10.4 Interference with Gas Exchange

Suppose it is your birthday and your family has just brought your birthday cake to the table. There are 16 lit candles. Even with a great deal of effort, you are only able to blow them out one at a time! You feel out of breath. This might be the situation if you were suffering from a disease of the respiratory system.

Disorders of the Respiratory System

There are numerous diseases and conditions that interfere with the primary function of the respiratory system—the uptake and delivery of oxygen to the body cells and the removal of carbon dioxide. Lung diseases such asthma and bronchitis restrict the flow of air into and out of the lungs, resulting in an inability to deliver sufficient air to the alveoli. Other diseases, such as emphysema, damage or destroy the respiratory membrane in the alveoli. This damage reduces the surface area for diffusion, which, in turn, impairs the process of gas exchange.

Smoke from cigarettes and other tobacco sources is the primary cause of lung disease in Canada. Other causes of lung disease include air pollution and airborne irritants such as asbestos. Regardless of the cause or mechanism, the result is the same: insufficient oxygen is available to the tissues of the body.

Asthma

asthma a chronic respiratory disease characterized by inflammation and swelling of the bronchi and bronchioles that obstructs airflow

Worldwide, asthma is one of the most prevalent respiratory problems and the most common chronic, or frequently recurring, condition in children. In Canada, nearly 10 % of the population suffers from asthma. **Asthma** is a chronic, long-term inflammation of the lining of the bronchi and bronchioles. Inflammation is a protective reaction designed to eliminate some foreign substances or infection. It is characterized by swelling and redness due to increased blood flow to the affected tissue. When the lining of the airways swells, airflow into the lungs is reduced. The inflammation stimulates the overproduction of sticky mucus in the airways, which also contributes to reduced airflow. In most cases, the muscles around the bronchi and bronchioles become sensitive and contract, further narrowing the openings and restricting the airflow (**Figure 1**).

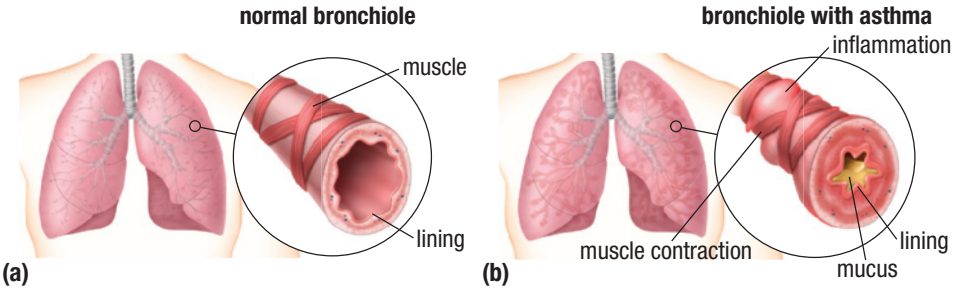


Figure 1 Compared to (a) normal bronchioles, the (b) bronchioles of a person with asthma are severely restricted by inflammation, excess mucus, and muscle contractions.

The symptoms of asthma include coughing, wheezing, tightness in the chest, and shortness of breath. The symptoms and their severity can vary between individuals and can occur intermittently or persistently. A sudden worsening of asthma symptoms is called an asthma attack. Many factors can trigger an asthma attack. These triggers include cigarette smoke, dust, cold air, physical exertion, and allergens such as pollen, pollution, dust mites, and animal dander.

Asthma is not curable but can be managed and treated successfully. Management involves identifying the triggers and avoiding them if possible. In many cases, however, it is virtually impossible to avoid widespread triggers such as pollen or pollution. In these situations, medication becomes necessary.

Medications for asthma include relief medications that open up, or dilate, the bronchi and bronchioles to allow greater airflow. Other medications can reduce the inflammation in the bronchi and bronchioles. Medications are often self-administered using inhalers, commonly called puffers, which deliver a measured dose of the drug directly into the airways and lungs (**Figure 2**). With proper management and medication, most asthma sufferers can lead normal, active lives.

