Actress Angelina Jolie carries a cancer-causing gene which puts her, and some of her children, at high risk of getting cancer.

6.1 What Is Cancer? Tumors Can Be Cancerous Risk Factors for Cancer

6.2 Passing Genes and Chromosomes to Daughter Cells Genes and Chromosomes DNA Replication

6.3 The Cell Cycle and Mitosis Interphase Mitosis Cytokinesis

6.4 Cell Cycle Control Tumor Suppressors Prevent Uncontrolled Cell Division Regulation of the Cell Cycle: A Closer Look

6.5 Cancer Detection and Treatment Detection Methods: Biopsy Treatment Methods: Chemotherapy and Radiation

6.6 Meiosis Interphase Meiosis I Meiosis II Crossing Over and Random Alignment

savvy reader

Alternative Cancer Treatments

SOUNDS RIGHT, BUT IS IT?
Cancer is a disease that will affect most people at some point in their lives. Of those who live an average life span, more than one in three will be directly affected with a diagnosis, and those who escape the disease themselves are likely to be affected by the diagnosis of a loved one.

Some types of cancer are genetically inherited, and others are acquired during an individual’s lifetime. Actress and humanitarian Angelina Jolie’s battle against a genetically inherited form of breast cancer led to her decision to have both of her breasts surgically removed. Prior to his fall from grace, Lance Armstrong acquired testicular cancer, requiring the surgical removal of one testicle. The difficult medical choices faced by these individuals, while frightening to consider, can serve as an impetus for each of us to attempt to better understand the biological basis of cancer.

A better understanding of cancer can help us to both protect ourselves and support those we love. Lifestyle changes can lead to the prevention, delayed onset, or slowed progression of many types of cancer. When a cancer diagnosis does occur, understanding the biological mechanisms of various treatments can help us support those we love as they make medical decisions and undergo treatments.

**DNA Synthesis, Mitosis, and Meiosis**

Cancer is a disease that will affect most people at some point in their lives. Of those who live an average life span, more than one in three will be directly affected with a diagnosis, and those who escape the disease themselves are likely to be affected by the diagnosis of a loved one.

Some types of cancer are genetically inherited, and others are acquired during an individual’s lifetime. Actress and humanitarian Angelina Jolie’s battle against a genetically inherited form of breast cancer led to her decision to have both of her breasts surgically removed. Prior to his fall from grace, Lance Armstrong acquired testicular cancer, requiring the surgical removal of one testicle. The difficult medical choices faced by these individuals, while frightening to consider, can serve as an impetus for each of us to attempt to better understand the biological basis of cancer.

A better understanding of cancer can help us to both protect ourselves and support those we love. Lifestyle changes can lead to the prevention, delayed onset, or slowed progression of many types of cancer. When a cancer diagnosis does occur, understanding the biological mechanisms of various treatments can help us support those we love as they make medical decisions and undergo treatments.

**DNA Synthesis, Mitosis, and Meiosis**

Cancer is a disease that will affect most people at some point in their lives. Of those who live an average life span, more than one in three will be directly affected with a diagnosis, and those who escape the disease themselves are likely to be affected by the diagnosis of a loved one.

Some types of cancer are genetically inherited, and others are acquired during an individual’s lifetime. Actress and humanitarian Angelina Jolie’s battle against a genetically inherited form of breast cancer led to her decision to have both of her breasts surgically removed. Prior to his fall from grace, Lance Armstrong acquired testicular cancer, requiring the surgical removal of one testicle. The difficult medical choices faced by these individuals, while frightening to consider, can serve as an impetus for each of us to attempt to better understand the biological basis of cancer.

A better understanding of cancer can help us to both protect ourselves and support those we love. Lifestyle changes can lead to the prevention, delayed onset, or slowed progression of many types of cancer. When a cancer diagnosis does occur, understanding the biological mechanisms of various treatments can help us support those we love as they make medical decisions and undergo treatments.
6.1 What Is Cancer?

Cancer is a disease that occurs when a cell makes copies of itself, or replicates, when it should not. Cell replication occurs during cell division, a process by which the original parent cell divides to form two daughter cells. This process is regulated so that a cell divides only when more cells are required.

Tumors Can Be Cancerous

Unregulated cell division leads to a pileup of cells that form a lump or tumor. A tumor is a mass of cells that has no apparent function in the body. Tumors that stay in one place and do not affect surrounding structures are said to be benign. Some benign tumors remain harmless; others become cancerous. Invasive tumors, or those that infiltrate surrounding tissues, are malignant cancers. Metastasis occurs when the cells of a malignant tumor break away and start new cancers at distant locations (FIGURE 6.1).

Cancer cells can travel virtually anywhere in the body via the lymphatic and circulatory systems. The lymphatic system collects fluid, called lymph, lost from blood vessels. The lymph is then returned to the blood vessels, a process that also allows cancer cells access to the bloodstream. Lymph nodes are structures that filter fluids released from blood vessels. When a cancer patient is undergoing surgery, the surgeon will often remove a few lymph nodes that will be analyzed for the presence of cancer cells. The presence of cancer cells in the nodes is an indication that some cells have broken away from the original tumor and might present elsewhere in the body. One of the reasons it was so incredible that Lance Armstrong survived cancer was that the original cancer in his testicle spread to his brain and lungs. Metastatic cancers are much more difficult to treat than cancers that are detected before they spread.

Risk Factors for Cancer

A risk factor is a condition or behavior that increases the likelihood of developing a disease. These risk factors can be impacted by genetics or environmental exposures.

Inherited Cancer Risk. Angelina Jolie carries a version of the BRCA1 gene (for breast cancer susceptibility) that makes her five times more likely to get breast cancer than other women. After being told that she had an 87% risk for breast cancer, she decided to undergo a double mastectomy—a procedure to remove both of her

![Diagram showing normal cell division and unregulated cell division leading to benign and malignant tumors.](image)

**Figure 6.1 What is cancer?** A tumor is a clump of cells with no function. Tumors may remain benign, or they can invade surrounding tissues and become malignant. Tumor cells may move, or metastasize, to other locations in the body. Malignant and metastatic tumors are cancerous.
breasts. The version of the gene that she carries also increases her risk for ovarian cancer—the disease that killed her mother. To eliminate her chances of developing ovarian cancer, Jolie is planning to have her ovaries removed as well. How did Jolie know her risks? Because several members of Jolie’s family had been diagnosed with breast and ovarian cancers, she was tested for the presence of this gene. Since only about 1% of people carry this particular gene, unless several immediate family members have been diagnosed with cancer, this testing is not usually performed.

