Pathophysiology

Pseudomonas aeruginosa

Although *P aeruginosa* is a common human saprophyte, it rarely causes disease in healthy persons. Most infections with this organism occur in compromised hosts. Examples of compromising conditions include disrupted physical barriers to bacterial invasion (eg, burn injuries, intravenous [IV] lines, urinary catheters, dialysis catheters, endotracheal tubes) and dysfunctional immune mechanisms, such as those that occur in neonates and in individuals with cystic fibrosis (CF), [1] acquired immunodeficiency syndrome (AIDS), neutropenia, complement deficiency, hypogammaglobulinemia, and iatrogenic immunosuppression.

The complete sequence of the genome of *P aeruginosa* strain, PAO1, is noted for its large size and diverse metabolic capacity. The pathogenesis of this organism is multifactorial and involves various toxins and proteases (eg, exotoxin A, lecithinase) and the glycocalyx "slime." *P aeruginosa* is both invasive and toxigenic. The 3 stages of *Pseudomonas* infections are (1) bacterial attachment and colonization, (2) local infection, and (3) bloodstream dissemination and systemic disease.

Efflux systems are thought to contribute to antimicrobial resistance in *P aeruginosa;* thus, efflux pump inhibitors are thought to be useful in reducing the invasiveness and antimicrobial resistance of *P aeruginosa* and may be promising as new anti-infectious agents. The genome annotation is continually updated, and the database functionality is being expanded to facilitate accelerated discovery of

P aeruginosa
drug targets and vaccine candidates.

Pseudomonal infection, as described by Pollack, occurs in 3 stages: (1) bacterial attachment and colonization, followed by (2) local invasion and (3) dissemination and systemic disease.[2]

In healthy children, disease is primarily limited to the first 2 stages (as in diseases such as otitis externa, urinary tract infections (UTIs), dermatitis, cellulitis, and osteomyelitis), although recent case reports describe bacteremia, sepsis, and GI infections in previously healthy children.

In immunocompromised hosts, including neonates, infection can progress rapidly through the 3 stages and cause pneumonia, endocarditis, peritonitis, meningitis, ecthyma gangrenosum (EG), bacteremia, and overwhelming septicemia.

Pseudomonas cepacia

In 1949, Walter Burkholder of Cornell University first described *P cepacia* (now known as *Burkh olderia cepacia*
) as the phytopathogen responsible for the bacterial rot of onions.
[3]
In the 1950s,
B cepacia
was first reported as a human pathogen that causes endocarditis. Subsequently, the organism has been found in numerous catheter-associated UTIs, wound infections, and IV catheter–associated bacteremias.

In 1971, this species was reported as the causative organism of foot rot in US troops on swamp training exercises in northern Florida; it also was isolated from troops serving in Vietnam's Mekong Delta. In 1972, *B cepacia* was discovered as an opportunistic human pathogen in a patient with CF. Since then, *B cepacia* has emerged with increasing frequency as the cause of pneumonia and septicemia in children with CF.

Pseudomonas mallei

P mallei (now known as *Burkholderia mallei*) causes glanders, a serious infectious disease of animals (primarily horses, although it has also been isolated in donkeys, mules, goats, dogs,

and cats). Transmission is believed to occur through direct contact. Glanders transmission to humans is rare and presumably occurs through inoculation of broken skin or the nasal mucosa with contaminated discharges. Manifestation of the disease in humans varies, ranging from an acute localized suppurative infection, acute pulmonary infection, or acute septicemic infection to chronic suppurative infection. Fulminant disease with multiple organ system involvement occurs with septicemic infection.

Pseudomonas pseudomallei

P pseudomallei (now known as *Burkholderia pseudomallei*) causes melioidosis (from the Greek, "resemblance to distemper of asses"). Melioidosis, also called Whitmore disease, clinically and pathologically resembles glanders but has an entirely different epidemiologic profile from *B mallei.* It occurs in many animals (eg, sheep, goats, horses, swine, cattle, dogs, cats). Transmission is believed to occur through direct contact, although inhalation reportedly is a possible route of acquisition. Since the first description of the disease from North Queensland, Australia, in 1962, melioidosis has spread to Southeast Asia.

