DISEASE SUMMARY

Definitions

Bacterial pneumonia (from the Greek pneuma, "breath") is a potentially fatal infection and inflammation of the lower respiratory tract (i.e., bronchioles and alveoli) usually caused by inhaled bacteria (most commonly Streptococcus pneumoniae, aka pneumococcus). The illness is frequently characterized by high fever, shortness of breath, rapid breathing, sharp chest pain, and a productive cough with thick phlegm. Pneumonia that develops outside the hospital setting is commonly referred to as community-acquired pneumonia. Pneumonia that develops 48 hours or later after admission to the hospital is known as nosocomial or hospital-acquired pneumonia.

Prevalence

Approximately 4.5 million cases of community-acquired pneumonia occur annually in the United States. The overall incidence of community-acquired pneumonia is reported to be 170 cases per 100,000 persons. Frequency estimates of nosocomial pneumonia in the United States range from 4 to 7 episodes per 1000 hospitalizations. Approximately 25% of patients in intensive care units develop pneumonia. Pneumonia is more prevalent during the winter months and in colder climates. Incidence is greater in males than in females and advanced age increases the frequency. Elderly people have a weaker immune response, a higher risk for aspiration of bacteria, and health conditions (e.g., heart failure) that increase one's vulnerability for developing bacterial pneumonia as a complication. With advancing age, the incidence of pneumonia increases from 94 cases per 100,000 persons aged 44 years to 280 cases per 100,000 persons older than 65 years.

Significance

Despite advances in the identification of causative microbes and the availability of new antimicrobial drugs, pneumonia continues to be a major health problem. In addition, there is still much controversy regarding diagnostic approaches and treatment choices.

CASE STUDY

BACTERIAL PNEUMONIA

For the Patient Case for this case study, see the printed book.
Pneumonia is the sixth leading cause of death in the United States and the most common cause of death from infectious disease. Furthermore, pneumonia is the leading cause of death among hospital-acquired infections.

Left untreated and depending on the causative microbe and population, bacterial pneumonia has a mortality rate that may exceed 30%. Every year more than 60,000 Americans die from pneumonia. Pneumococcal pneumonia alone accounts for an estimated 40,000 deaths yearly. The disease is a particular concern for older adults and people with chronic illnesses or an impaired immune system, but it can also strike previously healthy, young people. Worldwide, pneumonia is a leading cause of death in children, many of whom are younger than 1 year of age.

Bronchiectasis is a potential major complication of bacterial pneumonia. Destroyed alveoli and bronchioles are replaced by small sacs filled with infected debris. A low-grade, smoldering infection destroys more lung tissue with time. Bacterial pneumonia may also cause destruction of lung tissue with subsequent scarring, a permanent decrease in gas exchange, and a loss of respiratory reserve. The lungs also become less elastic and inflation of the lungs requires more energy and work during the inspiratory phase of respiration.

Bacterial pneumonia can turn deadly when fluid fills the air sacs and interferes with the ability to exchange oxygen and carbon dioxide. Circulating oxygen levels decrease (i.e., hypoxemia) and circulating carbon dioxide concentrations increase (i.e., hypercapnia), leading ultimately to respiratory failure and death. In some cases, microorganisms gain access to the blood—a condition known as bacteremia—spread rapidly to other organs, and cause life-threatening sepsis or septic shock.

**Causes and Risk Factors**

Dozens of types of bacteria can cause pneumonia. Bacterial pneumonia is caused by an infection of the lungs and may present as a primary disease or as secondary disease in a debilitated individual or following a viral upper respiratory infection, such as influenza or the common cold. Community-acquired pneumonia tends to be caused by different microorganisms than those infections acquired in the hospital. Some of the more common causative microorganisms are shown in Disease Summary Table 13.1.

Pneumonia caused by *Streptococcus pneumoniae* remains the most common cause of all bacterial pneumonias. High-risk groups include older adults and people with a chronic illness or compromised immune system. This type of pneumonia is a common complication of chronic cardiopulmonary disease (e.g., heart failure) or an upper respiratory tract infection. *Mycoplasma* are the smallest free-living agents of disease in man and have properties of both bacteria and viruses. These microbes are a cause of “walking pneumonia,” which occurs primarily in the summer and fall. Patients may not be sick enough to stay in bed or seek medical care and occasionally may not know that they have pneumonia. Mycoplasmal pneumonia is common in children who attend childcare centers and among school-age children and young adults. The disease may account for as many as one in three cases of childhood pneumonia.