**Environmental Exposures.** Exposure to particular substances, called carcinogens, is correlated with development of particular cancers. For example, exposure to the human papilloma virus (HPV) can cause anal and oral cancer in females and males, cervical cancer in females, and penile cancer in males. HPV-caused cancer risk can be all but eliminated by vaccination; vaccines are available to both males and females. You can also limit your risk for HPV-caused cancers by limiting the number of people you have sex with and by following safer sex guidelines.

Everyone knows that smoking increases risk of cancer. What is less well known is that smoking combined with excessive alcohol consumption increases cancer risk at a greater level than one would expect. This is because some carcinogens enhance the activity of other carcinogens. When this occurs, the substances involved are said to be acting in a synergistic manner. Cigarette smoking and alcohol consumption, two practices commonly combined by college students, have a far greater effect on cancer risk than the sum of each separate risk factor combined (Figure 6.2).

**Working with Data**

Is the cancer risk associated with smoking and drinking additive or multiplicative? Explain your answer.

**Figure 6.2** Alcohol and tobacco are synergists. Smoking cigarettes while drinking is an unhealthy practice.
While we have seen that exposures to particular agents can increase risks of particular cancers, there are general risk factors that increase risk of virtually every type of cancer. These include tobacco use, excessive alcohol consumption, a high-fat and low-fiber diet, lack of exercise, and obesity (TABLE 6.1).

Limiting these exposures can help prevent cancers from developing in our cells and from being passed on to daughter cells produced when cells divide.

### TABLE 6.1 Decreasing Your Cancer Risk

<table>
<thead>
<tr>
<th>Risk-Reducing Behavior</th>
<th>Specific Risk Reduction Information</th>
<th>Biological Mechanism of Risk Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t Use Tobacco.</td>
<td>The use of tobacco of any type, whether delivered via cigarettes, cigars, pipes, or chewing tobacco, increases your risk of many cancers. Electronic cigarettes, which contain nicotine only, are new enough that risks from their use have not yet been determined.</td>
<td>Tobacco and tobacco cigarette smoke contain more than 20 known cancer-causing substances. Chemicals present in tobacco and cigarette smoke have been shown to increase cell division, damage DNA, inhibit a cell’s ability to repair damaged DNA, and prevent cells from dying when they should.</td>
</tr>
<tr>
<td>Limit Alcohol Consumption.</td>
<td>Men who want to decrease their cancer risk should have no more than two alcoholic drinks a day, and women one or none.</td>
<td>When harmful chemicals dissolve in alcohol, they are able to traverse cell membranes and can damage DNA.</td>
</tr>
<tr>
<td>Eat a Low-Fat, High-Fiber Diet.</td>
<td>Eat at least 5 servings of fruits and vegetables every day as well as 6 servings of food from other plant sources, such as breads, cereals, grains, rice, pasta, or beans.</td>
<td>Fruits and vegetables are rich in antioxidants which help prevent DNA damage.</td>
</tr>
<tr>
<td>Exercise Regularly.</td>
<td>Engage in physical activity for at least 30 minutes 5 days a week.</td>
<td>Exercise keeps the immune system functioning effectively, allowing it to recognize and destroy cancer cells.</td>
</tr>
<tr>
<td>Maintain a Healthy Weight.</td>
<td>Avoid becoming obese. If you are obese, consult a physician for a weight loss program.</td>
<td>Because fatty tissues can store hormones, the abundance of fatty tissue has been hypothesized to increase the risk of hormone-sensitive cancers such as breast, uterine, ovarian, and prostate cancer.</td>
</tr>
</tbody>
</table>

#### FIGURE 6.3 Why do cells divide?
Cells divide in order to make more cells. This can allow an organism to grow (a). Each of us begins life as a single fertilized egg cell that underwent millions of rounds of cell division to produce all the cells that comprise the tissues and organs of our bodies. Cells also divide in order to heal wounds (b). As this cut heals, new cells will replaced those damaged by the injury.

### 6.2 Passing Genes and Chromosomes to Daughter Cells

Cells have evolved to divide for a variety of reasons having nothing to do with cancer. Cell division produces new cells to allow an organism to grow, to replace damaged cells, and, in some cases, to reproduce (FIGURE 6.3).

Some organisms reproduce by making exact copies of themselves. Reproduction of this type, called asexual reproduction, results in offspring...
that are genetically identical to the original parent cell. Single-celled organisms, such as bacteria and amoeba, reproduce in this manner (FIGURE 6.4a). Some multicellular organisms can reproduce asexually also. For example, some plants can grow from clippings of stems, leaves, or roots. Reproduction from such cuttings is also a form of asexual reproduction (FIGURE 6.4b). Organisms whose reproduction requires genetic information from two parents undergo sexual reproduction. Humans reproduce sexually when sperm and egg cells each contribute genetic information at fertilization.

**Genes and Chromosomes**

Whether reproducing sexually or asexually, all dividing cells must first make a copy of their genetic material, the DNA (deoxyribonucleic acid). DNA carries the instructions, called genes, for building all of the proteins that a cell requires. The DNA in the nucleus is wrapped around proteins to produce structures called chromosomes.

Chromosomes are in an uncondensed, string-like form when a cell is not preparing to divide (FIGURE 6.5a). In order for cell division to occur, the DNA in each chromosome is compressed into a more compact linear structure that is easier to maneuver during cell division. Condensed chromosomes are less likely to become tangled or broken than are the uncondensed and string-like structures.