Figure 2 Puffers are used to deliver medications by inhalation.

chronic obstructive pulmonary disease (COPD) a chronic, progressive disease that involves both obstructive bronchitis and emphysema

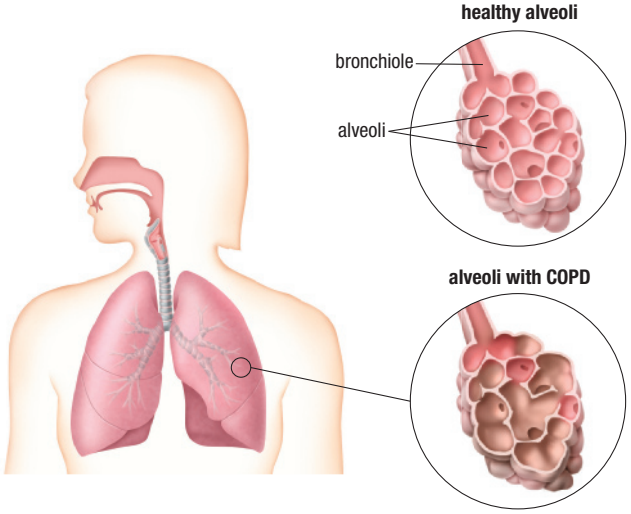
Chronic Obstructive Pulmonary Disease (COPD)

Approximately 1.5 million Canadians suffer from **chronic obstructive pulmonary disease (COPD)**, and an estimated 1.6 million remain undiagnosed. COPD is a long-term respiratory disease that is a combination of two diseases—bronchitis and emphysema. It is estimated that 80 % to 90 % of all cases of COPD are caused by cigarette smoke, but prolonged exposure to pollution, dust, or fumes can also contribute. Genetic disorders can also cause emphysema, even when other contributing factors, such as smoking, are absent. The symptoms of COPD are very similar to those of asthma: coughing, wheezing, chest tightness, and shortness of breath.

Similar to asthma, bronchitis is an irritation and inflammation of the airways. The linings of the bronchi and bronchioles swell and produce excess mucus, reducing airflow into the lungs.

The other condition of COPD, emphysema, causes permanent damage to the alveoli. The walls between the alveoli are damaged or destroyed, and the alveoli lose their elasticity and shape (**Figure 3**). The result is a reduction in the surface area of the respiratory membrane. Because there is less surface area for gas exchange, the amount of oxygen diffusing into the blood is reduced. Carbon dioxide diffusion is also reduced, causing carbon dioxide levels in the blood to increase. The respiratory system responds by increasing the breathing rate and the heart rate in an attempt to maintain appropriate oxygen and carbon dioxide levels.

(a)



(b)

Figure 3 (a) The black spots in the lung are areas where the alveoli are damaged. (b) Compared to normal alveoli, alveoli with COPD are essentially non-functional and significantly reduce the ability of the lung to exchange gases.

There is no cure for COPD. Damage to the alveoli is permanent and generally worsens over time. Proper management, medications, and lifestyle changes can help alleviate the symptoms and slow the progress of the disease. In severe cases, oxygen therapy may be necessary if oxygen levels drop below a critical level. In extreme cases, lung transplants are necessary. People who suffer from COPD are likely to die from it, or from a related complication such as pneumonia, heart failure, or respiratory failure. How long they live depends on many factors, such as age, the extent of lung damage, treatment, and any other health problems.

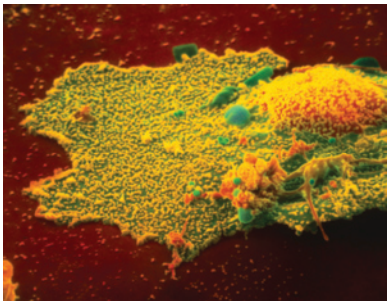


Figure 4 Once inside the body, the influenza virus (small yellow dots) takes over a cell and multiplies rapidly. The virus then spreads to other cells throughout the body.

CAREER **LINK**

Infectious Disease Specialist

The spread of infectious diseases is a concern to health authorities and governments. To find out more about a career as an infectious disease specialist,

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tuberculosis (TB) a bacterial infection that damages the tissues of the lungs and interferes with gas exchange

Respiratory Infections

The respiratory system is probably the most vulnerable part of the human body. The lungs are a prime target for infection because of constant exposure of living tissue to the external environment. Even though safety mechanisms, such as hairs and mucus in the nasal passages and cilia and mucus in the airways, trap most airborne particles, some still enter the farthest reaches of the respiratory system. There are many respiratory infectious diseases caused by viruses and airborne micro-organisms, such as bacteria or fungi.