Pneumonia from *Haemophilus influenzae* most commonly arises in the winter and early spring and often follows an upper respiratory infection. This pneumonia is also associated with hosts who are debilitated. Young age, old age, asthma, chronic obstructive pulmonary disease (COPD), smoking, and a compromised immune system are risk factors.

<table>
<thead>
<tr>
<th>Disease Summary Table 13.1 Common Causative Microbes of Community- and Hospital-Acquired Pneumonia</th>
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</thead>
<tbody>
<tr>
<td>Causes of Community-Acquired Pneumonia</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em></td>
</tr>
<tr>
<td><em>Mycoplasma pneumoniae</em></td>
</tr>
<tr>
<td><em>Haemophilus influenzae</em></td>
</tr>
<tr>
<td><em>Legionella pneumophila</em></td>
</tr>
<tr>
<td><em>Chlamydia pneumoniae</em></td>
</tr>
<tr>
<td><em>Moraxella catarrhalis</em></td>
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</tbody>
</table>

**Disease Summary Table 13.2 Risk Factors Associated with Specific Types of Bacterial Pneumonia**

<table>
<thead>
<tr>
<th>Risk Factors for Bacterial Pneumonia</th>
<th>Causative Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure to overcrowded institutions such as jails, shelters for homeless people, military training barracks, and childcare centers</td>
<td><em>Streptococcus pneumoniae</em>, <em>Mycoplasma pneumoniae</em>, <em>Chlamydia pneumoniae</em></td>
</tr>
<tr>
<td>Diabetic ketoacidosis</td>
<td><em>S. pneumoniae</em>, <em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td><em>Moraxella catarrhalis</em></td>
</tr>
<tr>
<td>Solid organ transplantation (primarily from immunosuppressant drugs)</td>
<td><em>S. pneumoniae</em>, <em>Legionella pneumophila</em>, <em>M. catarrhalis</em></td>
</tr>
<tr>
<td>Sickle cell disease (secondary to loss of splenic function)</td>
<td><em>S. pneumoniae</em>, <em>Haemophilus influenzae</em></td>
</tr>
<tr>
<td>Cystic fibrosis</td>
<td><em>S. aureus</em>, <em>Pseudomonas aeruginosa</em></td>
</tr>
<tr>
<td>Gastrointestinal surgery</td>
<td><em>Escherichia coli</em></td>
</tr>
</tbody>
</table>


* Legionella pneumophila* infections tend to occur sporadically and in local outbreaks. Although more than 14 types of *L. pneumophila* have been identified, serotype 1 accounts for more than 80% of reported cases of legionellosis. The organism frequently is found in warm, standing water. Legionella pneumonia was named after an outbreak in 1976 that affected approximately 180 members of the American Legion who were staying at the same Philadelphia hotel for an annual convention. Twenty-nine legionnaires died and the causative microbe was not identified until the following year. These infections usually arise in the summer and fall and bacteria may be found in the water condensed from air conditioning systems or in contaminated hospital water systems.

Although everyone is at risk, adolescents and young adults are most commonly affected by chlamydial pneumonia. The chlamydial strain that causes pneumonia is not the same microbe that causes sexually transmitted chlamydia.

Gram-negative pneumonias (e.g., caused by *Escherichia coli*, *Pseudomonas*, *Enterobacter*, or *Serratia*) are observed in individuals who are debilitated, immunocompromised, or recently hospitalized. Previous antibiotic therapy and mechanical ventilation are also risk factors.