Each chromosome carries hundreds of genes. When a chromosome is replicated, a copy is produced that carries those same genes. The copied chromosomes, now called sister chromatids, are attached to each other at a region toward the middle of the replicated chromosome, called the centromere (FIGURE 6.5b). Because the centromere is not always located precisely in the center of the chromosome, it can subdivide the chromosome into one long and one short arm. Scientists have mapped the location of the BRCA1 gene to the long arm of chromosome number 17.

**STOP & STRETCH** If humans have 23 pairs of chromosomes, each carrying hundreds of genes, roughly how many genes are there in the human genome?

**DNA Replication**

During the process of DNA replication that precedes cell division, the double-stranded DNA molecule is copied, first by splitting the molecule in half up the middle of the helix. New nucleotides are added to each side of the original parent molecule, maintaining the A-to-T and G-to-C base pairings. This process results in two daughter DNA molecules, each composed of one strand of
CHAPTER 6 Cancer

**Visualize This**

Assume another round of replication were to occur to one of the half purple, half red DNA molecules shown in part (a). How many total DNA molecules would be produced? If the nucleotides being added to the newly synthesized strand are purple, what proportion of each DNA molecule would be purple?

**FIGURE 6.6** DNA replication.

(a) DNA replication results in the production of two identical daughter DNA molecules from one parent molecule. Each daughter DNA molecule contains half of the parental DNA and half of the newly synthesized DNA. (b) The DNA polymerase enzyme moves along the unwound helix, tying together adjacent nucleotides on the newly forming daughter DNA strand. Free nucleotides have three phosphate groups, two of which are cleaved to provide energy for this reaction before the nucleotide is added to the growing chain.

Parental nucleotides and one newly synthesized strand (**FIGURE 6.6a**). Because each newly formed DNA molecule consists of one-half conserved parental DNA and one-half new daughter DNA, this method of DNA replication is referred to as **semiconservative replication**.

Replicating the DNA requires the assistance of enzymes, in particular, a **DNA polymerase**. The DNA polymerase moves along the length of the unwound parental DNA strand to facilitate synthesis of the newly formed strand (**FIGURE 6.6b**). When free nucleotides floating in the nucleus have an affinity for each other (A for T and G for C), these complementary nucleotides bind to each other across the width of the helix and then the DNA polymerase catalyzes the formation of the covalent bond between adjacent nucleotides along the length of the helix. When an entire chromosome has been replicated, the newly synthesized sister chromatids are identical to each other and attached to each other at the centromere (**FIGURE 6.7**).

**FIGURE 6.7** Unduplicated and duplicated chromosomes. An unreplicated chromosome is composed of one double-stranded DNA molecule. A replicated chromosome is X-shaped and composed of two identical double-stranded DNA molecules. Each DNA molecule of the duplicated chromosome is a copy of the original chromosome and is called a sister chromatid.

The DNA polymerase can make mistakes when facilitating base pairing. While uncommon, pairing an A with a G for instance, such mistakes can alter the sequence of the original gene. Changes in the DNA of a gene are called **mutations**. Normally, replication of the **BRCA1** gene produces an
exact copy of the gene. If mistakes in the copying occur, a mutant version of the gene can be produced, which appears to be the case in the version of the gene that Angelina Jolie carries.

6.3 The Cell Cycle and Mitosis

After a cell’s chromosomes and DNA have been replicated, the cell is able to undergo cell division and produce daughter cells. One type of cell division, **mitosis**, is an asexual division that produces two daughter cells that are identical to their original parent cell and to each other. Mitosis occurs in the type of body cells called somatic cells. **Somatic cells** include any cell type that does not produce sex cells. In plants, for example, the leaves and stem are composed of somatic cells and undergo mitosis. The reproductive organs of the plant produce pollen and egg cells, which are non-somatic cells called sex cells.

For cells that divide by mitosis, the cell cycle includes three steps: (1) **interphase**, when the DNA replicates; (2) **mitosis**, when the copied chromosomes split and move into the daughter nuclei; and (3) **cytokinesis**, when the **cytoplasm** of the parent cell splits (**Figure 6.8a**). As you will see, interphase and mitosis are further subdivided.

**Interphase**

A normal cell spends most of its time in interphase (**FIGURE 6.8b**). During this phase of the cell cycle, the cell performs its typical functions and produces the proteins required for the cell to do its particular job. For example, during interphase, a muscle cell produces proteins required for muscle contraction. Different cell types spend varying amounts of time in interphase. Cells that frequently divide, like skin cells, spend less time in interphase than do those that seldom divide, such as some nerve cells. A cell that will divide also begins preparations for division during interphase. Interphase can be separated into three phases: **G1**, **S**, and **G2**.

**FIGURE 6.8 The cell cycle.** (a) During interphase, the DNA is copied. Separation of the DNA into two daughter nuclei occurs during mitosis. Cytokinesis is the division of the cytoplasm, creating two daughter cells. (b) During interphase, there are two stages when the cell grows in preparation for cell division, **G1** and **G2** stages, and one stage where the DNA replicates, the **S** stage. The chromosomes are separated and two daughter cells are formed during the **M** phase.
During the G₁ (first gap or growth) phase, most of the cell’s organelles duplicate. Consequently, the cell grows larger during this phase. During the S (synthesis) phase, the DNA composing the chromosomes replicates. During the G₂ (second gap) phase of the cell cycle, the cell continues to grow and prepares for the division of chromosomes that will take place during mitosis.

STOP & STRETCH If a cell at G₁ contains 4 picograms of DNA, how many picograms of DNA will it contain at the end of the S phase of the cell cycle?

Mitosis

The movement of chromosomes from the original parent cell into two daughter cells occurs during mitosis. Whether these phases occur in an animal or a plant, the outcome of mitosis and the next phase, cytokinesis, is the same:

DNA has already replicated but has not yet condensed into chromosomes.

DNA condenses into chromosomes. Microtubules form and are anchored by centrioles. The nuclear envelope begins to break down.

