Drug Interactions with Antiretroviral Medications

Overview

Pharmacokinetic and pharmacodynamics principles are fundamental to achieving the optimal response to antiretroviral drug therapy: successful antiretroviral therapy depends on attaining a therapeutic drug concentration that maximizes efficacy and minimizes toxicity. Understanding drug interactions is important for clinicians to provide effective and safe antiretroviral therapy. Drug interactions can be classified into one of two general categories: those that alter pharmacokinetics or those that alter pharmacodynamics. Pharmacokinetics refers to the absorption, distribution, metabolism, and excretion of drugs in the body (Table 1), which is often influenced by a variety of biological, physiological, and chemical factors within each patient. Pharmacokinetic studies are used to define the steady-state concentration of a particular drug, taking into account dose, bioavailability, and clearance, as well as drug interactions that can alter the systemic concentration of coadministered medications. Pharmacodynamics describes the relationship of a drug and its effect on the body's receptors, which can be affected by the number and affinity of receptors, drug concentration, and genetics. In addition, genetic polymorphisms can influence the expression and availability of both receptor number and receptor affinity for a particular drug. Simplified, pharmacokinetics is what the body does to the medication, and pharmacodynamics is what the medication does to the body. Pharmacokinetic interactions generally have greater clinical relevance. This Topic Review will primarily focus on pharmacokinetic interactions that involve antiretroviral medications.

Types of Pharmacokinetic Interactions

Pharmacokinetic interactions can occur between antiretroviral and concomitant medications during the absorption, metabolism, or elimination phases and can involve several different mechanisms; however, most clinically significant interactions are mediated by the cytochrome P-450 system, a superfamily of microsomal, catalytic enzymes responsible for the metabolism of more than half of all drugs. Investigators have identified more than 50 cytochrome P-450 genes, but most of the cytochrome P-450 encoded proteins that play a significant role in drug metabolism belong to the CYP1, CYP2, or CYP3 families. Overall, the CYP3A enzyme is the most important enzyme involved in drug metabolism of antiretroviral medications and this enzyme is abundant in both enterocytes of the small intestinal epithelium and hepatocytes (Figure 1). Other enzymes in the cytochrome P-450 family, such as CYP1A2, 2C19, and 2D6, also play a role. The uridine diphosphate (UDP)-glucuronosyltransferase (UGT) 1A1 enzyme is an important mediator of pharmacokinetic interactions related to the metabolism of certain medications, including the integrase strand transfer inhibitors (INSTIs). Drug therapy may affect enzyme activity in one of three major ways: (1) by inhibiting the activity of the enzyme, (2) by inducing the activity of the enzyme, or (3) by acting as a substrate for the enzyme. Some medications may act both as an inhibitor and as an inducer of a particular enzyme, which can further complicate drug interactions.
Pharmacokinetic Inhibition

Drugs that inhibit enzymes (inhibitors) cause a decrease in the metabolism of other drugs that depend on the same enzyme, leading to increased drug levels of medications and potential drug toxicity (Figure 2). In the case of the cytochrome P-450 system of enzymes, inhibition of drug metabolism is usually rapid (based on drug half-life), with maximal effect occurring when the highest concentrations of the inhibiting drug are reached. Once the inhibitor is stopped, the effect of the inhibitor will typically dissipate after 3 to 5 half-lives.

Pharmacokinetic Induction

Drugs that induce enzymes (inducers) cause an increase in the clearance of drugs metabolized by the same enzyme, leading to decreased concentrations of the other drug(s) (Figure 3). The time to onset of induction is longer than the time to onset of inhibition and is based on the half-life of the inducing drug and the time required for new enzyme synthesis. As a general rule, the maximal effect of enzyme induction is apparent in 7 to 10 days, although for drugs with a relatively long half-life, the full effect of induction may take even longer. Upon discontinuation of the inducer, the effects of induction will last at least 3 to 5 half-lives plus the additional time for the induced enzyme to return to pre-induction levels; this will vary, but is likely to be approximately 7 to 10 additional days.

Drug Interactions in HIV Clinical Care

The most commonly encountered drug interactions in the context of HIV clinical care occur between antiretroviral therapies and medications used to manage common comorbidities. The following sections will address interactions between antiretroviral medications and several important therapeutic classes, including acid suppression medications, anticoagulants and antiplatelet agents, cardiac medications, anticonvulsants, medications used in the treatment of mental health and substance use disorders, and medications used in the management of hepatitis C and mycobacterial infections. Drug interactions are manifold and range from mild to severe (and even potentially fatal, requiring FDA labeling to prohibit coadministration). Medical providers who care for persons with HIV should always conduct a thorough medication history at each visit regarding the use of all medications, including prescription, over-the-counter, herbal, and recreational drugs, and consider potential interactions before prescribing a new medication. Among the highly potent anchor antiretroviral medications, the INSTIs bictegravir, dolutegravir, and raltegravir have the fewest drug interactions.[4,5] The use of the pharmacologic boosters cobicistat and ritonavir frequently leads to significant drug interactions, since they inhibit CYP3A and other transporters involved with the metabolism of many commonly used medications for general medical care.

Resources for Drug Interactions Involving Antiretroviral Medications

There are several excellent resources available to help guide providers in the management of drug interactions involving antiretroviral medications. The following list of resources include sites with drug interaction tables:

- Adult and Adolescent ARV Guidelines
- HIV Insite: Database of Antiretroviral Drug Interactions
- University of Liverpool: HIV Drug Interaction Checker
Acid Suppressive Therapy

Alterations in gastric pH and symptoms of dyspepsia, heartburn, and gastroesophageal reflux (GERD) are common among persons with HIV, and the medications used to treat these conditions, including antacids, histamine-2 receptor antagonists (H\textsubscript{2} blockers), and proton pump inhibitors, can impact the absorption of coadministered antiretroviral medications.\cite{6} In addition, other medications used to treat gastrointestinal symptoms, such as antacids and sucralfate, may contain polyvalent cations that can bind to and chelate certain integrase strand transfer inhibitors (INSTIs). The INSTIs exert their action via binding to magnesium in the active site of the HIV integrase enzyme, but if a polyvalent cation, including a divalent or trivalent metal cations, chelates with the INSTI, it can interfere with the INST binding to the integrase enzyme.\cite{7,8} For example sucralfate, which contains aluminum, can potentially bind with all of the INSTIs and should be separated in time from the INSTI dose, or avoided altogether if separation if not possible. Among the antiretroviral agents, atazanavir and rilpivirine are the most vulnerable to pharmacokinetic interactions with acid suppression medications, since both of these agents require an acidic gastric pH for dissolution and absorption.\cite{9,10,11} Medical providers can refer to the dosing recommendations in the drug interaction section of the Adult and Adolescent ARV Guidelines when coadministering antiretroviral medications and acid suppressors; the following summarizes some of these key recommendations:\cite{2}