B pseudomallei is found in contaminated water and soil. The pathogen spreads to humans and animals through direct contact with a contaminated source. In otherwise healthy hosts, disease manifestations range from acute to chronic local suppurative infections to septicemia with multiple abscesses in all organs of the body.

Mortality/Morbidity

Pseudomonal infections (eg, bacteremic pneumonia, sepsis, burn wound infections, meningitis) are associated with an extremely high mortality rate.

Monocular blindness is primarily due to bacterial keratitis, the causes of which include pseudomonal infection. Colonization with *B cepacia* has been associated with increased morbidity and mortality in patients who are immunocompromised, especially those with CF.

Untreated glanders and melioidosis bloodstream infections are usually fatal within 7-10 days. *P aeruginosa*
bacteremia has an estimated mortality rate exceeding 50% and is associated with fatality rates higher than those associated with other gram-negative bacteremic infections. Pseudomonal pneumonia, especially the bacteremic type, is associated with mortality that typically occurs 3-4 days after the first signs or symptoms of pulmonary or extrapulmonary infection.
Ventilator-associated pneumonia (VAP) caused by
P aeruginosa
is associated with higher mortality rates (estimated to be as high as 68%) than VAPs caused by other infectious organisms. The mortality rate is high for the septicemic form of EG and is approximately 15% for the nonsepticemic form of the disease.

History

Pseudomonas aeruginosa is so ubiquitous in the hospital environment that distinguishing infection from colonization is often difficult. Furthermore, symptoms are often identical to those observed in other gram-negative infections. As a result, clinical evidence of infection should accompany any culture of the organism at a potential infection site. *P aeruginosa*
reportedly emits a characteristic sweet odor.
P aeruginosa
is responsible for a broad spectrum of disease, including the following types of infections:

- AIDS-related infections
- Bacteremia and sepsis
- Fever is often the initial symptom. Some patients may also present with tachypnea or tachycardia.
- Hypotension and shock may develop.
- Jaundice may occur.
- Suspect pseudomonal bacteremia in individuals who are immunocompromised (including neonates), who have an extended hospitalization, who have received prolonged antibiotic administration or multiple antibiotics, or who have indwelling catheters.

- Febrile neutropenia
- Bone and joint infection (eg, osteochondritis, osteomyelitis, pyarthrosis)
- Infections of the bones and joints typically result from hematogenous spread from another primary site. This may occur in individuals who have used intravenous (IV) drugs and who have associated urinary tract infections (UTIs) or pelvic infections, in those with penetrating trauma, in postsurgical patients, in those with primary soft tissue infection, and in patients with diabetes

or rheumatoid disease.

- Patients (especially children) may present with osteochondritis after a puncture of the foot through a sneaker or tennis shoe.
- The sternoclavicular and sacroiliac joints, vertebra, and symphysis pubis are typically involved in individuals who have used IV drugs.
- Postsurgical patients tend to develop infections in the long bones, especially patients who underwent internal fixation for open fractures. Vertebral osteomyelitis is occasionally observed as a complication of UTI and genitourinary (GU) surgery or instrumentation. Because of vascular insufficiency in the lower extremities of patients with diabetes, they may develop osteomyelitis of the foot. Patients with rheumatoid disease may develop infections in large synovial joints.
- Children who present with osteochondritis typically experience pain and edema 3-4 days following a puncture wound, only to have symptoms recur or worsen later. Symptoms usually persist more than 1 week without any systemic signs or fever.
- Sternoarticular pyarthrosis, often seen in individuals who abuse IV drugs, is usually associated with endocarditis, although the primary site is often indiscernible. Joint involvement is typically monoarticular. Complaints include fever, pain, and restricted movement of the shoulder, with limited-to-severe anterior chest pain over the affected joint.
- Patients with vertebral osteomyelitis can present with pain that persists from weeks to months, especially in the neck or back region. Fever and constitutional symptoms are relatively rare.
- Chronic contiguous osteomyelitis commonly occurs after a compound fracture or as a complication of surgery for closed fracture of the long bones. It occasionally occurs after a foot puncture wound, as an extension of infection of ischemic ulcers in patients with peripheral vascular disease, following cardiac surgery, and as a complication of peripheral neuropathy associated with pressure necrosis of skin and soft tissue.