Aspiration plays a central role in the pathogenesis of nosocomial pneumonia. Approximately 45% of healthy subjects aspirate during sleep, and an even higher percentage of severely ill patients aspirate routinely. The oropharynx of hospitalized patients may become colonized with aerobic gram-negative bacteria within a few days after admission, and nosocomial pneumonia is predominantly caused by gram-negative bacteria. Any individual with a subnormal level of consciousness (e.g., due to seizures or alcohol or drug intoxication) or central nervous system impairment (e.g., due to a stroke) may have a reduced gag reflex that allows aspiration of stomach or oropharyngeal contents containing bacteria. Typical causative organisms include *Moraxella catarrhalis* and the anaerobic organisms *Bacteroides*, *Peptostreptococcus*, and *Fusobacterium*. When isolated, these bacteria are commonly part of a polymicrobial flora.

Bacterial pneumonia caused by *Staphylococcus aureus* is commonly observed in intravenous drug users, individuals with debilitating diseases (especially cystic fibrosis), patients with prosthetic devices, hospitalized patients, and residents of chronic care facilities. In patients who abuse intravenous drugs, the infection probably is spread through the blood to the lungs from contaminated injection sites. *S. aureus* also is an important cause of pneumonia following infection with influenza A virus.

Patients with chronic alcoholism, diabetes mellitus, or COPD are at increased risk for bacterial pneumonia caused by *Klebsiella pneumoniae*. Other risk factors that are associated with specific types of pneumonia are shown in Disease Summary Table 13.2.

### Pathophysiology

Bacteria commonly enter the respiratory tract but, due to multiple defense mechanisms, do not normally cause pneumonia. When pneumonia does occur, it usually is the result of an exceedingly virulent microbe, a large "dose" of bacteria, and/or impaired host defense.
mechanisms. A list of the five primary respiratory defense mechanisms and conditions that interfere with function is shown in Disease Summary Table 13.3.

When microorganisms evade upper respiratory defense mechanisms, the alveolar macrophage is capable of removing most infectious agents without triggering a significant inflammatory or immune response. However, if the microbe is virulent or present in sufficiently high numbers, it can overwhelm macrophages and result in a full-scale activation of systemic defense mechanisms. These mechanisms include the release of multiple chemical mediators of inflammation, infiltration of white blood cells, and activation of the immune response.

Tight adherence of some bacteria (e.g., Pseudomonas) to the tracheal lining and biofilm of an endotracheal tube makes clearance of these microbes from the airways difficult and accounts, in part, for their highly virulent nature.

In non-hospitalized people, bacteria reach the lung by one of four routes:
1. inhalation of microorganisms that have been released into the air when an infected individual coughs or sneezes
2. aspiration of bacteria from the upper airways
3. spread from contiguous infected sites
4. hematogenous spread

When bacteria enter the lower respiratory tract, they adhere to the walls of bronchi and bronchioles, multiply extracellularly, and trigger inflammation. Clinical risk factors that favor colonization of the lower airways include antibiotic therapy that alters the normal bacterial flora, diabetes, smoking, chronic bronchitis, and viral infections.

With the onset of inflammation, alveolar air spaces fill with an exudative fluid (i.e., rich in protein). Inflammatory cells (first neutrophils during the acute phase, later macrophages and lymphocytes during the chronic phase) subsequently invade the walls of the alveoli. Bacterial pneumonia may be associated with significant hypoxemia and hypercapnia because thick, inflammatory exudate (or pus) collects in the alveolar spaces and interferes with the diffusion of oxygen and carbon dioxide. Alveolar exudate tends to solidify—a process known as consolidation—and expectoration of infected phlegm becomes difficult. Legionella, Mycoplasma, and Chlamydia are examples of atypical bacterial agents in that they produce patchy inflammatory changes in the lungs (i.e., bronchopneumonia). The remaining typical bacterial causes of pneumonia produce widespread inflammation throughout one or more lobes of the lung (i.e., lobar pneumonia). Disease Summary Figure 13.1 illustrates the distinguishing features of bronchopneumonia and lobar pneumonia. The term “double pneumonia” is used to indicate the presence of infection and inflammation within both lungs.