Antacids and Buffered Medications

- **Atazanavir**: Coadministration of atazanavir with antacids (or buffered medications) is acceptable as long as atazanavir (alone or boosted with ritonavir or cobicistat) is given at least 2 hours before or at least 1 hour after the antacid (or buffered medication).
- **Bictegravir**: If bictegravir is used concomitantly with an aluminum- or magnesium-containing antacid, the antacid should be administered at least 2 hours after or 6 hours before the bictegravir dose. If a calcium-containing antacid is used, bictegravir should be given simultaneously with food. Bictegravir should not be coadministered with a calcium-containing antacid on an empty stomach.
- **Dolutegravir**: If dolutegravir is used concomitantly with a polyvalent cation acid reducer (sucralfate, cation-containing antacids or laxatives, or buffered medications), dolutegravir should be taken at least 2 hours before or 6 hours after medication that contains the polyvalent cation.
- **Elvitegravir**: Elvitegravir should be separated from antacid therapy by at least 2 hours.
- **Raltegravir**: Raltegravir (400 mg once daily or 1200 mg twice daily) should not be coadministered with any aluminum- or magnesium-containing antacid. Raltegravir 400 mg twice daily can be given with calcium-containing antacids and no dosing separation is required. The raltegravir 1200 mg once daily dose is not recommended with calcium-containing acids.
- **Rilpivirine**: Caution should be given with the concomitant use of rilpivirine and antacids. If used together, the antacid should be given at least 4 hours before or 2 hours after the rilpivirine dose.

\textbf{H\textsubscript{2}} blockers (H\textsubscript{2} antagonists)

- **Atazanavir**: For treatment-naïve patients taking atazanavir 300 mg (boosted with either ritonavir 100 mg or cobicistat 150 mg) and an H\textsubscript{2} blocker, the atazanavir plus booster should be taken with food and can be given at the same time or at least 10 hours after taking the H\textsubscript{2} blocker. The dose of H\textsubscript{2} blocker should not exceed a dose comparable to famotidine 40 mg twice daily. If unboosted atazanavir is used, atazanavir should be taken at least 2 hours before or at least 10 hours after taking an H\textsubscript{2} blocker, and the dose should not exceed the equivalent of famotidine 20 mg twice daily; no single dose should exceed a dose comparable to famotidine 20 mg. For antiretroviral treatment-experienced patients taking atazanavir, the H\textsubscript{2} blockers can be administered according to the same schedule as for treatment-naïve patients, but the maximum dose of the H\textsubscript{2} blocker should not exceed the equivalent of famotidine 20 mg twice daily. If the treatment-experienced patient is also taking tenofovir DF, the atazanavir dose should be increased to 400 mg and given with ritonavir 100 mg or cobicistat 150 mg. Unboosted atazanavir should not be coadministered with an H\textsubscript{2} blocker.
- **INSTIs**: H\textsubscript{2} blockers do not affect INSTI drug concentrations and no dose adjustment is necessary.
• **Rilpivirine**: Caution is recommended if using rilpivirine and an H\(_2\) blocker. If used together, the H\(_2\) blocker should be given at least 12 hours before or at least 4 hours after the dose of rilpivirine.

**Proton Pump Inhibitors**

- **Atazanavir**: In treatment-naïve patients, atazanavir (alone or boosted with ritonavir or cobicistat) should be taken at least 12 hours apart from the proton pump inhibitor. When taken with atazanavir, the dose of the proton pump inhibitor should not exceed the equivalent of omeprazole 20 mg daily. Proton pump inhibitors are not recommended for use in patients taking unboosted atazanavir. In treatment-experienced patients taking a proton pump inhibitor, both boosted and unboosted atazanavir should be avoided.
- **Darunavir**: For patients taking ritonavir-boosted darunavir, the omeprazole dose (or omeprazole equivalent dose) should not exceed 40 mg daily. There are no restrictions with the use of darunavir-cobicistat and proton pump inhibitors.
- **INSTIs**: Proton pump inhibitors do not affect INSTI drug concentrations and no dose adjustment is necessary.
- **Rilpivirine**: Proton pump inhibitors lower plasma rilpivirine levels to unacceptably low levels—omeprazole 20 mg has been shown to lower rilpivirine levels by as much as 40%. Coadministration of rilpivirine or combinations containing rilpivirine with a proton pump inhibitor is contraindicated.
- **Tipranavir**: The coadministration of proton pump inhibitors and tipranavir is not recommended.

**HIV Insite: Database of Antiretroviral Drug Interactions**

- [Interactions with Gastrointestinal Secretion and Motility](link)
Anticonvulsants

Significant pharmacokinetic drug interactions occur with concomitant use of anticonvulsants and antiretroviral medications. Several anticonvulsant medications significantly lower antiretroviral drug levels, potentially leading to virologic failure. This is particularly a concern with older anticonvulsants, particularly phenobarbital, phenytoin, carbamazepine, and oxcarbazepine, since these medications act as potent inducers of CYP enzymes; these older anticonvulsants can lower levels of PIs, NNRTIs, INSTIs, and also the newer coformulated medications that contain tenofovir alafenamide. Due to these potentially significant drug interactions, many antiretroviral-anticonvulsant combinations are contraindicated. Accordingly, prior to using concomitant therapy with an older anticonvulsant and antiretroviral medications, careful review of interactions and recommendations should be performed.[2] Among possible options for use of an anticonvulsant medication in persons on antiretroviral therapy, levetiracetam is considered the antiepileptic of choice due to its broad spectrum of activity, minimal drug interactions (since it is not metabolized via any CYP450 pathway), and low side effect profile.[12] For patients who are not candidates for levetiracetam therapy and require a different anticonvulsant, expert consultation is recommended.

HIV Insite: Database of Antiretroviral Drug Interactions

- Interactions between Antiepileptics and Antiretrovirals
Antimycobacterials

The interaction of antiretroviral therapy and medications used in treatment regimens for mycobacterial infections (including active and latent mycobacterial tuberculosis as well as the nontuberculous mycobacteria, including *Mycobacterium avium* complex, or MAC) is well recognized.