INFLUENZA

Influenza, commonly known as the flu, is caused by a virus (**Figure 4**). New strains of flu viruses are constantly appearing, often as a result of mutations of existing flu viruses. One well-publicized incidence of a new flu virus is H1N1 in 2009. The flu virus may affect the whole body or be confined to the lungs. Symptoms usually include a fever, dry cough, sore throat, runny nose, and muscle and joint aches and pains. If the infection is diagnosed within the first 24 h to 48 h, antiviral drugs can be administered, reducing the symptoms and shortening the length of the infection. However, most people usually recover without treatment in a week. During this time, the individual is infectious and is able to spread the virus to others.

Influenza is highly contagious. When an infected person coughs or sneezes, he or she sends droplets of moisture carrying the virus into the air. Another person may inhale the airborne virus and become infected. Viruses can also be spread through hand contact with contaminated surfaces such as door knobs. If the person touches their mouth or nose after touching a contaminated surface, the virus can enter the respiratory system.

Viruses can spread quickly from person to person in a community or region, creating an epidemic. If the virus spreads across a continent or globally, it is called a pandemic. Vaccines that prevent infection have been developed for many of the common flu viruses. It takes about six months to develop and test a vaccine, by which time the infection may have already spread.

TUBERCULOSIS

Tuberculosis (TB) is a bacterial infection caused by *Mycobacterium tuberculosis*. Like many other infectious agents, the bacterium is spread through the air when infected people sneeze or cough. The classic symptoms of TB include coughing, chest pain, weight loss, night sweats, and coughing up blood. If untreated, these symptoms generally worsen over time. TB usually affects the lungs but can move from the lungs to affect the nervous system, the bones and joints in the spine, and other parts of the body.

One of the problems with TB is that an infected person may show no obvious symptoms. Specific tests must be performed to confirm the presence of the bacteria. It is estimated that one-third of the world's population is currently infected. In most individuals, the infection remains inactive; unless the immune system is weakened, there is only a 5 % to 10 % chance that an inactive infection will progress to an active infection. The standard treatment is a six-month course of antibiotics. A vaccine has been available since 1921 that is effective in protecting children against TB.

After the introduction of antibiotics in 1948, and their subsequent widespread use, it was thought that TB would disappear. However, TB persists because some strains of the bacterium are resistant to antibiotics and because the antibiotic treatment process is both time-consuming and expensive. There are about 11 million active cases of TB worldwide, mostly in developing countries. The World Health Organization (WHO) estimates that TB kills almost 3 million people annually. In Canada, about 1600 cases of TB are reported annually. The incidence of TB among Aboriginal people in Canada is 30 times as high as that of the non-Aboriginal population. This may be due to socio-economic conditions such as overcrowded homes, poor living conditions, and lack of medical facilities.

PNEUMONIA

Pneumonia is an infection of the lungs caused by bacteria, viruses, or fungi. The infection causes inflammation of the lining of the bronchi, bronchioles, and alveoli. The infection also causes pus and mucus to accumulate in the alveoli, preventing gas exchange (**Figure 5**).

pneumonia an infection of the lungs that causes the alveoli to fill with pus and mucus, preventing gas exchange

