Table 9-8 Effects of Total-Body Ionizing Radiation

	0-1 Sv	1-2 Sv	2-10 Sv	10-20 Sv	>50 Sv
Main site of injury	None	Lymphocytes	Bone marrow	Small bowel	Brain
Main signs and symptoms	None	Moderate granulocytopenia Lymphopenia	Leukopenia, hemorrhage, hair loss, vomiting	Diarrhea, fever, electrolyte imbalance, vomiting	Ataxia, coma, convulsions, vomiting
Time of development	–	1 day to 1 week	2-6 weeks	5-14 days	1-4 hours
Lethality	None	None	Variable (0% to 80%)	100%	100%

DNA-protein cross-links. In surviving cells, simple defects may be repaired by various enzyme systems present in most mammalian cells. The most serious damage to DNA consists of *double-stranded breaks (DSBs).* Two types of mechanisms can repair DSBs in mammalian cells: *homologous recombination* and *nonhomologous end joining (NHEJ)*, with NHEJ being the most common repair pathway. DNA repair through NHEJ often produces mutations, including short deletions or duplications, or gross chromosomal aberrations such as translocations and inversions. If the replication of cells containing DSBs is not stopped by cell cycle checkpoint controls (Chapter 1), cells with chromosomal damage persist and may initiate carcinogenesis many years later. More recently it has been recognized that these abnormal cells also produce a "bystander effect," that is, they alter the behavior of nonirradiated surrounding cells through the production of growth factors and cytokines. Bystander effects are referred to as non-target effects of radiation.

Cancer Risks from Exposures to Radiation. Any cell capable of division that has sustained a mutation has the potential to become cancerous. Thus, an increased incidence of neoplasms may occur in any organ after exposure to ionizing radiation. The level of radiation required to increase the risk of cancer development is difficult to determine, but there is little doubt that acute or prolonged exposures that result in doses of greater than 100 mSv cause serious consequences, including cancer. Proof of this risk is found in the increased incidence of leukemias and solid tumors in several organs (e.g., thyroid, breast, and lungs) in survivors of the atomic bombings of Hiroshima and Nagasaki; the high number of thyroid cancers in survivors of the Chernobyl accident; the high incidence of thyroid tumors, and the elevated frequency of leukemias and birth defects, in inhabitants of the Marshall Islands exposed to nuclear fallout; and the development of "second cancers," such as acute myeloid leukemia, myelodysplastic syndrome, and solid tumors, in individuals who received radiation therapy for cancers such as Hodgkin lymphoma. The long-term cancer risks caused by radiation exposures in the range of 5 to 100 mSv are much more difficult to establish, because accurate measurements of risks require large population groups ranging from 50,000 to 5 million people. Nevertheless, for x-rays and gamma rays there is good evidence for a statistically significant increase in the risk of cancer at acute doses of greater than 50 mSv and "reasonable" evidence for acute doses of greater than 5 mSv; as a point of reference, a single posteroanterior chest radiograph, a lateral chest film chest radiograph, and a computed tomography of the chest deliver effective doses to the lungs of 0.01, 0.15, and 10 mSv, respectively. It is believed that the risk of secondary cancers following irradiation is greatest in children. This is based in part on

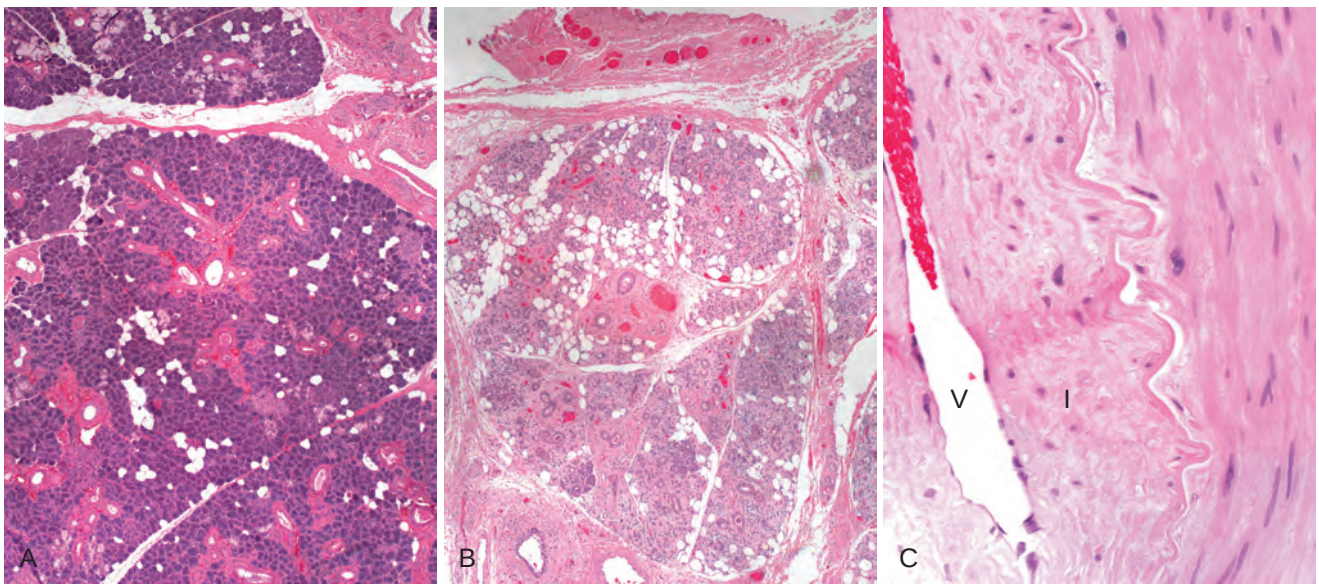

Figure 9-19 Fibrosis and vascular changes in salivary glands produced by radiation therapy of the neck region. **A,** Normal salivary gland; **B,** fibrosis caused by radiation; **C,** fibrosis and vascular changes consisting of fibrointimal thickening and arteriolar sclerosis. V, vessel lumen; I, thickened intima. (Courtesy Dr. Melissa Upton, Department of Pathology, University of Washington, Seattle, Wash.)