- **Azithromycin:** The macrolide azithromycin can be used with all antiretroviral medications without requiring any drug dosing adjustments. Atazanavir, with or without pharmacologic boosters, has a potential drug interaction that may elevate azithromycin levels, but this does not require any dose adjustment.[13]
- **Clarithromycin:** Clarithromycin is a commonly used antimycobacterial for treatment of nontuberculous mycobacteria. An alternative to clarithromycin should be considered if using with an NNRTI or a PI boosted with ritonavir or cobicistat.[13,14] For treatment of *Mycobacterium avium* complex (MAC) infections, azithromycin can typically be substituted for clarithromycin without a loss of efficacy.[15,16] Clarithromycin can be used with the INSTIs bictegravir, dolutegravir, and raltegravir without requiring any dose adjustments; clarithromycin can also be used at a standard dose with cobicistat-boosted elvitegravir if renal function is not impaired.[17]
- **Ethambutol:** There are no significant drug interactions involving ethambutol and antiretroviral medications.
- **Isoniazid:** There are no significant drug interactions involving isoniazid and antiretroviral medications.
- **Pyrazinamide:** There are no significant drug interactions involving pyrazinamide and antiretroviral medications.
- **Rifabutin:** Rifabutin can be safely coadministered with raltegravir or dolutegravir (without any dose adjustments), but should be avoided with regimens that contain bictegravir or elvitegravir boosted with cobicistat.[17] Patients taking etravirine or nevirapine (without a ritonavir-boosted PI) can use rifabutin without dose adjustment. With some antiretroviral regimens, dose adjustment of the antiretroviral medication or rifabutin may be needed. For example, if doravirine is used with rifabutin, the doravirine dose should be increased from 50 mg once daily to 50 mg every 12 hours.[14]
  Similarly, rilpivirine used with rifabutin requires a doubling of the rilpivirine dose to 50 mg twice daily.[14] Use of efavirenz with rifabutine requires a higher dose of rifabutin (450 to 600 mg per day).[14,18] In contrast, use of rifabutin with a ritonavir-boosted PI requires the rifabutin dose should be reduced to 150 mg daily or 300 mg three times per week.[13] Health care providers should also be aware that rifabutin, or any rifamycin, should not be used concurrently with tenofovir alafenamide, since rifamycins significantly reduce tenofovir levels.
- **Rifampin:** Rifampin significantly reduces the levels of protease inhibitors, NNRTIs, and INSTIs. The only acceptable antiretroviral anchor drugs that are acceptable for use with rifampin are efavirenz, raltegravir, and dolutegravir; when using these medications together, dose adjustments of the INSTIs are necessary, including doubling the dose of raltegravir from 400 mg twice daily to 800 mg twice daily and dolutegravir from 50 mg daily to 50 mg twice daily.[17] Efavirenz, at the standard 600 mg dose, can be used, but with close monitoring and possibly to include therapeutic drug monitoring to ensure adequate efavirenz levels.[19] Among the NRTIs, tenofovir alafenamide is not recommended in combination with rifampin due to the induction effect of rifampin on P-glycoprotein.[20]
- **Rifapentine:** Rifapentine can safely be used with efavirenz, and raltegravir, and all NRTIs (except for tenofovir alafenamide) without dose adjustment.[21,22] With the exception of these medications, all other INSTIs, NNRTIs, and PIs should be avoided with rifapentine.[14] The recommendation to not coadminister rifapentine and tenofovir alafenamide is due to the possible lowering of tenofovir levels.

**HIV Insite: Database of Antiretroviral Drug Interactions**

- Interactions between Antibiotics (including Antimycobacterials) and Antiretrovirals
- Interactions with Azithromycin and Antiretrovirals
- Interactions with Clarithromycin and Antiretrovirals
- Interactions with Isoniazid and Antiretrovirals
- Interactions with Rifabutin and Antiretrovirals
- Interactions with Rifampin and Antiretrovirals
- Interactions with Rifapentine and Antiretrovirals
Cardiovascular Medications

Hypertension affects approximately 25 to 35% of persons living with HIV.\[23,24,25,26,27\] Although data are conflicting regarding the association of HIV, antiretroviral therapy, and hypertension,\[26,28,29,30\] it is clear that important pharmacokinetic interactions exist between antiretroviral therapy and a number of cardiac medications used for control of blood pressure, rhythm, and rate.

Calcium Channel Blockers

Inhibition of the CYP4A, CYP2DG, and/or P-glycoprotein enzyme pathways by protease inhibitors and pharmacologic boosters (ritonavir and cobicistat) increases drug concentrations of calcium channel blockers.\[31\] These cardiac medications can generally be used, but with caution, starting with low doses, adjusting the dose for appropriate clinical response, and monitoring with electrocardiograms. For example, in patients taking boosted or unboosted atazanavir, the dose of diltiazem (a non-dihydropyridine calcium channel blocker) should be decreased by 50% since atazanavir significantly increases the area under the curve (AUC) of diltiazem.\[13\] Interactions between calcium channel blockers and NNRTIs are also possible, with efavirenz and nevirapine leading to decreased calcium channel blocker levels through induction of CYP34A enzymes; titration of the calcium channel blocker to achieve clinical efficacy is recommended.

Beta-Blockers

As with the calcium channel blockers, CYP enzyme inhibition by protease inhibitors and pharmacologic boosters (ritonavir and cobicistat) can be expected to increase levels of beta-blockers. It may be prudent to select a beta-blocker that is not metabolized through a CYP pathway (atenolol, labetalol, nadolol, or sotalol) in order to avoid these drug interactions. The NNRTIs have no significant impact on beta-blocker levels since beta-blockers are metabolized primarily by CYP2D6 and NNRTIs are inducers of CYP34A.\[32\]

Diuretics, ACE Inhibitors, and Angiotensin II Receptor Blockers

Diuretics, angiotensin-converting enzyme (ACE) inhibitors, and angiotensin II receptor blockers (ARBs) are not involved in significant CYP450-mediated interactions and thus have low potential for pharmacokinetic drug interactions with any of the antiretroviral therapies.\[32\]

Antiarrhythmics

Drug levels of antiarrhythmic medications, such as amiodarone, dofetilide, and flecainide, can increase with concomitant antiretroviral therapy that contains a PI or pharmacologic booster (ritonavir or cobicistat). The NNRTIs do not appear to impact antiarrhythmic therapy to a clinically significant degree. There are generally no significant class-wide interactions between INSTIs and cardiac medications, with the following exception: bictegravir and dolutegravir increase the serum drug concentration of dofetilide through inhibition of the renal cation transporter OCT2, which is primarily responsible for elimination of dofetilide.\[33\] Bictegravir and dolutegravir should not be coadministered with dofetilide.

Digoxin

Drug-induced inhibition of the efflux pump, P-glycoprotein, by ritonavir and other protease inhibitors can increase digoxin to toxic levels; cobicistat is also an inhibitor of P-glycoprotein, but no reports of interaction with digoxin have been reported.\[34,35\] Nevertheless, therapeutic drug monitoring of digoxin levels is recommended when any of these antiretroviral therapies are coadministered. No special monitoring is needed for concomitant NNRTI and digoxin therapy, since they have minimal effect on P-glycoprotein.