- Skin and soft tissue infections (eg, burn wound sepsis, dermatitis, ecthyma gangrenosum [EG], pyoderma, cellulitis, hot tub folliculitis, necrotizing fasciitis, chronic paronychia)
- Do not confuse EG with pyoderma gangrenosum or streptococcal ecthyma; EG is a rare but pathognomonic form of pseudomonal infection. Although EG is often due to *Pseudomonas,* case reports indicate that the same frequency is associated with non-*Pseudomonas* EG (ie, *Fusarium, Klebsiella*).

- EG in patients without neutropenia is very rare, as is nonbacteremic EG cases. However, nonsepticemic cases occur in patients without immunosuppression or neutropenia or following antibiotic therapy.
- Pseudomonal burn wound infections occur with systemic involvement (eg, bacteremia, fever, hypothermia, disorientation, obtundation, hypotension, oliguria, ileus, leukopenia).
- Chronic paronychia slowly evolves and initially presents with tenderness and mild swelling about the proximal and lateral nail folds.

- Pseudomonal toe web infections are distinctive clinical entities often misdiagnosed as tinea pedis. Dried exudate or a green stain (caused by pyoverdin) may be found on socks or toenails.
- Pseudomonal folliculitis presents as cutaneous lesions any time from 8 hours to 5 days or more (mean incubation period is 48 h) after using a contaminated whirlpool, home hot tub, water slide, physiotherapy pool, or contaminated loofah sponge. Malaise and fatigue may occur during initial days of the eruption. Fever (uncommon) is low grade when present.
- Localized cellulitis can occur as a secondary infection of tinea of the toe webs or groin; from bedsores, stasis ulcers, or burns; in grafted areas; or under the foreskin of the penis. Maceration or occlusion of these skin lesions leads to secondary infection. Deep erosions and tissue necrosis may occur before the condition is diagnosed correctly. Severe pain is highly characteristic of an evolving infection.

- CNS infection (eg, brain abscess, meningitis)
- CNS infections are more common among patients who are immunocompromised or in patients who recently have undergone a neurosurgical procedure.
- *P aeruginosa* has been isolated with increasing frequency in older patients with meningitis, but pseudomonal infections rarely cause neonatal meningitis.
- Clinical symptoms are indistinguishable from other forms of bacterial meningitis. Symptoms can be nonspecific (eg, headache, fever, nausea, vomiting, disorientation, lethargy, stiff neck).
- Often, CNS involvement is due to a complication from another site (eg, malignant external otitis). Although CNS complications are rare, they are often fatal. These include meningitis, brain abscess, and dural sinus thrombophlebitis.

- Ear infections (eg, otitis media, chronic suppurative otitis media, otitis externa, malignant external otitis)
- Involvement of the ear can present as a mild, superficial, and often self-limited infection (eg, swimmer ear) or as malignant otitis externa. Early stages of swimmer's ear are characterized by erythema, edema, accumulation of debris in the canal, and, sometimes, pain. As the disease progresses, the erythema radiates into the pinna, and purulent material partly obstructs the ear, exuding from the canal.
- More than 95% of cases of malignant external otitis are caused by *P aeruginosa*. Clinical presentation starts with a history of nonresolving otitis externa, especially in patients who have diabetes or AIDS. Patients present with severe ear pain (otalgia) that worsens at night and a purulent discharge (otorrhea). The pinna may be involved. As the disease progresses, osteomyelitis of the base of the skull and temporomandibular joint osteomyelitis can occur.

- Children with malignant external otitis have a higher incidence of facial palsy because of underdevelopment of their mastoid process and because of the more medial location of the fissures of Santorini, placing the facial nerve closer to the ear canal. The glossopharyngeal, vagal, spinal accessory, and hypoglossal nerves can be involved. The trigeminal and abducens nerves are rarely affected, and optic nerve involvement has been reported. Involvement of the olfactory, oculomotor, and trochlear nerves has not been reported.