Chromosomes align at the middle of the cell between the two poles. The microtubules grow long enough to attach to the chromosomes at their centromeres.
the production of genetically identical daughter cells. To achieve this outcome, the sister chromatids of a replicated chromosome are pulled apart, and one copy of each is placed into each newly forming nucleus. Mitosis is accomplished during four stages: prophase, metaphase, anaphase, and telophase. FIGURE 6.9 summarizes the cell cycle in animal cells. The four stages of mitosis are nearly identical in plant cells.

During prophase, the replicated chromosomes condense, allowing them to move around in the cell without becoming entangled. Protein structures called microtubules also form and grow, ultimately radiating out from opposite ends, or poles, of the dividing cell. The growth of microtubules helps the cell to expand. Motor proteins attached to microtubules also help pull the chromosomes around during cell division. The membrane that surrounds the nucleus, called the nuclear envelope, breaks down so that the microtubules can gain access to the replicated chromosomes. At the poles of each dividing animal cell,

FIGURE 6.9 Cell division in animal cells. This diagram illustrates how cell division proceeds from interphase through mitosis and cytokinesis.
structures called centrioles physically anchor one end of each forming microtubule. Plant cells do not contain centrioles, but microtubules in these cells do remain anchored at a pole.

During **metaphase**, the replicated chromosomes are aligned across the middle, or equator, of each cell. To do this, the microtubules, which are attached to each chromosome at the centromere, line up the chromosomes in single file across the middle of the cell.

During **anaphase**, the centromere splits, and the microtubules shorten to pull each sister chromatid of a chromosome to opposite poles of the cell.

In the last stage of mitosis, **telophase**, the nuclear envelopes re-form around the newly produced daughter nuclei, and the chromosomes revert to their uncondensed form.

### Cytokinesis

Cytokinesis is the division of the cytoplasm that takes place directly after telophase. During cytokinesis in animal cells, a band of proteins encircles the cell at the equator and divides the cytoplasm. This band of proteins contracts to pinch apart the two nuclei and the surrounding cytoplasm, creating two daughter cells from the original parent cell. Cytokinesis in plant cells requires that cells build a new cell wall, an inflexible structure surrounding the plant cells. **Figure 6.10** shows the difference between cytokinesis in animal and plant cells. During telophase of mitosis in a plant cell, membrane-bound vesicles deliver the materials required for building the cell wall to the center of the cell. These materials include a tough, fibrous carbohydrate called cellulose as well as some proteins. The membranes surrounding the vesicles gather in the center of the cell to form a structure called a cell plate. The cell plate and forming cell wall grow across the width of the cell and form a barrier that eventually separates the products of mitosis into two daughter cells. After cytokinesis, the cell reenters interphase, and if the conditions are favorable, the cell can divide again.

Any tissue that undergoes mitotic cell division can give rise to a tumor if a cell begins to divide when it should not. That tumor can increase in size if cell division remains uncontrolled.

### 6.4 Cell Cycle Control

When cell division is working properly, it is a tightly controlled process and tumor formation is prevented. Even if one renegade cell escapes these regulatory controls and forms a tumor, mechanisms are in place to get rid of the tumor. How is such regulation accomplished?

#### Tumor Suppressors Prevent Uncontrolled Cell Division

Cells do not simply proceed through the cell cycle from start to finish. Instead, proteins are continuously surveying cells to make sure that, among other things, the DNA has been replicated properly. Proteins called tumor suppressors inspect newly replicated DNA. If it is damaged in any way, for example, if a G:T base pair exists, the cell does not continue the process of cell division.

The normal BRCA1 gene encodes a protein that functions as a tumor suppressor. The mutant version of the BRCA1 gene that Angelina Jolie inherited is not able to carry out this function. Therefore, cells where this mutant gene is expressed (i.e., cells composing breast and ovarian tissues), could divide more than they are supposed to. If this happens, tumors can form (**Figure 6.11**).
Regulation of the Cell Cycle: A Closer Look

Tumor suppressors are not the only proteins guarding checkpoints. After every major event in the cell cycle, additional proteins determine whether the cell should be allowed to continue through the cell cycle (Figure 6.12). At the G₁ checkpoint, proteins check to determine if the cell has grown enough to be able to subdivide into two daughter cells. After the DNA has undergone replication during the S phase, the success of that replication is assessed at the G₂ checkpoint. Late in the M phase, proteins at the third checkpoint double check that each chromosome is present in the proper duplicated configuration and attached to microtubule.

The proteins that participate in this regulation are coded for cell cycle control genes that we all carry. These cell cycle genes, called proto-oncogenes (proto meaning before, and onco meaning cancer) can give rise to cancer-causing oncogenes if they are mutated. Proto-oncogenes encode proteins that stimulate cell division when conditions are right. Oncogenes stimulate cell division when they should not (Figure 6.13, on the next page). Proto-oncogenes and tumor suppressors work together to facilitate the passage of healthy cells, and to impede the passage of damaged cells, through cellular checkpoints.

proto- means before.
onco- means cancer.
Most of us will inherit few, if any, mutant cell-cycle control genes. Instead, our level of exposure to environmental risk factors will determine whether enough mutations will accumulate during our lifetime to cause cancer. This is why cancer is more common in the elderly. Older people have tissues that have undergone more cell division and cells that have been exposed to more carcinogens, leading to increased likelihood of mutation to genes controlling the cell cycle.

### 6.5 Cancer Detection and Treatment

When cancers are detected and treated early, their progression can be halted and the odds of survival increase. Being on the lookout for warning signs (Figure 6.14) can help alert individuals that a cancer is developing.

#### Detection Methods: Biopsy

Many cancers are first detected when a lump is discovered either by self-examination or during a medical exam. Once a lump has been discovered, a physician might perform a biopsy to surgically remove and analyze some of the cells. If the lump is composed of fluid, not cells, it is most likely a benign cyst. Cysts can arise in response to hormones or inflammation caused by injury. They do not progress to cancers and often go away without any form of treatment.

When a solid mass of cells is found, the cells can be viewed under a microscope. Benign tumors consist of orderly growths of cells that resemble the cells of the tissue from which they were taken. Malignant or cancerous cells do not resemble other cells found in the same tissue; they divide so rapidly that they do not have time to produce all the proteins necessary to build normal cells, which leads to an abnormal appearance that a trained technician can identify.