HIV Insite: Database of Antiretroviral Drug Interactions
• **Interactions between Cardiovascular Medications and Antiretrovirals**
Corticosteroids

The risk of significant pharmacokinetic drug interactions between antiretroviral therapy and corticosteroid treatment was first identified in patients taking the inhaled or nasal preparation of the corticosteroid, fluticasone. Multiple subsequent reports have documented iatrogenic severe adrenal suppression and Cushing's syndrome in patients (children and adults) concomitantly receiving a corticosteroid and a ritonavir-boosted antiretroviral regimen.\[36,37,38,39,40\] This complication results from ritonavir-mediated inhibition of CYP3A4 enzymes, which increases the levels of certain corticosteroids that are also metabolized via CYP3A enzymes. Most cases of ritonavir-associated adrenal suppression have involved fluticasone, but other corticosteroids, such as budesonide and mometasone, were subsequently also identified with this unfavorable interaction.\[41\] Most of these cases have involved oral or inhaled corticosteroids, but recent reports have also described this complication with corticosteroids delivered through topical and injectable ocular preparations, as well as following intrabursal, intraarticular, and epidural injections.\[42,43,44,45,46\] A similar drug interaction between cobicistat, also a potent inhibitor of CYP3A4, and fluticasone has been documented, and it is expected that cobicistat will have similar effects as ritonavir on the metabolism of other steroids.\[47\]

Use of Corticosteroids Not Metabolized by CYP3A

To mitigate these drug interactions in patients taking ritonavir or cobicistat, clinicians should consider using a corticosteroid other than fluticasone or budesonide, such as inhaled or nasal beclomethasone (which is not metabolized by the CYP3A4 enzyme and, thus, does not produce the same interaction).\[13,48\] Until further pharmacokinetic research is completed with other inhaled steroids, caution is recommended when any inhaled or nasal steroid other than beclomethasone is used concomitantly with ritonavir or cobicistat. Injectable forms of methylprednisolone, prednisolone, and triamcinolone should also be avoided in patients taking antiretroviral regimens containing PIs or boosting agent (ritonavir or cobicistat) As a consequence of reciprocal corticosteroid induction of the CYP3A4 enzyme pathway, dexamethasone may decrease levels of all NNRTIs and compromise virologic efficacy; rilpivirine is most affected by this interaction, so more than a single dose of dexamethasone is contraindicated in patients taking rilpivirine.\[49\] Systemic dexamethasone may also decrease levels of bictegravir and cobicistat-boosted elvitegravir.\[17\]

HIV Insite: Database of Antiretroviral Drug Interactions

- Interactions between Antiinflammatories and Antiretrovirals
Hepatitis C Treatments

Most persons coinfected with HCV and HIV are taking multi-drug antiretroviral therapy, which may pose a problem with drug interactions when initiating therapy with HCV direct-acting antiviral medications.[50, 51] There are three major classes of direct-acting antiviral medications used to treat hepatitis C: NS3/4A protease inhibitors, NS5A inhibitors, and NS5B polymerase inhibitors (Figure 5).[52, 53] The following provides key summary points for drug interactions between HCV direct-acting antiviral medication regimens and HIV antiretroviral therapy. Although ribavirin is not considered a direct-acting antiviral medication, information is included on ribavirin since it is used in some regimen combinations to treat HCV, and it has the potential to cause adverse effects due to drug interactions with HIV antiretroviral medications.

- **Elbasvir-Grazoprevir**: The NS5A inhibitor elbasvir and the HCV NS3A/4A protease inhibitor grazoprevir are substrates for CYP3A and P-gp. Thus, use of strong CYP3A inducers or inhibitors can impact levels of elbasvir and grazoprevir. Elbasvir-grazoprevir is contraindicated for use with efavirenz due to marked reductions in elbasvir and grazoprevir; the coadministration of elbasvir-grazoprevir with etravirine or nevirapine is not recommended due to expected reductions in elbasvir and grazoprevir levels. The coadministration of elbasvir-grazoprevir is contraindicated with protease inhibitors (unboosted and boosted with cobicistat or ritonavir), elvitegravir-cobicistat-tenofovir DF-emtricitabine, or elvitegravir-cobicistat-tenofovir alafenamide-emtricitabine due to the risk of hepatotoxicity from increased elbasvir and grazoprevir levels.

- **Glecaprevir-Pibrentasvir**: The medications glecaprevir (NS3/4A protease inhibitor) and pibrentasvir (NS5A inhibitors) both have the potential to inhibit P-glycoprotein (P-gp), breast cancer resistance protein (BCRP), and organic anion transporting polypeptide (OATP) 1B1/3. In addition, both glecaprevir and pibrentasvir are weak inhibitors of CYP3A4, CYP1A2 and uridine glucuronosyltransferase (UGT) 1A1. Coadministration of glecaprevir-pibrentasvir with atazanavir (with or without ritonavir or cobicistat) is contraindicated because of increased glecaprevir and pibrentasvir levels. In addition, although not contraindicated, it is recommended to avoid using glecaprevir-pibrentasvir with darunavir-cobicistat, darunavir boosted with ritonavir, lopinavir-ritonavir, or tipranavir boosted with ritonavir; this recommendation is because of the potential major increases in glecaprevir and pibrentasvir levels. Coadministration of glecaprevir-pibrentasvir with either efavirenz, etravirine, or nevirapine is not recommended because of substantial reductions in the levels of glecaprevir and pibrentasvir.

- **Ledipasvir-Sofosbuvir**: The NS5A inhibitor ledipasvir is not metabolized by the cytochrome p450 system, but is a substrate of p-glycoprotein. Ledipasvir increases tenofovir levels 1.3- to 2.6-fold when concomitantly given with either rilpivirine or efavirenz. Although ledipasvir administered concomitantly with tenofovir DF and an HIV protease inhibitor has not been studied, there is concern that tenofovir levels may increase substantially with this combination. Because of this concern and lack of data, the use of ledipasvir with ritonavir-boosted (or cobicistat-boosted) HIV protease inhibitors should, if possible, be avoided. If coadministration is needed, then close monitoring for tenofovir DF-associated toxicity should occur. Coadministration of ledipasvir-sofosbuvir with cobicistat-elvitegravir-tenofovir DF-emtricitabine or tipranavir is not recommended. Ledipasvir-sofosbuvir should not be used in patients with HIV infection if they are taking tenofovir DF and the baseline creatinine clearance is less than 60 mL/min. Coadministration with tenofovir alafenamide, however, is permissible.

