outlined below, which can be applied broadly to therapeutics, have been developed in these arenas.

PRINCIPLES OF PHARMACOKINETICS

The processes of absorption, distribution, metabolism, and excretion—collectively termed *drug disposition*—determine the concentration of drug delivered to target effector molecules.

ABSORPTION AND BIOAVAILABILITY

When a drug is administered orally, subcutaneously, intramuscularly, rectally, sublingually, or directly into desired sites of action, the amount of drug actually entering the systemic circulation may be less than with the intravenous route (Fig. 5-2*A*). The fraction of drug available to the systemic circulation by other routes is termed *bioavailability*. Bioavailability may be <100% for two main reasons: (1) absorption is reduced, or (2) the drug undergoes metabolism or elimination prior to entering the systemic circulation. Occasionally, the administered drug formulation is inconsistent or has degraded with time; for example, the anticoagulant dabigatran degrades rapidly (over weeks) once exposed to air, so the amount administered may be less than prescribed.

When a drug is administered by a nonintravenous route, the peak concentration occurs later and is lower than after the same dose given by rapid intravenous injection, reflecting absorption from the site of administration (Fig. 5-2). The extent of absorption may be reduced because a drug is incompletely released from its dosage form, undergoes destruction at its site of administration, or has physicochemical properties such as insolubility that prevent complete absorption from its site of administration. Slow absorption rates are deliberately designed into "slow-release" or "sustained-release" drug formulations in order to minimize variation in plasma concentrations during the interval between doses.

"First-Pass" Effect When a drug is administered orally, it must traverse the intestinal epithelium, the portal venous system, and the liver prior to entering the systemic circulation (Fig. 5-3). Once a drug enters the enterocyte, it may undergo metabolism, be transported into the portal vein, or be excreted back into the intestinal lumen. Both excretion into the intestinal lumen and metabolism decrease systemic bioavailability. Once a drug passes this enterocyte barrier, it may also be taken up into the hepatocyte, where bioavailability can be further limited by metabolism or excretion into the bile. This elimination in intestine and liver, which reduces the amount of drug delivered to the systemic circulation, is termed *presystemic elimination*, *presystemic extraction*, or *first-pass elimination*.

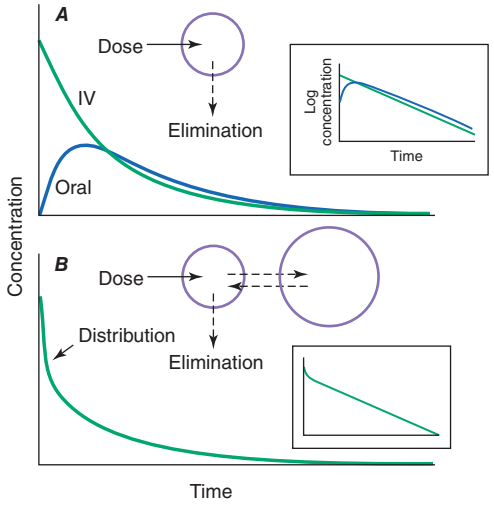

FIGURE 5-2 Idealized time-plasma concentration curves after a single dose of drug. ***A.*** The time course of drug concentration after an instantaneous IV bolus or an oral dose in the one-compartment model shown. The area under the time-concentration curve is clearly less with the oral drug than the IV, indicating incomplete bioavailability. Note that despite this incomplete bioavailability, concentration after the oral dose can be higher than after the IV dose at some time points. The inset shows that the decline of concentrations over time is linear on a log-linear plot, characteristic of first-order elimination, and that oral and IV drugs have the same elimination (parallel) time course. ***B.*** The decline of central compartment concentration when drug is distributed both to and from a peripheral compartment and eliminated from the central compartment. The rapid initial decline of concentration reflects not drug elimination but distribution.

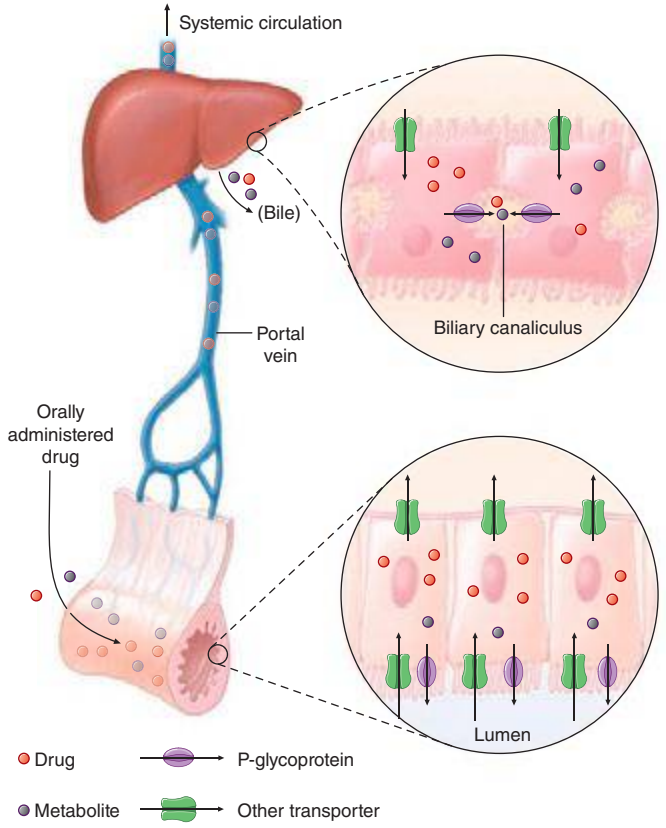

FIGURE 5-3 Mechanism of presystemic clearance. After drug enters the enterocyte, it can undergo metabolism, excretion into the intestinal lumen, or transport into the portal vein. Similarly, the hepatocyte may accomplish metabolism and biliary excretion prior to the entry of drug and metabolites to the systemic circulation. *(Adapted by permission from DM Roden, in DP Zipes, J Jalife [eds]: Cardiac Electrophysiology: From Cell to Bedside, 4th ed. Philadelphia, Saunders, 2003. Copyright 2003 with permission from Elsevier.)*

Drug movement across the membrane of any cell, including enterocytes and hepatocytes, is a combination of passive diffusion and active transport, mediated by specific drug uptake and efflux molecules. One widely studied drug transport molecule is P-glycoprotein, the product of the *MDR1* gene. P-glycoprotein is expressed on the apical aspect of the enterocyte and on the canalicular aspect of the hepatocyte (Fig. 5-3). In both locations, it serves as an efflux pump, limiting availability of drug to the systemic circulation. P-glycoprotein–mediated drug efflux from cerebral capillaries limits drug brain penetration and is an important component of the blood-brain barrier.

Drug metabolism generates compounds that are usually more polar and, hence, more readily excreted than parent drug. Metabolism takes place predominantly in the liver but can occur at other sites such as kidney, intestinal epithelium, lung, and plasma. "Phase I" metabolism involves chemical modification, most often oxidation accomplished by members of the cytochrome P450 (CYP) monooxygenase superfamily. CYPs that are especially important for drug metabolism are presented in Table 5-1, and each drug may be a substrate for one or more of these enzymes. "Phase II" metabolism involves conjugation of specific endogenous compounds to drugs or their metabolites. The enzymes