Since Angelina Jolie chose to have her breasts removed before cancer developed, she did not have to be concerned about whether the cancer had spread and there was no reason to undergo further treatment.
Treatment Methods: Chemotherapy and Radiation

Unfortunately, a biopsy of Lance Armstrong’s tumor showed that it was cancerous, and subsequent tests showed that the cancer had spread. The day after his cancer diagnosis, Lance Armstrong had one testicle surgically removed. Because the cancer had spread, he also underwent chemotherapy and radiation.

Chemotherapy. During chemotherapy, chemicals that selectively kill dividing cells are injected into the bloodstream. Because cancer is a disease caused by mutations, some cancer cells carry mutations that will allow them to be resistant to various chemotherapeutic agents. Therefore, treating a cancer patient with a combination of chemotherapeutic agents aimed at different cell cycle events increases the chances of destroying all the cancerous cells in a tumor. For example, some chemotherapeutic agents prevent the chromosomes from being pulled to the equator during cell division and others prevent DNA synthesis.

Unfortunately, normal cells that divide rapidly can also be affected by chemotherapy. Hair follicles, cells that produce red and white blood cells, and cells that line the intestines and stomach are often damaged or destroyed. The effects of chemotherapy therefore include temporary hair loss (FIGURE 6.15), anemia (dizziness and fatigue due to decreased numbers of red blood cells), and lowered protection from infection due to decreases in the number of white blood cells. In addition, damage to the cells of the stomach and intestines can lead to nausea, vomiting, and diarrhea.

Radiation Therapy. After a tumor is surgically removed, there is always a chance that some cancer cells from the tumor were not excised and remain in the body. Radiation therapy is the use of high-energy particles aimed at the location of the tumor in an effort to kill any cancer cells that might remain. This therapy is typically used only when cancers are located close to the surface of the body because it is difficult to focus a beam of radiation on internal organs and tissue damage can be quite severe.

Because a testicle can be removed in its entirety, radiation therapy is usually not necessary for men with testicular cancer, like Lance Armstrong. However, the cancer that had spread to his brain would normally have been subject to radiation treatment. It is very difficult for a surgeon to remove a brain tumor without affecting surrounding tissues or leaving some cancer cells behind. Because he was still allowed to participate in professional cycling events, and because he feared that radiation to his brain would affect his balance and ability to ride a bike, Lance Armstrong chose not to undergo radiation therapy on the tumors that metastasized to his brain. He hoped that surgical removal and chemotherapy would kill those cancer cells.

Understanding cancer can help us take better care of ourselves and help support a loved one with the diagnosis.

STOP & STRETCH One risk of radiation therapy is an increased likelihood of new tumors emerging 5 to 15 years later. Why might this treatment increase cancer risk?

Angelina Jolie carries a gene that increased her risk of cancer. Could she pass that risk on to her children? What about Lance Armstrong? At the time of his diagnosis, he did not have children but now he has five. Are they at increased risk of cancer because he underwent cell-damaging chemotherapy prior to their birth?

An understanding of the type of cell division that produces sperm and eggs will help you answer these questions.
6.6 Meiosis

Meiosis is a form of cell division that produces specialized cells called gametes that contain half the number of chromosomes of the parent cell. Gametes are produced only within the gonads, or sex organs.

In humans, the male gonads are testes, and the female gonads are ovaries. The male gametes are called sperm cells, female are called egg cells. Because human somatic cells have 46 chromosomes and meiosis reduces that number by half, the gametes produced during meiosis contain 23 chromosomes each.

Chromosomes in somatic cells occur in pairs. The 46 chromosomes in human somatic cells are actually 23 different pairs of chromosomes. In somatic cells, one member of each pair was inherited from the mother and one from the father. The members of a homologous pair of chromosomes are the same size and shape and carry the same genes, although not necessarily the same versions (FIGURE 6.16). Different versions of the same gene are called alleles of a gene. We have seen that there are different versions of the BRCA1 gene. The normal version of the gene helps control the cell cycle, while a mutant version does not.

A karyotype is a highly magnified photograph of the chromosomes, arranged in pairs. The 46 human chromosomes can be arranged into 22 pairs of nonsex chromosomes, or autosomes, and one pair of sex chromosomes (the X and Y chromosomes) to make a total of 23 pairs. Human males have an X and a Y chromosome, while females have two X chromosomes (FIGURE 6.17).

Once meiosis is completed, there is one copy of each chromosome (1–23) in every gamete. When only one member of each homologous pair

---

**FIGURE 6.16** A homologous pair of chromosomes. Homologous pairs of chromosomes have the same genes (shown here as A, B, and C) but may have different alleles. The dominant allele is represented by an uppercase letter, while the recessive allele is shown with the same letter in lowercase. Note that the chromosomes of a homologous pair each have the same size, shape, and positioning of the centromere.

**FIGURE 6.17** Karyotype. The pairs of chromosomes in this karyotype are arranged in order of decreasing size and numbered from 1 to 22. The X and Y sex chromosomes are the 23rd pair.

meio- means to make smaller.
SECTION 6.6  Meiosis

is present in a cell, we say that the cell is haploid (n)—both egg cells and sperm cells are haploid. After the sperm and egg fuse, the fertilized cell, or zygote, will contain two sets of chromosomes and is said to be diploid (2n) (FIGURE 6.18). Like mitosis, meiosis is preceded by an interphase stage that includes G1, S, and G2. Interphase is followed by two phases of meiosis, meiosis I and meiosis II, in which divisions of the nucleus take place (FIGURE 6.19). Meiosis I separates the members of a homologous pair from each other. Meiosis II separates the chromatids from each other. Both meiotic divisions are followed by cytokinesis, during which the cytoplasm is divided between the resulting daughter cells.

Interphase

The interphase that precedes meiosis consists of G1, S, and G2. This interphase of meiosis is similar in most respects to the interphase that precedes mitosis. The centrioles from which the microtubules will originate are present. The G phases are times of cell growth and preparation for division. The S phase is when DNA replication occurs. Once the cell’s DNA has been replicated, it can enter meiosis I.
CHAPTER 6  Cancer

Meiosis I

The first meiotic division, meiosis I, consists of prophase I, metaphase I, anaphase I, and telophase I (Figure 6.20).