- **Ribavirin**: Significant and serious toxic drug interactions can occur with the simultaneous use of ribavirin and certain HIV nucleoside reverse transcriptase inhibitors. The use of ribavirin with didanosine is strictly contraindicated due to a marked increase in intracellular didanosine levels, which may cause hepatic failure, pancreatitis, and lactic acidosis. This can also occur with stavudine or zidovudine. Thus, simultaneous use of ribavirin with either didanosine, stavudine, or zidovudine should be avoided. Concurrent use of ribavirin and zidovudine should also be avoided because of additive hematologic toxicity and increased risk of severe anemia with this combination.

- **Sofosbuvir**: This NS5B polymerase inhibitor is rapidly converted to a dominant circulating metabolite (GS-331007). Sofosbuvir is not metabolized by the cytochrome p450 system, but is a substrate of p-glycoprotein. The only significant interaction with antiretroviral medications occurs with the p-
glycoprotein inducer tipranavir, which may decrease levels of sofosbuvir and the GS-331007 metabolite. Accordingly, sofosbuvir should not be used concomitantly with tipranavir, though it can be used with all other antiretroviral medications.

- **Sofosbuvir-Velpatasvir**: The NS5A inhibitor velpatasvir is metabolized predominantly by CYP2B6, CYP2C8, and CYP3A4 enzymes. The NNRTI medications efavirenz, etravirine, and nevirapine should not be administered concurrently with velpatasvir. Similarly, ritonavir-boosted tipranavir lowers velpatasvir levels and coadministration of these medications should be avoided.

- **Sofosbuvir-Velpatasvir-Voxilaprevir**: The combination sofosbuvir-velpatasvir-voxilaprevir with either efavirenz, etravirine, or nevirapine should be avoided. The coadministration of sofosbuvir-velpatasvir-voxilaprevir with either atazanavir or lopinavir would likely increase voxilaprevir levels and thus is not recommended. Coadministration of sofosbuvir-velpatasvir-voxilaprevir with ritonavir plus tipranavir is not recommended due to expected lowered levels of sofosbuvir and velpatasvir.

**Antiretroviral Therapy Guidelines**

- [Concomitant Use of Selected Antiretroviral Drugs and Hepatitis C Virus Direct-Acting Antiviral Drugs for Treatment of HCV in Adults with HIV](#)
HMG-CoA Reductase Inhibitors (Statins)

Dyslipidemia is prevalent among persons with chronic HIV and has been associated with traditional risk factors, HIV itself, and certain antiretroviral medications. The HMG-CoA reductase inhibitors, more commonly referred to as statins, are frequently used to treat lipid disorders in persons with HIV who are taking antiretroviral therapy. Statins have been associated with elevations of hepatic aminotransferase levels, as well as adverse effects on skeletal muscle abnormalities (ranging from mild muscle pain to fatal rhabdomyolysis) and these adverse effects are directly linked to statin concentration.[54] The key pharmacokinetic drug interactions between antiretroviral medications and statins occur with the statins that are metabolized through the CYP3A4 pathway (simvastatin, lovastatin, and atorvastatin) when taken concomitantly with the potent CYP3A inhibitors ritonavir or cobicistat.[54] Clinically important interactions also occur through induction of the CYP3A4 pathway by certain NNRTI medications, which do not cause adverse effects but can decrease statin efficacy.[55] It is important to recognize that antiretroviral medications may contribute independently to higher lipid levels; in most situations, switching to a different antiretroviral regimen with a more favorable lipid profile is preferable to initiating statin therapy as long as the new regimen can be expected to maintain virologic suppression.[56,57]

Atorvastatin

Levels of atorvastatin can also be increased by ritonavir-boosted PIs and cobicistat-containing regimens, though the increases in drug levels are not as substantial as seen with simvastatin and lovastatin.[54] If atorvastatin is to be used in conjunction with a ritonavir-boosted PI and cobicistat-containing regimen, a low dose (20 mg or less of atorvastatin) should be used as initial therapy, since this dose is likely to provide the lipid-lowering effect equivalent to a dose 3 to 5 times higher if administered without a ritonavir-boosted PI or cobicistat-containing regimen.[13,54] Since atorvastatin is considered a more potent statin, this may be preferred to pravastatin in patients with known cardiovascular disease. Medical providers should be cautious not to exceed the recommended dosing of atorvastatin since there are case reports of rhabdomyolysis and acute renal failure associated with protease inhibitors and atorvastatin.[58,59] Some NNRTIs (efavirenz and etravirine) may decrease atorvastatin levels, necessitating higher dosing of atorvastatin, but should not exceed the recommended maximum dose.[14,55,60]

Lovastatin and Simvastatin

The use of simvastatin or lovastatin is contraindicated in patients receiving PI-containing or cobicistat-containing regimens due to significant increases in serum statin levels.[13] For example, when twice daily saquinavir (400 mg) boosted with ritonavir (400 mg) was combined with simvastatin, the AUC of simvastatin increased 32-fold (Figure 4).[61] As might be expected, the combination of various PIs with simvastatin has been associated with rhabdomyolysis and acute renal failure, and a similar response is expected with the use of lovastatin.[62,63,64,65] The use of simvastatin with efavirenz is also not recommended, though for the opposite reason that coadministration of efavirenz with simvastatin results in induction of statin metabolism and decreased lipid-reducing effect.[55]

Pitavastatin

Recent studies indicate that no significant pharmacokinetic interactions occur between pitavastatin and efavirenz or ritonavir-boosted darunavir; thus pitavastatin may be safety coadministered with PIs and NNRTIs without dose adjustment.[13,66,67] Furthermore, the efficacy of pitavastatin 4 mg daily was found to be superior to pravastatin 40 mg in reduction of low-density lipoprotein (LDL) and other atherogenic lipid parameters.[68] The large, international REPRIEVE study is currently evaluating whether pitavastatin is effective in the prevention of cardiovascular events in persons with HIV infection.[69] There are inadequate data regarding interactions between pitavastatin and the pharmacologic booster cobicistat; however, based upon data with ritonavir-boosted PIs, it is unlikely to interact and should be considered safe to use in this setting.
Pravastatin

Because pravastatin is not metabolized by CYP3A4, it is considered one of the safest statins for use in combination with antiretroviral medications, with the exception that pravastatin levels increase by about 80% when used concomitantly with darunavir.\[13, 70\] Therefore, when combining pravastatin and darunavir, initiating pravastatin therapy at lowest doses is appropriate.