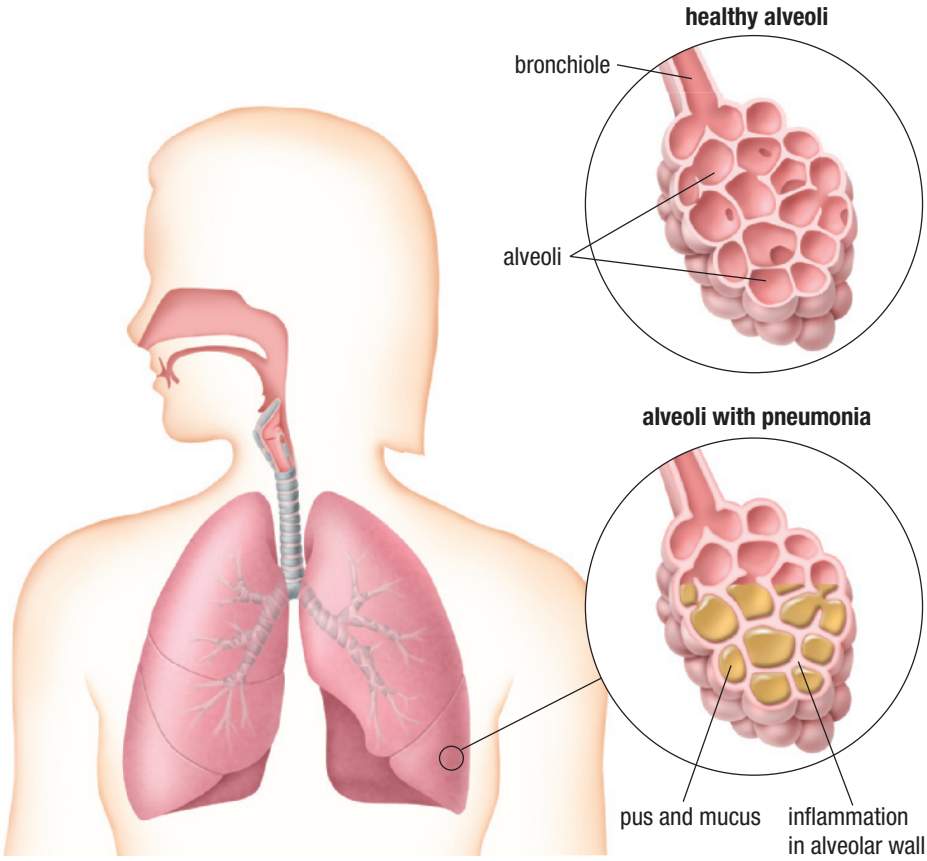

Figure 5 In a person suffering from pneumonia, some alveoli become filled with pus and mucus, preventing gas exchange. Individuals with pneumonia often cough up greenish or yellow mucus from their lungs.

Pneumonia has typical symptoms of an infection and a respiratory disease—fever, cough, and shortness of breath. Pneumonia can be diagnosed by analyzing the mucus in the respiratory system, or phlegm, that is coughed up from the lungs. X-rays can also show if areas of the lungs are blocked with fluids.

Most individuals with healthy immune systems are able to resist or fight off the infection before it progresses. However, pneumonia can be severe or fatal for those with weakened immune systems. For this reason, it is often associated with other long-term illnesses in which the immune system is already compromised. Infants and seniors are also especially susceptible to pneumonia. Bacterial pneumonia can be treated with antibiotics. Before antibiotics existed, pneumonia was fatal for about one-third of those who contracted it. Even with antibiotics and other modern treatments, there is a 5 % fatality rate among those who develop pneumonia.

Cystic Fibrosis

As you read in Chapter 5, cystic fibrosis (CF) is a hereditary disorder in which the gene that influences mucus production is defective. The respiratory system of a person with CF produces unusually thick and sticky mucus that clogs the airways. Like asthma and bronchitis, the airflow to the lungs is reduced. Symptoms include a persistent cough and excess mucus. In 1989 a team of researchers at the Hospital for Sick Children in Toronto, led by Dr. Lap-chee Tsui, discovered the defective gene that causes CF (**Figure 6**).

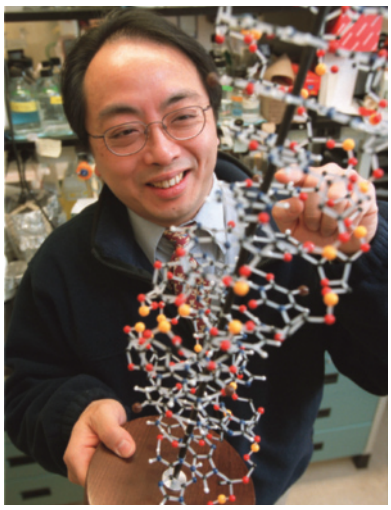

Figure 6 Dr. Lap-chee Tsui

CAREER **LINK**

Respiratory Therapist

To find out more about a career as a respiratory therapist,

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CF also makes the individual more susceptible to lung infections. The increased production of mucus in the lungs creates an ideal environment for the growth of bacteria and fungi. CF patients often suffer from persistent lung infections, and much of the treatment of the disease focuses on fighting the infections with antibiotics. Treatment also includes clearing excess mucus from the lungs to help prevent further infections (**Figure 7**). As the disease progresses, lung transplants may become necessary. Many patients with respiratory diseases require ongoing and continuous therapy to alleviate their symptoms and prevent a worsening of the condition.

Figure 7 (a) Regular percussion (gentle pounding) of the chest is a standard CF therapy that helps loosen the mucus so that it can be coughed up more easily. (b) A mechanical vest has been developed to simulate the pounding of the chest.