- Eye infections (eg, endophthalmitis, keratitis, ophthalmia neonatorum, blepharoconjunctivitis, scleral abscess, orbital cellulitis)
- Although pseudomonal eye infections are often associated with hydrophilic contact lens wear, infections have also been reported in patients who do not wear contact lenses.
- Pseudomonal keratitis can present as a rapidly developing, necrotic, grayish stromal infiltrate in a bed of epithelial injury and surrounding edema. Disease progression varies but can rapidly progress and involve the entire cornea within 48 hours, leading to perforation. Fever and systemic symptoms are usually absent.
- Pseudomonal corneal ulcers may lead to rapid loss of visual function and are considered a medical emergency.
- Pseudomonal endophthalmitis progresses more rapidly than other bacterial infections. Clinical features may include pain, conjunctival hyperemia, chemosis, lid edema, decreased visual acuity, hypopyon, or severe anterior uveitis with involvement of the vitreous and panophthalmitis.

- GI infections (eg, epidemic diarrhea, necrotizing enterocolitis (NEC), typhlitis, rectal abscess, Shanghai fever)
- Presentation is indistinguishable from other bacteremic GI infections.
- Neonates may present with NEC.
- Those with hematological malignancies may develop typhlitis or a rectal abscess.
- Epidemics of pseudomonal diarrheal diseases occur in children.

- GU infections (eg, epididymitis, prostatitis, urethritis, UTIs): The clinical presentation of pseudomonal UTIs is indistinguishable from other bacterial UTIs.
- Cardiovascular (CV) infections (eg, endocarditis, pericarditis, cardiac tamponade)
- Pseudomonal infectious endocarditis (IE) affects normal and abnormal valves on both sides of the heart, resulting in valve destruction and heart failure. Biventricular and multiple valve infections are common in pseudomonal IE.
- This organism has been isolated in patients with IE who abuse IV drugs, specifically pentazocine and tripelennamine (ie, "Ts" and "blues"). Individuals who abuse pentazocine and tripelennamine have a propensity for right-sided IE.
- Fever is the most common symptom.

- Respiratory infections (eg, primary or nonbacteremic, bacteremic, colonization, and nosocomial pneumonia, lower respiratory tract infections of cystic fibrosis [CF], ventilator-associated pneumonia [VAP])
- Symptoms in patients with CF vary from frequent upper respiratory infections (URIs) and a persistent cough after each bout to recurrent episodes of pneumonia, with or without a lingering cough between exacerbations. Most patients eventually develop a chronic and increasingly severe productive cough, decreased appetite, weight loss, and diminished activity, particularly during exacerbation. Evidence suggests that chronic *P aeruginosa* lung infection plays a role in bronchiectasis development. Other symptoms include wheezing, tachypnea, and

irritability. Low-grade fever often accompanies exacerbations; high-grade fever is uncommon.

- Bacteremic pseudomonal pneumonia usually occurs in patients with malignancies (especially malignancies involving the hematopoietic system), in patients who are neutropenic as a result of chemotherapy, and in children and adults with AIDS.
- Primary or nonbacteremic pneumonia results from aspiration of *Pseudomonas* species from upper respiratory structures that have been colonized. The disease process is fulminant, usually fatal, and characterized clinically by fever, chills, severe dyspnea, copious and purulent-productive cough, cyanosis, apprehension, mental confusion, and systemic toxicity.

- Glanders
- Glanders also occurs in stages, with symptoms depending on the organism's route of infection. Generalized symptoms include fever, muscle aches, chest pain, muscle tightness, and headache. Additional symptoms may include excessive eye tearing, light sensitivity, and diarrhea.
- Types of infections associated with glanders include the following:
- Localized infections: From a cut or scratch in the skin, a localized infection with ulceration develops within 1-5 days at the site where the bacteria penetrated the body. Lymph nodes may also be swollen. Infections involving the mucous membranes in the eyes, nose, and respiratory tract cause increased mucus production from the respective sites.
- Pulmonary infections: These may cause pneumonia, pulmonary abscesses, and pleural effusion. Radiography reveals localized infection in the lobes of the lungs.
- Bloodstream infections: A bloodstream infection associated with glanders is usually fatal within 7-10 days without any treatment.
- Chronic infections: The chronic form of glanders involves multiple abscesses within the muscles of the arms and legs or in the spleen or liver.