Rosuvastatin

Rosuvastatin is not a CYP3A4 substrate, but clinically relevant interactions with antiretroviral medications primarily occur through other transporters, specifically with OATP1B1 or BCRP.\[71\] When coadministering rosuvastatin with PIs or cobicistat-containing regimens, rosuvastatin should be initiated at the lowest possible dose, with close observation for evidence of statin toxicity.\[72\] The maximum recommended dose of rosuvastatin in persons taking ritonavir-boosted atazanavir or lopinavir is 10 mg daily.\[13\] No significant effect on rosuvastatin levels is expected with NNRTI therapy; lipid levels should be monitored and rosuvastatin dose adjusted as needed.\[14\]

HIV Insite: Lipid-Lowering Agents and Antiretroviral Drug Interactions

- Interactions between Lipid-Lowering Agents and Antiretrovirals
Mental Health Medications

In the United States, persons with HIV have a high prevalence of coexisting mental health conditions.[73] In the process of managing these coexisting conditions, clinicians caring for persons with HIV often need to manage complex drug interactions between antiretroviral medications and medications used to treat depression, anxiety, or other mood disorders.[74] Several of the key interactions are discussed below.

Antipsychotics

Many antipsychotic medications are metabolized by CYP450, in particular CYP3A4, and thus levels of antipsychotic medications may increase when used concurrently with cobicistat- or ritonavir-containing regimens. Several case reports have highlighted clinically significant adverse effects resulting from combining quetiapine and ritonavir-boosted PI regimens. Thus, when initiating quetiapine in a patient already taking any PI, including ritonavir or cobicistat as a booster, the lowest possible dose of quetiapine should be used; if a patient is already taking quetiapine and is starting antiretroviral therapy with a regimen that includes PIs, ritonavir, or cobicistat, the quetiapine dose should be reduced to approximately one-sixth of the current dose to avoid toxicity.[13,75,76] Similar interactions may occur when cobicistat- or ritonavir-containing antiretroviral regimens are combined with older antipsychotics, such as perphenazine and thioridazine, as well as with some of the newer agents, such as risperidone and lurasidone. Recent label updates to cobicistat and protease inhibitors demonstrate concern with concomitant use of these agents with lurasidone. Thus, medical providers should exert caution and carefully evaluate potential drug interactions when using antipsychotics and antiretroviral regimens that contain a PI, ritonavir, or cobicistat, especially when making changes to either regimen. Since most of the medications in NNRTI class decrease antipsychotic drug concentrations, primarily due to induction of CYP34A and CYP2D6 enzymes, caution is advised with coadministration of these agents; the use of rilpivirine or doravirine is less likely to lead to significant interactions with antipsychotic medications.

Selective Serotonin Reuptake Inhibitors (SSRIs)

Similar to the interactions noted between antiretroviral medications and antipsychotics, selective serotonin reuptake inhibitors (SSRIs) may also interact with pharmacologic boosters (cobicistat and ritonavir), PIs, and NNRTIs. In general, most SSRIs are safe with concurrent antiretroviral therapy; nonetheless, the effects of coadministration are variable, and treatment should be titrated to response. For example, lopinavir-ritonavir raises paroxetine levels, darunavir given with ritonavir lowers paroxetine levels, and efavirenz does not significantly impact paroxetine levels.[13,77] Bictegravir, dolutegravir, and raltegravir do not appear to impact SSRI levels.[78]

Tricyclic Antidepressants (TCAs)

Protease inhibitors, ritonavir, and cobicistat have also been shown to increase levels of tricyclic antidepressants and trazodone. When using TCAs or trazodone concurrently with other protease inhibitors or cobicistat, the lowest possible starting dose of the TCA or trazodone should be used and then titrated for clinical effect.[13] Due to toxicity risk, trazodone is contraindicated in patients taking ritonavir-boosted saquinavir.[13,74,77]

Benzodiazepines

Benzodiazepines are commonly used for acute anxiety and are extensively used in anesthesia as sedative hypnotics. The use of benzodiazepines in the setting of antiretroviral therapy is complicated because benzodiazepines are metabolized via several different pathways, and thus drug interactions are not always predictable. In patients taking a PI, ritonavir, cobicistat, or an NNRTI, the safest benzodiazepines to use are those that are not metabolized via CYP-450; these include lorazepam, oxazepam and temazepam.[2,13] Drug concentrations of other benzodiazepines, such as alprazolam, clonazepam, and diazepam, are likely to be
increased by PIs, boosting agents (ritonavir and cobicistat), and NNRTIs, so these benzodiazepines and antiretroviral medications should not be used concurrently, with the exception that clonazepam appears to be safe in combination with NNRTIs. Chronic administration of midazolam (oral or parenteral) is contraindicated in patients taking a PI, ritonavir, cobicistat, or an NNRTI, but midazolam can be used with caution in these patients when given parenterally as a single-dose, pre-procedural medication.[2,13]

**HIV Insite: Database of Antiretroviral Drug Interactions**

- Interactions between Antidepressants and Antiretrovirals
- Interactions between Antipsychotics and Antiretrovirals
- Interactions between Sedative Hypnotics and Antiretrovirals
Opioid Agonist Therapy

A substantial proportion of persons with HIV have an opioid use disorder. Thus, HIV medical care providers should become familiar with the pharmacologic interactions between antiretroviral medications and opioid agonist medications used for the treatment of opioid use disorder.[79] This has become more complex with the introduction of several new antiretroviral and antiviral therapies for HIV and HCV, respectively, and with the increasing use of buprenorphine-based therapies to treat persons with substance use disorders. Key interactions between antiretroviral therapies, methadone, buprenorphine, and buprenorphine-naloxone will be addressed here.

Methadone

- **Integrase Strand Transfer Inhibitors (INSTIs):** There are no significant pharmacokinetic interactions between methadone and the INSTIs dolutegravir, elvitegravir (boosted with cobicistat), or raltegravir.[79,80,81,82] Although bictegravir coadministration with methadone has not yet been studied, no significant interaction is expected.

- **Non-Nucleoside Reverse Transcriptase Inhibitors (NNRTIs):** As a result of potent CYP34A induction by select NNRTIs, an increased methadone dose is often necessary in patients who are taking efavirenz or nevirapine; no methadone dose adjustment is required for concurrent therapy with either doravirine, etravirine, or rilpivirine.[80,83,84,85]

- **Protease Inhibitors:** Although PIs generally inhibit CYP enzymes and increase plasma concentrations of drugs metabolized through CYP pathways, all ritonavir-boosted protease inhibitors have the potential to reduce methadone exposure, possibly through induction of CYP2B6 or through other mechanisms; therefore, methadone dose adjustment may be necessary to avoid precipitating opiate withdrawal.[86,87]

Buprenorphine and Buprenorphine-naloxone

- **Integrase Strand Transfer Inhibitors (INSTIs):** Raltegravir does not appear to have any clinically significant interaction with buprenorphine or buprenorphine-naloxone.[79,80] Although cobicistat-boosted elvitegravir raises buprenorphine levels, no dose adjustment is necessary.[80] Although dolutegravir and bictegravir coadministration with buprenorphine or buprenorphine-naloxone have not been studied, no significant interaction is expected.