During prophase I of meiosis, the nuclear envelope starts to break down, and the microtubules begin to assemble. The previously replicated chromosomes condense so that they can be moved around the cell without becoming entangled. The condensed chromosomes can be seen under a microscope. At this time, the homologous pairs of chromosomes exchange genetic information in a process called crossing over, which will be explained in a moment.

At metaphase I, the chromosomes line up at the equator, but they do so in homologous pairs. This is the key difference between meiosis and mitosis, where the chromosomes align single file at the equator. Homologous pairs are arranged arbitrarily regarding which member faces which pole. This process is called random alignment. At the end of this section, you will find detailed descriptions of crossing over and random alignment along with their impact on genetic diversity.

At anaphase I, the homologous pairs are separated from each other by the shortening of the microtubules, and at telophase I, nuclear envelopes reform around the chromosomes. DNA is then partitioned into each of the two

Visualize This

There is a short interphase between meiosis I and meiosis II. Look at the structure of chromosomes as they leave meiosis I and again at prophase II. Does DNA duplication occur during the interphase preceding meiosis II?
daughter cells by cytokinesis. Because each daughter cell contains only one copy of each member of a homologous pair, at this point the cells are haploid. Now both of these daughter cells are ready to undergo meiosis II.

**STOP & STRETCH** How is meiosis I similar to mitosis? How is it different?

**Meiosis II**
Meiosis II consists of prophase II, metaphase II, anaphase II, and telophase II. This second meiotic division is virtually identical to mitosis and serves to separate the sister chromatids of the replicated chromosome from each other.

At prophase II of meiosis, the cell is readying for another round of division, and the microtubules are lengthening again. At metaphase II, the chromosomes align in single file across the equator in much the same way that they do during mitosis. At anaphase II, the sister chromatids separate from each other and move to opposite poles of the cell. At telophase II, the separated chromosomes each become enclosed in their own nucleus.

Each individual can produce millions of different types of gametes due to two events that occur during meiosis I—crossing over and random alignment.
Both of these processes greatly increase the number of different kinds of gametes that an individual can produce and therefore increase the variation in individuals that can be produced when gametes combine.

**Crossing Over and Random Alignment**

**Crossing over** occurs during prophase I of meiosis I. It involves the exchange of portions of chromosomes from one member of a homologous pair to the other member. Crossing over can occur several times on each homologous pair during each occurrence of meiosis.

To illustrate crossing over, consider an example using genes involved in the production of flower color and pollen shape in sweet pea plants. These two genes are on the same chromosome and are called linked genes. Linked genes move together on the same chromosome to a gamete, and they may or may not undergo crossing over.

If a pea plant has red flowers and long pollen grains, the chromosomes may appear as shown in **Figure 6.21**. It is possible for this plant to produce four different types of gametes with respect to these two genes. Two types of gametes would result if no crossing over occurred between these genes—the gamete containing the red flower and long pollen chromosome and the gamete containing the white flower and short pollen chromosome. Two additional types of gametes could be produced if crossing over did

**FIGURE 6.21** Crossing over. If a flower with the above arrangement of alleles undergoes meiosis, it can produce (a) two different types of gametes for these two genes if crossing over does not occur or (b) four different types of gametes for these two genes if crossing over occurs at L.
Meiosis

Random alignment of homologous pairs also increases the number of genetically distinct types of gametes that can be produced. The arrangement of homologous pairs of chromosomes at metaphase I determines which chromosomes will end up together in a gamete. If we consider only two homologous pairs of chromosomes, then two different alignments are possible, and four different gametes can be produced. As the number of chromosomes in an organism’s genome increases, so does the number of possible alignments and the number of genetically distinct gametes that organism can produce (Figure 6.22).

Random alignment does not occur during mitosis, because the chromosomes align single file across the equator in order to produce identical daughter cells.

Visualize This

The cell below has two homologous pairs. How many different alignments are possible with three homologous pairs of chromosomes?

(a) One possible metaphase I alignment

(b) Another possible metaphase I alignment

FIGURE 6.22 Random alignment. In this example, the organism undergoing meiosis has only four chromosomes. The organism inherited the blue chromosomes from its father and the red chromosomes from its mother. When there are two homologous pairs of chromosomes, two possible alignments, (a) and (b), can occur. These different alignments can lead to novel combinations of genes in the gametes.
cells. For a summary of the differences between mitosis and meiosis, see FIGURE 6.23.

Now that you have a clear understanding of cell division, we can turn our attention to the question of whether people can pass cancer on to their children. In the cases of Angelina Jolie and Lance Armstrong, the answer to that question will differ.

Genetic testing showed that Angelina Jolie inherited the \textit{BRCA1} gene from her mother. Typically, it takes more than one mutation to cause a cancer, but this particular mutation of the \textit{BRCA1} will cause breast or ovarian cancer in the vast majority of women that carry the gene. Since Jolie inherited one mutant version of the \textit{BRCA1} gene, she can produce egg cells carrying the mutant version or the normal version. Therefore, each of her biological children—daughters Shiloh and Vivienne and son Knox—has a 50% chance of carrying the mutant version of this gene. If they did inherit the mutant
version of the gene, Jolie’s daughters are at increased risk of breast and ovarian cancer and her son is at increased risk of breast and prostate cancer. Any of her biological children who did not receive the mutant version of the BRCA1 gene have a cancer risk that is equal to that of their adopted siblings Maddox, Zahara, and Pax, assuming that they didn’t inherit the mutant version from their biological parents.