### Disease Summary Table 13.3 Conditions That Interfere with Primary Respiratory Defense Mechanisms

<table>
<thead>
<tr>
<th>Respiratory Defense Mechanism</th>
<th>Function(s)</th>
<th>Factors That Impair Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasopharyngeal defenses</td>
<td>IgA protects against bacterial proliferation, Sneezing removes microbes from respiratory tract</td>
<td>IgA deficiency, Hay fever, Common cold, Trauma to the nose</td>
</tr>
<tr>
<td>Glottic and cough reflexes</td>
<td>Protect against aspiration</td>
<td>Reduced cough reflex due to stroke, neuromuscular disease, sedation, anesthesia, tracheal intubation</td>
</tr>
<tr>
<td>Mucociliary clearance system</td>
<td>Removes microbes from nasopharynx down to alveoli</td>
<td>Smoking, Viruses, Cold, dry air, Tracheal intubation</td>
</tr>
<tr>
<td>Alveolar macrophage</td>
<td>Removes microbes from alveoli</td>
<td>Cold, dry air, Alcohol use, Smoking, Obstruction → hypoxia</td>
</tr>
<tr>
<td>IgG and IgM</td>
<td>Help to remove microbes from the blood</td>
<td>IgG and/or IgM deficiency</td>
</tr>
</tbody>
</table>

Adapted with permission from Porth CM. Pneumonias. In: Porth CM, ed. Pathophysiology—Concepts of Altered Disease States. 7th Ed. Philadelphia: Lippincott Williams & Wilkins, 2005; Table 30-1:666.
Colonization of the pharynx and, possibly, the stomach with bacteria is the most important factor in the pathophysiology of hospital-acquired pneumonia, followed closely by aspiration of infected secretions into the lower airways. Pharyngeal colonization is promoted by several exogenous factors: instrumentation of the upper airways with contaminated nasogastric or endotracheal tubes, contamination by dirty hands, and treatment with broad-spectrum antibiotics that promote the emergence of drug-resistant bacteria. Certain patient
characteristics (e.g., malnutrition, advanced age, altered consciousness, swallowing disorders, immunodeficiency) are also major contributing factors.

The role of the stomach in the pathophysiology of nosocomial pneumonia remains controversial. However, research studies suggest that elevations in gastric pH resulting from the use of antacids, H₂-receptor blockers, and enteral feeding are associated with gastric microbial overgrowth and tracheobronchial colonization.

Pneumococcal pneumonia remains the most common type of bacterial pneumonia and its pathophysiology has been extensively studied. The initial step in the development of this disease is the attachment of *S. pneumoniae* to cells of the nasopharynx and subsequent colonization. Colonization alone, however, does not cause clinical manifestations of illness because perfectly healthy people can harbor the microbe without evidence of infection. Factors that permit pneumococci to spread beyond the nasopharynx include the virulence of the strain, impaired host defense mechanisms, and viral infections of the respiratory tract. Viruses can damage respiratory tract lining cells, enhance bacterial adherence, and increase the production of mucus, which protects pneumococci from phagocytosis. In the alveoli, pneumococci infect type II alveolar cells and adhere to alveolar walls, causing an outpouring of fluid, red and white blood cells, and fibrin from the circulation, which, in turn, results in consolidation of the lung. Fluid in the lower airways creates a medium for further multiplication of bacteria and aids in the spread of infection through pores of Kohn into adjacent regions of the lung.

**Diagnosis: Clinical Manifestations and Laboratory Tests**

A diagnosis of bacterial pneumonia is based primarily on chest x-ray findings, white blood cell count, and a sputum culture together with fever (often as high as 106°F), recurrent chills, cough, shortness of breath (i.e., dyspnea), and abnormal chest sounds.

The clinical presentation of bacterial pneumonia varies from a mildly ill, ambulatory patient to a critically ill patient with respiratory failure or septic shock. The sudden onset of symptoms with rapid progression of the illness is typical of bacterial pneumonia. A thorough past medical history and history of potential exposures are usually obtained. If the patient has been healthy previously, the cause of pneumonia is usually *Mycoplasma* or a gram-positive microbe. However, if the patient has been hospitalized or has a chronic illness, gram-negative microbes are suspected.

Although not diagnostic of a particular causative agent, characteristics of the sputum may suggest a particular pathogen. Pneumococci may cause bloody or rust-colored sputum. Patients with *Pseudomonas*, *Haemophilus*, or pneumococcal infections are known to expectorate green sputum. Anaerobic infections typically produce foul-smelling and bad-tasting sputum. *Klebsiella* and type 3 pneumococci cause the production of thick, dark red sputum.