- **Non-Nucleoside Reverse Transcriptase Inhibitors (NNRTIs):** No dose adjustments are necessary when buprenorphine or buprenorphine-naloxone is used concurrently with NNRTIs, but efavirenz has been demonstrated to lower buprenorphine levels so monitoring for withdrawal is recommended.[80]

- **Protease Inhibitors (PIs):** Buprenorphine (and buprenorphine-naloxone) are metabolized by CYP34A and also undergo glucuronidation by UGT1A1. The drug interactions with PIs are variable. No buprenorphine or buprenorphine-naloxone dosage adjustment is necessary in patients taking darunavir-ritonavir, but lower doses of buprenorphine may be needed in patients taking atazanavir plus ritonavir (since atazanavir inhibits both CYP34A and UGT1A1) or any cobicistat-boosted PI.[79,86,88] Buprenorphine should not be coadministered with unboosted atazanavir due to the risk of subtherapeutic atazanavir levels.[13,79]

HIV Insite: Database of Antiretroviral Drug Interactions

- **Interactions between Methadone and Antiretrovirals**
- **Interactions between Buprenorphine and Antiretrovirals**
Oral Anticoagulants and Antiplatelet Therapy

Direct-Acting Oral Anticoagulant Medications

Among the commonly used direct-acting oral anticoagulant medications (DOACs)—apixaban, dabigatran, edoxaban, and rivaroxaban are eliminated either via CYP450 enzymes, P-glycoprotein, or both. Therefore, potent cytochrome P-450 enzyme inhibition by protease inhibitors or pharmacologic enhancers (ritonavir or cobicistat) may lead to higher plasma drug concentrations of the DOAC and potentially increase the risk of bleeding.[89] Therefore, potent cytochrome P-450 enzyme inhibition by protease inhibitors or pharmacologic enhancers (ritonavir or cobicistat) may lead to higher plasma drug concentrations of the DOAC and potentially increase the risk of bleeding.[13,89] In contrast, cytochrome P-450 enzyme induction by non-nucleoside reverse transcriptase inhibitors (NNRTIs) may lower the levels of the anticoagulant, which may lead to failure of the anticoagulant to prevent or treat thrombosis.[14,89] The Adult and Adolescent ARV Guidelines recommend avoiding concomitant use of most DOACs with ritonavir- or cobicistat-boosted PIs and with elvitegravir-cobicistat due to potential increases in the DOAC concentrations and potential risk of bleeding.[13,17] In general, the use of apixaban, betrixaban, edoxaban and rivaroxaban should be avoided in this setting.

In some situations, medical providers may use dabigatran with ritonavir-boosted PI therapy, but the extent of the interaction when combining these medications is not known. Recent data evaluating the use of ritonavir 100 mg with dabigatran given 2 hours prior to ritonavir demonstrated that the dabigatran AUC was reduced by 29%; if these medications are used in combination, the dabigatran should be taken simultaneously with the ritonavir-boosted PI.[13,89] In a separate study, the use of dabigatran was evaluated with concurrent use of cobicistat 150 mg and the dabigatran AUC increased more than 2-fold; therefore, atazanavir-cobicistat, darunavir-cobicistat, and elvitegravir-cobicistat should not be used with dabigatran. Although the use of apixaban has not been studied to date with ritonavir- or cobicistat-containing regimens (including elvitegravir-cobicistat), the Adult and Adolescent ARV Guidelines recommend avoiding coadministration of these agents, but note that if coadministration is necessary, a 50% reduction in apixaban dose is required, with close monitoring for apixaban toxicity.[13,17]

In a small retrospective case series using reduced-dose apixaban with either ritonavir- or cobicistat-boosted antiretroviral therapy, all 6 patients tolerated the combination of DOAC with antiretroviral therapy.[90] Rivaroxaban also has not been adequately studied to date with ritonavir- or cobicistat-containing regimens, but case reports have documented increased bleeding risk when rivaroxaban was combined with ritonavir.[91,92] Thus, with regard to coadministration of DOACs with boosted-PI therapy, dabigatran has the most data to guide use, and rivaroxaban should be avoided given the paucity of data and potential risk for increased bleeding.

Warfarin

Warfarin is metabolized via CYP2C9, and its use is complicated by a narrow therapeutic window, significant inter-patient variability, and major drug-drug and drug-food interactions.[9] Pharmacokinetic interactions between warfarin and antiretroviral medications are variable and often difficult to predict. Coadministration of warfarin with an antiretroviral regimen that contains a PI, NNRTI, or cobicistat is likely to alter warfarin levels. Therefore, close monitoring of the international normalized ratio (INR) is recommended whenever warfarin is combined with any of these antiretroviral medications. In addition, upon changing antiretroviral therapy in patients on a stable warfarin regimen, close INR monitoring is warranted. If reversal of warfarin anticoagulation is required, phytonadione (Vitamin K1) may be used. Bictegravir, dolutegravir, and raltegravir are not extensively metabolized via CYP450 and thus are unlikely to cause significant drug interactions with warfarin.

Platelet Aggregate Inhibitors

The platelet aggregate inhibitors, such as clopidogrel, prasugrel, and ticagrelor, can interact with either PI or NNRTI antiretroviral medications due to overlapping metabolism via CYP34A and CYP2C19 enzymes.[89] These interactions are complex, and the net effect can be difficult to predict. For example, PI-mediated
inhibition of CYP34A may decrease metabolism of ticagrelor, thereby increasing drug levels, but at the same time, PIs can delay the conversion of prasugrel to its active metabolite, which may reduce the antiplatelet effect of prasugrel. Similarly, NNRTI-mediated inhibition of CYP2C19, particularly by efavirenz or etravirine, blocks the conversion of clopidogrel to its active metabolite, resulting in a decreased antiplatelet drug effect; clopidogrel should be avoided in individuals taking efavirenz or etravirine, but is considered acceptable in combination with rilpivirine or nevirapine.[89] The inhibition of CYP2C19 by NNRTIs does not appear to result in clinically relevant interactions with either prasugrel or ticagrelor, so these agents could be used in patients taking any of the NNRTI medications.[89] These interactions can be difficult to predict and manage, especially in patients who are receiving both PI- and NNRTI-based therapies that interact with each of the medications in this class. An assay that measures platelet activation is available that may help measure the extent to which platelets are inhibited. Expert consultation is recommended.