- Melioidosis
- Melioidosis stages include acute, localized, and chronic infections. The incubation period is not clearly defined but may range from 2 days to years.
- Stages of melioidosis include the following:
- Acute: Characterized by a localized nodule, caused by inoculation of the bacteria through a break in the skin, which can lead to secondary lymphangitis, regional lymphadenitis, fever, and myalgia. Acute melioidosis may rapidly progress to infect the bloodstream.
- Pulmonary infection: The clinical picture ranges from mild bronchitis to severe pneumonia. Onset of pulmonary melioidosis is usually associated with high fever, headache, anorexia, and general myalgia. Chest pain is also common. The hallmark is a nonproductive or productive cough with normal sputum.
- Acute bloodstream infection: Patients with underlying illness (eg, HIV, renal failure, diabetes) are predisposed to this form of the disease, which usually results in septic shock. Symptoms of bloodstream infection vary, depending on the original infection site, but generally

include respiratory distress, severe headache, fever, diarrhea, development of pus-filled lesions on the skin, myalgia, and disorientation. The infection typically has short duration, although abscesses form throughout the body.

- Chronic suppurative infection: Chronic melioidosis is an infection involving several organs, typically including the joints, viscera, lymph nodes, skin, brain, liver, lung, bones, and spleen. Chronic apical lung disease often resembles tuberculosis (TB).

Physical

The clinical presentation of pseudomonal infections depends on the site of infection and is often indistinguishable from other gram-negative organisms.

Glanders and melioidosis infections have different stages with varied clinical presentations.

- Bacteremia and sepsis
- Clinical presentation is often identical to other gram-negative organisms.
- Fever is usually present, except in very young or premature infants. Fever is often accompanied by tachycardia and tachypnea.
- Patients appear toxic and may present with apprehension, disorientation, or obtundation.
- Signs of shock, including hypotension, azotemia, or acute renal failure, may be observed.

- Respiratory failure occurs in the presence of bacteremic pseudomonal pneumonia or in conjunction with airway restrictive disease syndrome.
- Jaundice appears to occur more often than in other forms of gram-negative sepsis, but disseminated intravascular coagulation (DIC) is relatively uncommon.
- Skin lesions may be an important distinguishing feature of pseudomonal bacteremia, especially typical EG lesions.
- A diffuse maculopapular eruption, primarily on the trunk, has also been reported in early stages of pseudomonal sepsis. Metastatic abscesses of the extremities and fingertips occasionally manifest later in the course of the disease.

- Bone infections
- Because pseudomonal infections have a predilection for fibrocartilaginous joints of the axial skeleton, determining whether arthritis preceded or resulted from the infection is difficult. The disease process is usually indolent, and it is not as destructive and does not progress as

rapidly as other infections.

- Pseudomonal osteochondritis presents with a superficial area of cellulitis on the plantar surface of the foot; deep palpation reveals slight tenderness.
- Physical signs of sternoarticular pyarthrosis include erythema, edema, tenderness over the affected joint, and restricted range of motion of the ipsilateral shoulder.
- Physical signs in patients with vertebral osteomyelitis include local tenderness and decreased range of motion of the spine. Neurologic deficits, which tend to be mild, occur in approximately 15% of cases.
- Differentiate between patients with infection of the pubic symphysis and those with osteitis pubis.

- Skin infections
- The hallmark lesions resulting from pseudomonal wound infections are multifocal, with dark-brown to black or violaceous discoloration of the burn eschar, and are accompanied by edema and hemorrhagic necrosis.
- EG lesions are multiple noncontiguous ulcers or solitary ulcers. These lesions begin as isolated, red, purpuric macules that become vesicular, indurated, and, eventually, bullous or pustular. The bullae may be hemorrhagic but contain little if any pus. Lesions can remain localized or, more often, can extend over several centimeters. The central area of these lesions becomes hemorrhagic and necrotic, and then the lesion denudes to form a gangrenous ulcer with a gray-black eschar and erythematous halo. Although lesions can occur anywhere, they occur mainly in the gluteal and perineal regions (57%), the extremities (30%), the trunk (6%), and the face (6%). These skin lesions slowly heal. Patients with septicemia have associated signs that include elevated temperatures, chills, hypotension, tachycardia, and tachypnea.