Rigors or severe shaking chills may be observed with any infectious process. However, and for reasons that are not clear; the presence of rigors suggests pneumococcal pneumonia more often than pneumonia caused by other bacterial pathogens. Patients may complain of non-specific symptoms that include headache, malaise, nausea, vomiting, and diarrhea. Although these symptoms may be observed with many other systemic illnesses, their presence is suggestive of infection with *Legionella* species. Patients may also complain of cough, myalgia, shortness of breath, abdominal pain, loss of appetite, and unintentional weight loss. Sharp or stabbing chest pain worsened by deep breathing or coughing and secondary to pleuritis is a common symptom of pneumococcal infection, but may also occur with other types of pneumonia.

Physical examination findings vary depending on the type of microorganism, severity of pneumonia, age of the patient, coexisting host factors, and presence of complications and may include the following:

- fever or hypothermia
- rapid, shallow breathing
- tachycardia or bradycardia
- cyanosis
- decreased breath sounds
• crackles (rales) with auscultation of the lungs
• egophony on auscultation
• pleural friction rub
• dullness of the chest to percussion
• altered mental status (especially confusion)

Leukocytosis (>15,000 white blood cells/mm$^3$) with a “shift to the left” and a predominance of neutrophils in the circulation may be observed with any bacterial infection. However, its absence, particularly in patients who are elderly or debilitated, should not cause the clinician to discount the possibility of a bacterial infection. Leukopenia is an ominous sign of impending sepsis and portends a poor outcome. An assessment of the arterial blood gases is essential to determine if hospital admission or oxygen supplementation is indicated and may reveal hypoxemia and respiratory acidosis. A pulse oximetric finding that is <90% indicates significant hypoxemia.

Hyponatremia and microhematuria may be associated with *Legionella* pneumonia. Urinary antigen testing for *Legionella* serogroup 1 microbes is accurate. A *Legionella* serum antibody titer of 1:128 or more is suggestive of *Legionella* pneumonia. The presence of *Mycoplasma* and *Chlamydia* immunoglobulin M antibodies contribute to the diagnosis.

*Chest radiographs* reveal white shadows in the involved area indicative of an alveolar inflammatory process and may also indicate the following:
• a segmental or lobar opacity is observed with *S. pneumoniae*
• cavitory lesions and bulging lung fissures are caused by *K. pneumoniae* and *S. aureus*
• cavitation and pleural effusions are caused by *S. aureus*, anaerobic infections, and gram-negative infections
• *Legionella* tends to affect the lower lung fields
• *Klebsiella* tends to affect the upper lung zones

In unclear cases, high-resolution computed tomography (CT) scanning of the lungs may aid in the diagnosis.

*Sputum examination* provides an accurate diagnosis in approximately 50% of patients. A gram stain of expectorated sputum helps to distinguish bacterial from viral pneumonia and gram-negative from gram-positive microbes. Sputum samples that result from deep cough provide the best results. A single predominant microbe present with the gram stain is indicative of bacterial pneumonia. Disease Summary Figure 13.2 shows a positive gram stain in which *S. pneumoniae* appear in blue. Mixed flora may be observed with anaerobic infections.

*Blood cultures* are positive in only approximately 40% of cases, but, when positive, results confirm a causative agent. Cultures may require 24–48 hours incubation before results are available. When there is fluid within the pleural space, transthoracic needle aspiration (i.e., *thoracentesis*) with examination and culture of the fluid is performed to assist in identification of the causative microorganism.

Distinguishing clinical features of selected types of bacterial pneumonia are listed in Disease Summary Table 13.4.
**Disease Summary Question 1.** Distinguish between *rales* and *crackles*.

**Disease Summary Question 2.** What causes tachypnea and tachycardia secondary to bacterial pneumonia?

**Disease Summary Question 3.** What is *egophony*?

**Disease Summary Question 4.** The only signs of bacterial pneumonia in an elderly patient are often a loss of appetite and deterioration in mental status. What causes deterioration in mental status secondary to bacterial pneumonia?

**Disease Summary Question 5.** Would you expect a patient with bacterial pneumonia to have a *high*, *low*, or *normal* erythrocyte sedimentation rate?