The causes of Lance Armstrong’s cancer are not as clear-cut as Jolie’s genetic predisposition. His family history of cancer is not nearly as pronounced as hers, so his cancer could have developed in response to some combination of inherited mutations and mutations caused by carcinogens he was exposed to during his lifetime. When it comes to cancer risk in children of those diagnosed with cancer, there is also concern about mutations caused by chemotherapy. When chemotherapeutic agents injure somatic cells, that damage is not transmissible to offspring. However, if the chemotherapy damages cells that undergo meiosis to produce sperm, mutations could be passed to children. Because of this risk, Armstrong stored sperm in a sperm bank before undergoing chemotherapy. Of his five children, three with his first wife were conceived with sperm stored before his surgery and chemotherapy, and two with his current wife were conceived naturally. Because the specific cause of Lance Armstrong’s cancer is not known, it is not possible to determine the risk of cancer for any of his five children. Likewise, it is not possible to determine whether the two children born after his chemotherapy are at increased risk since we don’t know whether the sperm involved in their conception carried chemotherapy-damaged, cell-cycle, control genes. Therefore, for any children that Armstrong (or any of us) might have, the combined effects of inherited mutant alleles and any mutations induced by environmental exposures in conjunction with lifestyle factors will determine whether and when cancers may develop.

One website claims that 80% of cancer therapies are blocked by the patient’s emotions and that these blocks can be removed by a technique called tapping. Just download the file, follow the tapping instructions, and you will feel better in no time. Another website claims that sharks do not get cancer and that taking shark-cartilage supplements can help treat cancer in humans. In a study of the effectiveness of shark cartilage, the study authors report that 15 of 29 patients diagnosed with terminal cancer were still alive one year after beginning to take the supplements, which is “a remarkable result by any measure,” according to the study authors.

Websites for alternative cancer treatment centers offer unproven treatments to patients that cost tens of thousands of dollars and are not covered by insurance. According to advertisements, these treatments are often supervised by medical doctors. The sites are filled with testimonials, but no data, about the effectiveness of such treatments.

1. The website that suggested that emotions can block cancer therapies presented no evidence to back up this claim. What would you do if you wanted to know whether that claim had any merit?

2. The study on shark cartilage was published in a non-peer reviewed journal. Does this fact add or subtract from the credibility of this article? Why?
3. What other information do you need to determine whether the one-year survival rate of the shark cartilage study has any real meaning?

4. Would the fact that the author of the shark cartilage study owns a company that sells the product make you more or less skeptical of his findings? What about the fact that sharks actually do get cancer?

5. While most medical doctors have dedicated their lives to helping people in need, a few will promote products and services simply to make money. Should you always believe the word of someone with an advanced degree?

6. Why do you think that so many people fall prey to dubious cancer cures?

---

**SOUNDS RIGHT BUT IS IT?**

A tanning salon located near campus gives a 20% discount to students. Two girls on your dorm floor have been using the tanning beds. When you question the safety of this practice, your friends claim that being exposed to 20 minutes of ultraviolet light from tanning beds is actually safer than being in the sun for a few hours. When you point out that tanning beds can cause skin cancer, they say that most salons have switched to bulbs that have only one kind of ultraviolet light, making them much safer than before. They also claim that using tanning beds makes them look and feel more healthful, in part because using tanning beds helps them to get the recommended amount of vitamin D.

**The use of tanning beds is not only safe, it improves health.**

Sounds right, but it isn’t.

1. Even if there were evidence that tanning for 20 minutes was safer than being in the sun for a few hours, would this provide evidence that tanning beds are safe? Why or why not?

2. Ultraviolet light (UV) from the sun occurs in two different DNA wavelengths, longer UVA rays and shorter UVB rays. UVB rays cause the surface of the skin to burn while the longer UVA rays penetrate further into the skin. Early tanning beds used UVB bulbs, but most have now switched to UVA bulbs. From an economic standpoint, why might it benefit tanning bed manufacturers and salon owners to switch to UVA?

3. When light-skinned people are exposed to damaging levels of UV light, their skin temporarily darkens in an attempt to prevent further damage from occurring. (Dark-skinned people have naturally high levels of pigments in the skin, an evolutionary adaptation that occurred when their ancestors were living in a geographic range with high UV light exposure.) A tan in light-skinned people is evidence that the skin has been injured. Should a tan in light-skinned people be considered evidence of good health?

4. While sunlight is required for the body to synthesize vitamin D, the American Cancer Society recommends that no one be exposed to more than 15 minutes of sunlight before applying sunscreen. If you wanted to ensure that you were getting enough vitamin D without exposing yourself to ultraviolet light from any source, what could you do?

5. Consider your answers to questions 1–4 and explain why the original statement bolded above sounds right, but isn’t.
Chapter Review

Summary

Section 6.1
Describe the cellular basis of cancer:
• Unregulated cell division can lead to the formation of a tumor (p. 108).

Compare and contrast benign and malignant tumors:
• Benign or noncancerous tumors stay in one place and do not prevent surrounding tissues and organs from functioning. Malignant tumors are those that are invasive or those that metastasize to surrounding tissues, starting new cancers (p. 108).

List several risk factors for cancer development that are under your control:
• Apart from genetics and aging, most cancer risk factors are things you can control. These include not smoking, eating a healthy diet, exercising, maintaining a healthy weight, and minimizing alcohol consumption (pp. 108–110).

Section 6.2
List the normal functions of cell division:
• Cell division is a process cells undergo to produce new cells for growth, repair, and asexual reproduction (pp. 110–111).

Describe the structure and function of chromosomes:
• Chromosomes are composed of DNA wrapped around proteins. They can be uncondensed and string-like or condensed, depending on whether the cell is actively dividing. Chromosomes carry genes (pp. 111–113).

Outline the process of DNA replication:
• During DNA replication, one strand of the double-stranded DNA molecule is used as a template for the synthesis of a new daughter strand of DNA. The newly synthesized DNA strand is complementary to the parent strand. The enzyme DNA polymerase ties together the nucleotides on the forming daughter strand (pp. 111–113).

Section 6.3
Describe the events that occur during interphase of the cell cycle:
• Interphase consists of two gap phases of the cell cycle ($G_1$ and $G_2$), during which the cell grows and prepares to enter mitosis or meiosis, and the $S$ (synthesis) phase, during which time the DNA replicates. The $S$ phase of interphase occurs between $G_1$ and $G_2$ (pp. 113–114).