In addition to affecting the respiratory system, CF affects the digestive system. The name of the disease comes from the characteristic fibroid scar tissue that forms in the pancreas. Thick secretions of mucus in the pancreas prevent it from secreting digestive enzymes. Scar tissue in the pancreas can also prevent it from producing insulin, which can lead to a form of diabetes associated only with CF patients.

Like many other inherited characteristics, there are two alleles of the CF gene. As long as one allele for normal mucus production is present, the disease is not expressed. CF occurs when a child receives two recessive, or defective, CF genes, one from each parent. About 4 % of Canadians carry the defective version of the gene responsible for CF, and about one in every 3600 children has CF. Because CF is an inherited disease, genetic testing can identify affected individuals.

In some provinces, including Ontario, all newborns are checked at birth for CF, and about 60 % of diagnoses are made in the first year. The disease gets progressively worse with age, so it is beneficial to begin treatment as early as possible. At present, there is no cure, but major advances have been made in medical knowledge and the development of new treatments. These advances have significantly improved both the quality of life and life expectancy of individuals with CF. Research continues in the area of gene therapy, which holds some promise for a cure. This area of research focuses on replacing the defective gene so that cells in the respiratory system will produce normal mucus.

Effect of Smoking on Gas Exchange

It is well established that smoking is the single greatest cause of respiratory diseases and preventable deaths in the developed world. Smoking is known to cause lung cancer, COPD, bronchitis, emphysema, and asthma. It is also linked to diseases of the circulatory system, such as arteriosclerosis, and heart attacks, which you will learn about in Chapter 11.

Three substances in cigarette smoke cause most of the problems for the respiratory system and the body in general: nicotine, carbon monoxide, and tar. Nicotine is a natural insecticide produced by tobacco plants to kill insect pests. It is an addictive chemical that stimulates the reward pathways in the brain to produce dopamine and endorphins. Dopamine and endorphins are chemicals that act as natural painkillers. The effect of nicotine lasts only about 40 min, and the need for further positive feelings leads to continued smoking to the point of addiction. Unfortunately, nicotine also has many negative effects on the nervous system, such as blocking other chemicals that allow signals to be sent from the brain around the body.

The carbon monoxide from tobacco smoke or from other sources affects the ability of the respiratory system to deliver oxygen to the body cells. Hemoglobin has a much greater tendency to bond with carbon monoxide than it does with oxygen. This means that if carbon monoxide diffuses into the bloodstream, hemoglobin picks it up instead of oxygen, thereby reducing the amount of oxygen delivered to the cells. To make matters worse, the bond between hemoglobin and carbon monoxide is 200 times stronger than the bond between hemoglobin and oxygen, so carbon monoxide does not release from hemoglobin nearly as easily as oxygen does.

Tar is a black, sticky substance that accumulates in the alveoli, effectively preventing any exchange of gases (**Figure 8**). The tar in cigarette smoke is made up of hundreds of different chemicals, many of which are toxic and some of which are carcinogenic, or cancer causing. Some of these chemicals irritate the linings of the airways, causing swelling and increased mucus production. Furthermore, tar causes the cilia on the cells lining the bronchi to become inactive. The cilia do not perform their function of sweeping dust particles and foreign material out of the airways. This can trigger asthma attacks and lead to emphysema.

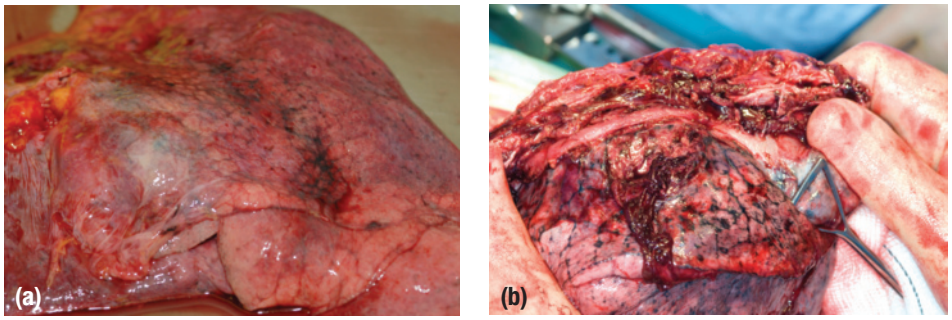

Figure 8 (a) The pink colour of the healthy lungs shows that there is good blood circulation throughout the lungs. (b) The buildup of tar in the lungs as a result of smoking dramatically interferes with the lungs' primary function—the exchange of gases between the body and the environment.