**HIV Insite: Oral Anticoagulants and Antiretroviral Drug Interactions**

- Interactions between Apixaban and Antiretroviral Medications
- Interactions between Dabigatran and Antiretroviral Medications
- Interactions between Rivaroxaban and Antiretroviral Medications
- Interactions between Warfarin and Antiretroviral Medications
- Interactions between Clopidogrel and Antiretroviral Medications
- Interactions between Ticagrelor and Antiretroviral Medications
Phosphodiesterase Type 5 (PDE5) Inhibitors

Phosphodiesterase type 5 (PDE-5) inhibitors are frequently prescribed in men with HIV for symptoms of erectile dysfunction; pharmacokinetic interactions between antiretroviral therapies and the PDE-5 inhibitors—avanafil, sildenafil, tadalafil, and vardenafil—are well recognized.[93,94] Protease inhibitors and pharmacologic boosters (ritonavir and cobicistat) generally increase the levels of PDE-5 inhibitor medications, which can result in priapism, hypotension, and other adverse effects. In contrast, etravirine and efavirenz lower levels of PDE-5 levels and may necessitate dose increases for the PDE-5 inhibitors sildenafil, tadalafil, and vardenafil; rilpivirine has been studied with sildenafil and tadalafil, and no dose adjustment appears to be necessary with either combination.[10,93,94,95] Due to lack of data, coadministration of antiretroviral therapies from any class with avanafil is not recommended. Before treating men with HIV infection with a PDE-5 inhibitor, medical providers should consider evaluation for testosterone deficiency, since high rates of hypogonadism have been reported across many studies of men with HIV infection.[96,97] The 2013 HIVMA Primary Care Guidelines and the Endocrine Society Testosterone Guidelines recommend testing for testosterone deficiency in adult men with HIV who have decreased libido, erectile dysfunction, or other signs of androgen deficiency; if testosterone therapy is warranted and symptoms of sexual dysfunction resolve with testosterone therapy, treatment with a PDE-5 inhibitor is not warranted.[98,99]

HIV Insite: PDE-5 and Antiretroviral Drug Interactions

- Interactions with Avanafil and Antiretrovirals
- Interactions with Sildenafil and Antiretrovirals
- Interactions with Tadalafil and Antiretrovirals
- Interactions with Vardenafil and Antiretrovirals
Miscellaneous Interactions

The use of metformin with concurrent dolutegravir therapy results in a roughly 2-fold increase in metformin levels, likely due to the inhibition of organic cation transporter 2 (OCT2) by dolutegravir.[100, 101] Medical providers should use caution with this combination and limit the metformin dose to no more than 1 gram per day.[17] Less pronounced effects on metformin concentrations were seen with bictegravir coadministration, so the recommendation is to monitor for adverse events from metformin.[17] None of the other INSTIs, or other classes of antiretrovirals, have demonstrated a significant drug interaction with metformin.

HIV Insite: Metformin and Antiretroviral Drug Interactions

- Interactions between Metformin and Antiretrovirals
Summary Points

- Effective antiretroviral therapy depends on attaining a therapeutic serum drug concentration that maximizes efficacy and minimizes toxicity.
- Pharmacokinetic interactions may occur during absorption, metabolism, or elimination of the antiretroviral and/or the interacting drugs.
- The most common mechanisms involve absorption or interactions mediated by the CYP and UGT1A1 enzymes, which can increase or decrease serum drug levels.
- Regimens containing protease inhibitors and/or cobicistat generally confer the greatest risk of drug interactions, whereas regimens containing integrase inhibitors (without cobicistat) are generally the “cleanest” and confer the lowest risk of drug interactions.
- Ritonavir and cobicistat are both pharmacologic enhancers (boosters) that are potent inhibitors of CYP3A4; however, they may have different effects on other CYP and UGT enzymes or other transporters so should not be considered interchangeable. Cobicistat has also been less studied than ritonavir.
- Any changes to a drug regimen require careful consideration of potential drug interactions.
- Excellent online resources are available to help clinicians manage drug interactions.


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- Panel on Antiretroviral Guidelines for Adults and Adolescents. Guidelines for the use of antiretroviral agents in adults and adolescents with HIV. Department of Health and Human Services. Drug interactions: interactions between integrase inhibitors and non-nucleoside reverse transcriptase inhibitors or protease inhibitors. December 18, 2019. [AIDSinfo] -


Figures

**Figure 1 First-Pass Metabolism after Oral Administration of a Drug and Its Interaction with Grapefruit Juice**

Figure legend from article: CYP3A enzymes (e.g. CYP3A4) present in enterocytes of the intestinal epithelium extensively metabolize felodipine during its absorption, and on average only 30% of the administered dose enters the portal vein (solid line). Subsequently, CYP3A enzymes in the liver further metabolize the drug so that only 15% of the dose is bioavailable and finally reaches the systemic circulation and is able to exert its effects. Grapefruit juice selectively inhibits CYP3A in the enterocyte, with the net result being an increase in the oral bioavailability of felodipine by a factor of three, denoted by the asterisks and the dashed lines.

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Figure 2 CYP 450 Inhibition

Source: Illustration by John J. Faragon, PharmD

CYP 450 Inhibition

![Graph showing CYP 450 inhibition over time with an inhibiting drug added leading to steady state levels.]
Figure 3 CYP 450 Induction

Source: Illustration by John J. Faragon, PharmD

CYP 450 Induction

Inducing drug added

Drug Levels

Steady State Levels

Time
Figure 4 Ritonavir-Boosted Saquinavir Interactions with Statins

### Figure 5 Classes of Direct-Acting Antiviral Medications Used to Treat HCV

Note that all medications in gray boxes have been discontinued and are no longer manufactured in the United States.

<table>
<thead>
<tr>
<th>NS3/4A Protease Inhibitors</th>
<th>NS5A Inhibitors</th>
<th>NS5B Polymerase Inhibitors</th>
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<tbody>
<tr>
<td>Boceprevir</td>
<td>Daclatasvir</td>
<td>Dasabuvir</td>
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<tr>
<td>Glecaprevir</td>
<td>Elbasvir</td>
<td>Sofosbuvir</td>
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<td>Grazoprevir</td>
<td>Ledipasvir</td>
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<td>Paritaprevir</td>
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<td>Simeprevir</td>
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<td>Telaprevir</td>
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<td>Voxilaprevir</td>
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</table>
Table 1.
Pharmacokinetic Drug Interactions

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption</td>
<td>Concurrent therapy or food ingestion results in increase or decrease in drug absorption, thereby increasing or decreasing bioavailability.</td>
</tr>
<tr>
<td>Distribution</td>
<td>Concurrent therapy leads to protein binding displacement, altering the activity of either drug.</td>
</tr>
<tr>
<td>Metabolism</td>
<td>Therapy induces or inhibits CYP450 enzymes, thereby increasing or decreasing drug concentration.</td>
</tr>
<tr>
<td>Excretion</td>
<td>Concurrent therapy results in enhanced or decreased renal excretion of drug.</td>
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</table>