though multiple antibiotics have proven effective against *Paenibacillus* infections. Given reports of persistent infections, ongoing patient monitoring following treatment is essential [33]. In controlling *Paenibacillus* infections, it can be beneficial to eliminate localized sources of infection in conjunction with the administration of effective antibiotics for patients with localized infections.

Upon discharge, the patient's condition showed improvement, emphasizing the necessity of regular follow-up appointments to maintain treatment continuity. Regrettably, the patient failed to adhere to prescribed treatment due to personal reasons, leading to unavailability for further contact.

The limitation of the project stems from the loss of the sole case information during the post-discharge follow-up period. Future strategies entail the utilization of PCR testing [28] to investigate *Paenibacillus* infection in endophthalmitis, offering theoretical underpinning for endophthalmitis associated with *Paenibacillus* infection.

Conclusion

While *Paenibacillus* is a widespread bacterium in nature and can act as an opportunistic pathogen, only a limited number of *Paenibacillus* strains are known to cause infection in humans. This relative scarcity, combined with the challenges of identifying *Paenibacillus* in medical settings, can result in diagnostic complexities and delays in patient treatment. In cases where patients present with infections that are difficult to identify and understand, it is important to consider the possibility of *Bacteroidetes* infection. Once the diagnosis is confirmed, it becomes essential to administer appropriate and effective antibiotics in sufficient quantities. Also, if necessary, targeted interventions to eliminate affected areas can significantly contribute to favorable outcomes for the majority of patients.

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Author contributions

Shuwen Lu: Conceptualization, Writing– original draft, Writing– review & editing, Data curation, Formal analysis. Haoyu Li: Data curation, Formal analysis. Chao Ma: Project administration, Funding acquisition. Xian Li: Data curation.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study adhered to the Declaration of Helsinki, and therefore, formal approval was not deemed necessary. The patient willingly provided written informed consent to participate in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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