- In chronic paronychia, the skin around the nail becomes pale, red, painful, and swollen. A small amount of pus may occasionally be expressed from beneath the proximal nail fold. The nail plate turns green-black, which is characteristic of pseudomonal infections. The conditions cause little discomfort or inflammation. This presentation is often confused with subungual hematoma.
- A *Pseudomonas* -infected toe web presents as a thick, white, macerated scale with a green discoloration in the toe webs. The most consistent clinical feature is soggy wet toe webs and adjacent skin. In the mildest form of pseudomonal infection in the toe web, the affected tissue is damp, softened, boggy, and white. The second, third, and fourth toe webs are the most common sites of initial involvement. Severe forms may progress to denuded skin and profuse, serous, or purulent material.
- Pseudomonal folliculitis presents with a few to more than 50 urticarial plaques that measure 0.5-3 cm in diameter, with a central papule or pustule on all skin surfaces other than the head. The rash can be a polymorphous eruption or a mixture of follicular, maculopapular, vesicular, or pustular lesions. These lesions often are pruritic; most clear in 7-10 days, leaving round spots of red-brown postinflammatory hyperpigmentation. However, some patients may have recurrent crops of lesions over an extended period of 3 months

- Pseudomonal cellulitis presents with a dusky red–to–bluish green skin discoloration and purulent discharge. The typical fruity or mouselike odor has been linked to pseudomonal infection. Vesicles and pustules may occur as satellite lesions. The eruption may spread to cover wide areas and cause systemic manifestations.
- CNS infections
- Clinical signs of pseudomonal meningitis are indistinguishable from bacterial meningitis, except for the hallmark EG skin lesions.
- Signs of CNS infections in neonates are often nonspecific and subtle (eg, fever, hypothermia, lethargy, seizures, irritability, bulging fontanel, respiratory distress, feeding intolerance, vomiting).
- In children and adults, physical presentations of bacterial meningitis can include fever, photophobia, nuchal rigidity, lethargy, disorientation, coma, and ataxia.

- Ear infections
- Involvement of the ear can be mild to severe.
- Pain can be elicited by traction of the tragus or pinna, although pain becomes persistent as the disease progresses.
- Typical presentations include erythema, edema, pain, and warmth; however, many individuals who are immunocompromised may manifest no signs.

- Eye infections
- Ring ulcers can reportedly develop.
- The corneal epithelium peripheral to the primary ulcer typically develops a diffuse, gray, ground-glass appearance. The ulcer is also associated with marked anterior chamber reaction and hypopyon formation.
- Extensive keratitis can extend to the limbus and produce an infectious scleritis.
- Diffuse epithelial disease is usually associated with hydrophilic contact lens wear.

- GI infections
- Pseudomonal infections can affect the entire alimentary canal, from the oropharynx to the rectum. The clinical presentation is often indolent, except for occasional NEC (in premature infants), typhlitis, hemorrhagic and necrotic ulcers, and abscesses in infants, older children, and adults. Skin manifestations can occur.
- NEC presents with irritability, signs of dehydration, vomiting, diarrhea, dehydration, abdominal distension, and signs of peritonitis.
- Diarrheal epidemics can present with mild-to-severe diarrhea, signs of dehydration, and vascular collapse. Pseudomonal infections have also been causally associated with Shanghai fever, a syndrome associated with diarrhea or constipation, rash, and fever persisting as long as 1-2 weeks.
- The pathological changes observed in patients with typhlitis range from localized lesions in the cecum to necrosis and gangrene with perforation and peritonitis.
- Although rare, rectal abscesses can spread to the scrotum and penis, leading to Fournier

gangrene.

- GU infections
- Presentations of pseudomonal UTIs are generally indistinguishable from other bacterial UTIs.
- One rare exception is development of ulcerative lesions of the bladder mucosa, ureters, and renal pelvis, resulting in sloughing of vesical membrane in the urine.
- Another rare sequela is the development of multiple renal infarcts.

- CV infections
- Endocarditis can present with a cardiac murmur, depending on the valve affected.
- Skin and soft tissue manifestations (eg, Osler nodes, Janeway lesions) are rare in both right-sided and left-sided diseases.