Diagram two chromosomes as they proceed through mitosis of the cell cycle:
• During prophase, the replicated chromosomes condense into linear X-shaped chromosomes. At metaphase, these replicated chromosomes align across the middle of the cell. At anaphase, the sister chromatids separate from each other and align at opposite poles of the cells. At telophase, separate nuclear envelopes re-form around the linear chromosomes present at both poles of the cell (pp. 114–116).

Describe the process of cytokinesis in animal and plant cells:
• Cytokinesis is the last phase of the cell cycle. During cytokinesis, the cytoplasm is divided into two portions, one for each daughter cell. In animal cells, this involves the pinching of one cell into two cells by a band of filaments. In plant cells, this involves the construction of a cell wall in the middle of the subdivided plant cell (p. 116).

Section 6.4
Describe how the cell cycle is regulated and how disregulation can lead to tumor formation:
• When cell division is working properly, it is a tightly controlled process. Normal cells divide only when conditions are favorable. Proteins survey the cell and its environment at checkpoints as the cell moves through the cell cycle, and can halt cell division if conditions are not favorable. Mistakes in regulating the cell cycle arise when genes that control the cell cycle are mutated. Tumor suppressors are normal genes that can encode proteins that stop cell division if conditions are not favorable and can repair damage to the DNA. Protooncogenes encode genes to stimulate cell division when conditions are favorable. Oncogenes are mutated versions of these genes that stimulate cell division when they should not (pp. 116–118).
Section 6.5
Describe why chemotherapy and radiation are used to treat cancer.
• Chemotherapy selectively targets rapidly dividing cells. Radiation kills cells by exposing them to high-energy particles (p. 119).

Section 6.6
Explain what types of cells undergo meiosis, the end result of this process, and how meiosis increases genetic diversity.
• Meiosis is a type of cell division that occurs in cells that give rise to gametes. Gametes contain half as many chromosomes as somatic cells do. The reduction of chromosome number that occurs during meiosis begins with diploid cells and ends with haploid cells (p. 120).
• Meiosis is preceded by an interphase stage in which the DNA is replicated. During meiosis I, the members of a homologous pair of chromosomes are separated from each other. During meiosis II, the sister chromatids are separated from each other (pp. 120–121).

Diagram four chromosomes from a diploid organism undergoing meiosis.
• Homologues align in pairs during meiosis I and as individual chromosomes at metaphase II (pp. 122–123).

Explain the significance of crossing over and random alignment in terms of genetic diversity.
• Homologous pairs of chromosomes exchange genetic information during crossing over at prophase I of meiosis, thereby increasing the number of genetically distinct gametes that an individual can produce. The alignment of members of a homologous pair at metaphase I is random with regard to which member of a pair faces which pole. This random alignment of homologous chromosomes increases the number of different kinds of gametes an individual can produce (pp. 124–125).

Roots to Remember
The following roots of words come mainly from Latin and Greek and will help you decipher terms:

- **meio-** means to make smaller. Chapter term: meiosis
- **meta-** means change or between. Chapter terms: metastasis, metaphase
- **mito-** means a thread. Chapter term: mitosis
- **onco-** means cancer. Chapter term: oncogene
- **proto-** means before. Chapter term: proto-oncogene
- **soma-** and -some mean body. Chapter terms: somatic, chromosome
- **telo-** means end or completion. Chapter term: telophase

Learning the Basics
1. List the ways in which mitosis and meiosis differ.
2. What property of cancer cells do chemotherapeutic agents attempt to exploit?
3. A cell that begins mitosis with 46 chromosomes produces daughter cells with ______.
   A. 13 chromosomes; B. 23 chromosomes; C. 26 chromosomes; D. 46 chromosomes.
4. The centromere is a region at which ______.
   A. sister chromatids are attached to each other; B. metaphase chromosomes align; C. the tips of chromosomes are found; D. the nucleus is located.
5. Mitosis ______.
   A. occurs in cells that give rise to gametes; B. produces haploid cells from diploid cells; C. produces daughter cells that are exact genetic copies of the parent cell; D. consists of two separate divisions, mitosis I and mitosis II.
6. At metaphase of mitosis, ______.
   A. the chromosomes are condensed and found at the poles; B. the chromosomes are composed of one sister chromatid; C. cytokinesis begins; D. the chromosomes are composed of two sister chromatids and are lined up along the equator of the cell.
7. Sister chromatids ______.
   A. are two different chromosomes attached to each other; B. are exact copies of one chromosome that are attached to each other; C. arise from the centrioles; D. are broken down by mitosis; E. are chromosomes that carry different genes.
8. DNA polymerase ______.
   A. attaches sister chromatids at the centromere; B. synthesizes daughter DNA molecules from fats and phospholipids; C. is the enzyme that facilitates DNA synthesis; D. causes cancer cells to stop dividing.
9. After telophase I of meiosis, each daughter cell is ______.
   A. diploid, and the chromosomes are composed of one double-stranded DNA molecule;  
   B. diploid, and the chromosomes are composed of two sister chromatids;  
   C. haploid, and the chromosomes are composed of one double-stranded DNA molecule;  
   D. haploid, and the chromosomes are composed of two sister chromatids.

10. List two things that happen during meiosis that cause gametes to differ from one another.

11. Define the terms *proto-oncogene* and *oncogene*.

12. In what ways is the cell cycle similar in plant and animal cells, and in what ways does it differ?

13. Describe three ways that cancer cells differ from normal cells.

---

**Analyzing and Applying the Basics**

1. If your father obtained a mutation to his skin cell from ultraviolet light exposure during his youth, could he have passed that mutation on to you?

2. Will all tumors progress to cancers?

3. Why are some cancers treated with radiation therapy while others are treated with chemotherapy?

---

**Connecting the Science**

1. Should members of society be forced to pay the medical bills of smokers when the cancer risk from smoking is so evident and publicized? Explain your reasoning.

2. Would you want to be tested for the presence of cell-cycle control mutations? How would knowing whether you had some mutated proto-oncogenes be beneficial or harmful?