workplace) or high-voltage currents carried by high-power lines or produced by lightning. Injuries are of two types: (1) burns and (2) ventricular fibrillation or cardiac and respiratory center failure, resulting from disruption of normal electrical impulses. The type of injury and the severity and extent of burns depend on the strength (amperage), duration, and path of the electric current within the body.

Voltage in the household and workplace (120 or 220 V) is high enough that with low resistance at the site of contact (as when the skin is wet), sufficient current can pass through the body to cause serious injury, including *ventricular fibrillation*. If the current flow is sustained, it may generate enough heat to produce burns at the site of entry and exit as well as in internal organs. An important characteristic of alternating current, the type supplied to most homes, is that it induces tetanic muscle spasm, so that when a live wire or switch is grasped, irreversible clutching is likely to occur, prolonging the period of current flow. This results in a greater likelihood of developing extensive electrical burns and, in some cases, spasm of the chest wall muscles, producing death from asphyxia. Currents generated from high-voltage sources cause similar damage; however, because of the large current flows generated, these are more likely to produce paralysis of medullary centers and extensive burns. Lightning is a classic cause of high-voltage electrical injury. Magnetic fields and microwave radiation, when sufficiently intense, may also produce burns, usually of the skin and subjacent connective tissue, and may also interfere with cardiac pacemakers.

Injury Produced by Ionizing Radiation

Radiation is energy that travels in the form of waves or high-speed particles. Radiation has a wide range of energies that span the electromagnetic spectrum; it can be divided into nonionizing and ionizing radiation. The energy of nonionizing radiation such as UV and infrared light, microwave, and sound waves, can move atoms in a molecule or cause them to vibrate, but is not sufficient to displace bound electrons from atoms. By contrast, *ionizing radiation* has sufficient energy to remove tightly bound electrons. Collision of electrons with other molecules releases electrons in a reaction cascade, referred to as ionization. The main sources of ionizing radiation are *x-rays* and *gamma rays* (electromagnetic waves of very high frequencies), *high-energy neutrons*, *alpha particles* (composed of two protons and two neutrons), and *beta particles*, which are essentially electrons. At equivalent amounts of energy, alpha particles induce heavy damage in a restricted area, whereas x-rays and gamma rays dissipate energy over a longer, deeper course, and produce considerably less damage per unit of tissue. About 50% of the total dose of ionizing radiation received by the U.S. population is human-made, mostly originating from medical devices and radioisotopes. In fact, the exposure of patients to ionizing radiation during radiologic imaging tests roughly doubled between the early 1980s and 2006, mainly because of much more widespread use of CT scans.

Ionizing radiation is a double-edged sword. It is indispensable in medical practice, being used in the treatment of cancer, in diagnostic imaging, and in therapeutic or diagnostic radioisotopes, but it also produces adverse short- and long-term effects such as *fibrosis*, *mutagenesis*, *carcinogenesis*, and *teratogenesis*.

Radiation Units. Several somewhat confusing terms are used to describe radiation dose, which can be quantified according to the amount of radiation emitted by a source, the amount of radiation that is absorbed by a person, and the biologic effect of the radiation. Commonly used terms are as follows:

- *Curie* (Ci) represents the disintegrations per second of a radionuclide (radioisotope). One Ci is equal to 3.7×10^{10} disintegrations per second. This is an expression of the amount of radiation emitted by a source.
- *Gray* (Gy) is a unit that expresses the energy absorbed by the target tissue per unit mass. One Gray corresponds to absorption of 10^4 erg/gm of tissue. A Centigray (cGy), which is the absorption of 100 erg/gm of tissue, is equivalent to 100 Rad (radiation absorbed dose), abbreviated as R. The cGy terminology has now replaced the Rad in medical practice.
- *Sievert* (Sv) is a unit of equivalent dose that depends on the biologic rather than the physical effects of radiation (it replaced a unit called "Rem"). For the same absorbed dose, various types of radiation produce different amounts of damage. The equivalent dose controls for this variation and thereby provides a uniform measure of biologic dose. The equivalent dose (expressed in *Sieverts*) corresponds to the absorbed dose (expressed in Grays) multiplied by the relative biologic effectiveness of the radiation. The relative biologic effectiveness depends on the type of radiation, the type and volume of the exposed tissue, the duration of the exposure, and some other biologic factors (discussed below). The effective dose of x-rays in radiographs and computed tomography is commonly expressed in milliSieverts (mSv). For x-radiation, 1 mSv = 1 mGy.

Main Determinants of the Biologic Effects of Ionizing Radiation. In addition to the physical properties of the radiation, its biologic effects depend heavily on the following factors.

- *Rate of delivery* significantly modifies the biologic effect. Although the effect of radiant energy is cumulative, divided doses may allow cells to repair some of the damage between exposures. Thus, fractionated doses of radiant energy have a cumulative effect only to the extent that repair during the "recovery" intervals is incomplete. Radiation therapy of tumors exploits the general capability of normal cells to repair themselves and recover more rapidly than tumor cells, and thus not sustain as much cumulative radiation damage.
- *Field size* has a great influence on the consequences of irradiation. The body can sustain relatively high doses of radiation when delivered to small, carefully shielded fields, whereas smaller doses delivered to larger fields may be lethal.
- *Cell proliferation.* Because ionizing radiation damages DNA, rapidly dividing cells are more vulnerable to injury than are quiescent cells (Fig. 9-16). Except at extremely high doses that impair DNA transcription,