In addition to carbon monoxide and tar, cigarette smoke contains many toxic and likely carcinogenic substances, notably formaldehyde, benzene, and hydrogen cyanide. The carcinogenic chemicals can cause mutations in the genetic material that controls the growth of cells. Cancer results when the damaged cells grow and reproduce too quickly, and form a tumour. **Figure 9** shows a frontal view chest X-ray with a visible cancerous tumor. To confirm an X-ray diagnosis, a lung tissue examination such as a biopsy must be performed.

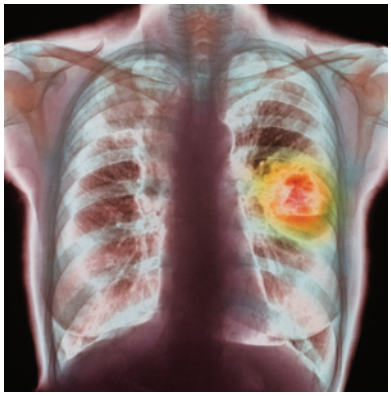

Figure 9 This X-ray reveals a cancerous tumour (red and yellow) in the left lung.

Cancer can originate in the lungs, but it can also spread to the lungs through the circulatory system from tumours in other parts of the body. The tumour invades the tissues of the lungs, replacing normal cells or interfering with the blood flow to the tissues. This reduces the area of the respiratory membrane available for gas exchange and consequently affects the ability to take up oxygen and eliminate carbon dioxide.

UNIT TASK BOOKMARK

Consider what you have learned about respiratory diseases and disorders, as well as the effects of smoking on gas exchange. How can this information help you when you create a health and fitness profile in the Unit Task?

10.4 Summary

- Respiratory system diseases can affect the amount of airflow into the lungs, the process of gas exchange through the respiratory membrane, or both. Many diseases of the respiratory system interfere with the exchange of gases.
- Asthma is the inflammation of the lining of the bronchi and bronchioles, which reduces airflow into the lungs.
- COPD is the inflammation of the airways combined with the permanent destruction of alveoli. The reduced airflow and the damage to the respiratory membrane both contribute to reduced gas exchange.
- Infectious diseases such as influenza, tuberculosis (TB), and pneumonia are caused by viruses or bacteria.
- Cystic fibrosis (CF) is a genetic disorder that affects the respiratory and digestive systems. One of its main symptoms is an overproduction of sticky mucus in the airways; this mucus obstructs airflow to and from the alveoli.
- Cigarette and other tobacco smoke is a primary cause of lung disease. Air pollution and airborne irritants are also contributing factors.
- Carbon monoxide and tar from cigarette smoke cause problems in the respiratory and circulatory systems.

10.4 Questions

1. (a) What is the fundamental problem in most respiratory diseases?
   (b) What are some common symptoms that accompany most respiratory diseases? K/U
2. How is the management of asthma different from the treatment of asthma? K/U
3. A patient suffering from a lung infection was prescribed antibiotics. After seven days of treatment, the condition had not improved. Propose a possible explanation. K/U T/I A
4. Use a T-chart to compare asthma and pneumonia. In your comparison, consider the causes, symptoms, and treatments of each disease. K/U C
5. TB is a serious disease among the homeless, in prison populations, and in developing countries. How might these observations be explained? T/I A
6. In the 1960s, most CF patients did not live to attend elementary school. Today, many are living into their 40s. What accounts for this improvement? K/U A
7. (a) What substances in tobacco smoke cause problems for the respiratory system?
   (b) Explain how each of these substances affects the respiratory system.
   (c) It is well known that smoking has serious health risks. Why do you think people continue to smoke? K/U T/I A
8. Use the Internet and other sources to research ONE of the following topics and write a brief summary: T/I C A
   - the effects of smoking on body systems
   - the current status of TB among Canada's northern Aboriginal populations
   - recent advances in the search for a cure for CF
9. Use the Internet and other sources to research a condition called "the bends." This condition, also known as decompression sickness, is experienced by divers who ascend from their dive too quickly. Prepare a brief report on the cause, symptoms, and treatments of the condition. T/I C

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