- Respiratory infections
- Physical signs in patients with CF include evidence of undernutrition, increased anteroposterior diameter, retractions, cyanosis, inspiratory and expiratory wheezing, rhonchi, localized or generalized moist rales, abdominal distention, and clubbing of fingers and toes.

- A rapid progression from pulmonary vascular congestion to pulmonary edema to necrotizing bronchopneumonia occurs in patients with bacteremic pseudomonal infections. Physical signs that can be expected include retraction, crackles, rhonchi, dulled reflexes, fever, and cyanosis.
- Primary nonbacteremic pseudomonal infections can present as a diffuse bronchopneumonia, which is typically bilateral. Small pleural effusions are common, empyema is rare, and a pattern of lobar consolidation is sometimes noted. Correlating physical signs include crackles, rhonchi, and dulled reflexes at bases.

- Bacteremia: Conditions that predispose disease progress to bacteremia include hematological malignancies, immunoglobulin deficiency states, neutropenia, diabetes mellitus (DM), organ transplantation, severe burns, diffuse dermatitis, and AIDS. Other predisposing factors include cancer chemotherapy that causes neutropenia or ulceration of the respiratory and GI tracts, steroid administration, antibiotic therapy, placement of IV lines, urinary tract instrumentation or catheterization, surgery, trauma, and premature birth. IV lines should be inserted under sterile conditions and should be changed per hospital protocol.
- Bone infections: Individuals at risk include persons who abuse IV drugs; postsurgical patients; patients with penetrating trauma, diabetes, peripheral vascular disease, or rheumatoid arthritis; older persons; and patients with chronic debilitation.
- Skin infections: *Pseudomonas* species do not grow on dry skin. Patients who are exposed to moisture have an increased risk for skin infections. Separation of the cuticle from the nail plate (ie, onycholysis) leaves the space between the proximal nail fold and nail plate exposed to bacteria, which results in chronic paronychia and pseudomonal toe web. People who wear

heavy wet boots also are more likely to develop pseudomonal toe web infections. Children have higher risk than adults of developing folliculitis from exposure to
Pseudomonas
organisms in a contaminated whirlpool, home hot tub, water slide, physiotherapy pool, or contaminated loofah sponge.

- CNS infections: Pseudomonal meningitis occurs in patients who have had recent neurosurgical procedures or who are immunocompromised. A brain abscess, however, rarely occurs in an immunocompromised host; the risk of brain abscess is higher is patients with otitis media or paranasal sinusitis, and it is a common etiology in older patients. Predisposing factors of neonatal meningitis include maternal infections (especially UTI and uterine infections) and the following obstetrical risk factors:
- Prolonged and premature rupture of membranes
- Birth trauma
- Prematurity
- Low birth weight (ie, <2500 g)
- Congenital anomalies
- Perinatal hypoxia or asphyxia
- Neonates whose treatment included cardiopulmonary resuscitation and monitoring, prolonged ventilatory support, and/or multiple IV line insertions

- Ear infections: Malignant otitis externa occurs in patients who are older and in patients who have diabetes or AIDS.
- Eye infections: Contact lens wearers have an increased risk of developing gram-negative infections, including pseudomonal infections. Pseudomonal endophthalmitis may result from penetrating trauma, intraocular surgery, posterior perforation of a corneal ulcer, or hematogenous spread from another primary site.
- GI infections: Pseudomonal infections can affect every portion of the GI tract. The disease is often underestimated; the highest risk is among young infants, children, and persons with hematological malignancies and chemotherapy-induced neutropenia. Additionally, colonization of the GI tract is an important portal of entry for pseudomonal bacteremia in patients who are neutropenic. The spectrum of disease can range from very mild symptoms to severe NEC with significant morbidity and mortality.
- GU infections: The greatest risk is among patients who are hospitalized and patients who had urinary tract catheterization, instrumentation, or surgery. These infections can involve the urinary tract through an ascending infection or through bacteremic spread and are a frequent source of bacteremia. An obvious preventive measure is to avoid catheterization. If this is not possible, the catheter should be removed as soon as possible. Catheters should be inserted aseptically under sterile conditions. The most important hygienic measure is handwashing by health care personnel. If a urinary catheter is required for long periods, it should be replaced per hospital protocol. Catheters and the area around the urethra should be cleaned with soap and water daily and after each bowel movement. Prophylactic use of antibiotics is not recommended because it leads to the emergence of resistant strains of bacteria.
- CV infections: The risk of endocarditis among individuals who abuse IV drugs (ie, 2-5% per person-year) is much greater than the risk for patients with rheumatic heart disease or