**Disease Summary Question 6.** Would you expect a patient with bacterial pneumonia to have a *high*, *low*, or *normal* serum C-reactive protein concentration?

**Disease Summary Question 7.** What is meant by a “shift to the left”?

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**Appropriate Therapy**

The primary goals of treatment are to eradicate the infection, reduce morbidity, and prevent complications. The pneumonia severity of illness scoring system (PSI) evaluates 19 different characteristics of the patient that are easily obtained. The PSI is used to make a decision whether patients can be safely treated in an outpatient setting and is displayed in Disease Summary Table 13.5.

Patients in risk class I (older than 50 years but no coexisting illness or vital sign abnormality) and risk class II (<70 total points) can be treated at home with planned outpatient follow-up evaluations. Patients in risk class III (71–90 total points) should be observed in the emergency room before their disposition is decided. Patients in risk class IV (91–130 total points) and V (>130 total points) are seriously ill and usually require hospital admission.
Since many patients are hypoxemic, the first step in the management of bacterial pneumonia is establishing adequate ventilation and oxygenation. For patients with mild dyspnea, only supplemental low-flow oxygen administered with a nasal cannula may be required. Patients with underlying chronic lung disease who need high oxygen concentrations may require endotracheal intubation. Other important measures include the following:

- adequate hydration to loosen secretions and help bring up phlegm
- correction of serum electrolyte abnormalities
- control of fever with antipyretic agents
- bedrest
- good pulmonary hygiene (e.g., deep breathing and coughing exercises, suction of secretions, chest physical therapy)

Early mobilization of patients with encouragement to sit, stand, and walk when tolerated also speeds recovery.

The **mainstay of pharmacotherapy for bacterial pneumonia is antibiotic treatment.** Antibiotic therapy should be initiated promptly after the diagnosis is established and appropriate specimens are obtained, especially in patients who require hospitalization. Delays in obtaining diagnostic specimens or the results of testing should not preclude the early administration of antibiotics to acutely ill patients. The choice of pharmacotherapeutic agent(s) is based on the severity of the patient’s illness, host factors (e.g., coexisting illness and age), and the presumed or identified causative agent. Outpatients are given oral agents and, for the most part, parenteral medications are given to hospitalized patients. A table showing preferred pharmacotherapy for many of the microorganisms that cause bacterial pneumonia is displayed in Disease Summary Table 13.6.
**Disease Summary Question 8.** Why are so many different antibiotics necessary to effectively treat bacterial pneumonia today?

### Serious Complications and Prognosis

Potential serious complications of bacterial pneumonia are multiple and include the following:

- Local destruction of lung tissue with subsequent scarring and significant loss of gas exchange
- Bronchiectasis
- Empyema (i.e., accumulation of pus in the pleural space that often requires surgery and aspiration)
- Respiratory failure
- Dependence on mechanical ventilation
- Septic shock

Prognosis generally is good in the otherwise healthy patient with uncomplicated pneumonia. With appropriate treatment, most patients improve markedly within 2 weeks. Several factors, alone or in combination, increase morbidity and mortality and include the following:

- Advanced age
- Aggressive microbes (e.g., *Klebsiella*, *Legionella*)
- Coexisting illness
- Development of respiratory failure
**Disease Summary Table 13.7 Thirty-Day Mortality Rates Based On PSISS Risk Classes**

<table>
<thead>
<tr>
<th>PSISS Risk Class</th>
<th>Mortality in 30 Days, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.1–0.4</td>
</tr>
<tr>
<td>II</td>
<td>0.6–0.7</td>
</tr>
<tr>
<td>III</td>
<td>0.9–2.8</td>
</tr>
<tr>
<td>IV</td>
<td>8.2–9.3</td>
</tr>
<tr>
<td>V</td>
<td>27.0–31.1</td>
</tr>
</tbody>
</table>


* neutropenia or immunodeficiency state
* features of sepsis

In general, the mortality rate for community-acquired bacterial pneumonia is reported to be 1% when treated in an outpatient setting, but may increase up to 25% among those who require hospital admission. Thirty-day mortality rates are based on PSISS risk classes as shown in Disease Summary Table 13.7.

**Suggested Readings**