prosthetic valves. A case report describes an infant with human immunodeficiency virus (HIV) who developed pseudomonal pericarditis and tamponade, which suggests pericardial effusions are more common in patients with HIV than previously recognized. [4]

- Respiratory infections: Lower respiratory tract infections with *P aeruginosa* occur almost exclusively in persons with compromised respiratory systems, especially patients with CF. Most bacteremic pseudomonal pneumonia occurs in patients with malignancies and immunodeficiencies. Primary nonbacteremic pseudomonal pneumonia occurs in patients who have colonization of
Pseudomonas
organisms. It can be hospital-associated in the ICU setting and is associated with positive-pressure ventilation and endotracheal tubes. The pneumonia may be primary or may follow aspiration of the organism from the upper respiratory tract, especially in patients on mechanical ventilation. Alternatively, it may occur as a result of bacteremic spread to the lungs. Because
Pseudomonas
species can multiply in nebulizer fluid, proper cleaning, sterilization, and disinfection of reusable equipment are required.

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- Ear infections: Malignant otitis externa occurs in patients who are older and in patients who have diabetes or AIDS.
- Eye infections: Contact lens wearers have an increased risk of developing gram-negative infections, including pseudomonal infections. Pseudomonal endophthalmitis may result from penetrating trauma, intraocular surgery, posterior perforation of a corneal ulcer, or hematogenous spread from another primary site.
- GI infections: Pseudomonal infections can affect every portion of the GI tract. The disease is often underestimated; the highest risk is among young infants, children, and persons with hematological malignancies and chemotherapy-induced neutropenia. Additionally, colonization of the GI tract is an important portal of entry for pseudomonal bacteremia in patients who are neutropenic. The spectrum of disease can range from very mild symptoms to severe NEC with significant morbidity and mortality.
- GU infections: The greatest risk is among patients who are hospitalized and patients who had urinary tract catheterization, instrumentation, or surgery. These infections can involve the urinary tract through an ascending infection or through bacteremic spread and are a frequent source of bacteremia. An obvious preventive measure is to avoid catheterization. If this is not possible, the catheter should be removed as soon as possible. Catheters should be inserted aseptically under sterile conditions. The most important hygienic measure is handwashing by health care personnel. If a urinary catheter is required for long periods, it should be replaced per hospital protocol. Catheters and the area around the urethra should be cleaned with soap and water daily and after each bowel movement. Prophylactic use of antibiotics is not recommended because it leads to the emergence of resistant strains of bacteria.
- CV infections: The risk of endocarditis among individuals who abuse IV drugs (ie, 2-5% per person-year) is much greater than the risk for patients with rheumatic heart disease or prosthetic valves. A case report describes an infant with human immunodeficiency virus (HIV) who developed pseudomonal pericarditis and tamponade, which suggests pericardial effusions are more common in patients with HIV than previously recognized. [4]
- Respiratory infections: Lower respiratory tract infections with *P aeruginosa* occur almost exclusively in persons with compromised respiratory systems, especially patients with CF. Most bacteremic pseudomonal pneumonia occurs in patients with malignancies and immunodeficiencies. Primary nonbacteremic pseudomonal pneumonia occurs in patients who have colonization of
Pseudomonas
organisms. It can be hospital-associated in the ICU setting and is associated with positive-pressure ventilation and endotracheal tubes. The pneumonia may be primary or may follow aspiration of the organism from the upper respiratory tract, especially in patients on

mechanical ventilation. Alternatively, it may occur as a result of bacteremic spread to the lungs. Because
Pseudomonas
species can multiply in nebulizer fluid, proper cleaning, sterilization, and disinfection of reusable equipment are required.