Introduction

Background

Antiretroviral therapy has transformed HIV into a manageable chronic disease, but antiretroviral medications have the potential to cause short-term and long-term adverse effects. Medication-related adverse effects may manifest in overt symptoms or initially only as laboratory abnormalities. The spectrum of potential antiretroviral drug toxicity is broad, including renal toxicity, mitochondrial and metabolic effects, gastrointestinal symptoms, weight gain, cardiovascular effects, hypersensitivity, skin reactions, insomnia, and neuropsychiatric manifestations. In general, newer antiretroviral medications have improved safety profiles compared with older antiretroviral medications, and this is reflected in the recommendations issued in the Adult and Adolescent ARV Guidelines. Clinicians who provide care to persons with HIV should have an understanding of the basic toxicity profile of antiretroviral medications, keeping in mind that the potential adverse effects of most antiretroviral medications are less toxic than the effects of untreated HIV. This Topic Review will explore antiretroviral-associated adverse effects by drug class and by specific drug. Issues related to drug interactions with antiretroviral medications are addressed in the Topic Review Drug Interactions with Antiretroviral Therapy.

Safety Laboratory Monitoring in Persons Taking Antiretroviral Therapy

All persons with HIV who initiate antiretroviral therapy should have laboratory studies performed at the initial visit, before initiating or changing a regimen, and as regular monitoring for long-term safety once a regimen is initiated. If abacavir or any abacavir fixed-dose combination is used in the regimen, baseline HLA-B*5701 testing should be performed. The following summarizes key baseline and safety laboratory studies recommended for individuals taking antiretroviral therapy (Table 1).
Entry Inhibitors

Enfuvirtide

Enfuvirtide is the only fusion inhibitor medication and the fusion inhibitor approved for use by the U.S. FDA. Enfuvirtide is used primarily in treatment-experienced patients who have limited other treatment options; it is administered twice daily by subcutaneous injection. Injection site reactions are common (occurring in up to 98% of patients in some studies) and include erythema, induration, cysts, nodules, and rarely more severe reactions.\textsuperscript{4,5} The acute injection site reactions appear within hours after the injection and some patients have persistent sclerotic lesions that can persist for months after discontinuation of enfuvirtide.

Fostemsavir

Fostemsavir is the only attachment entry inhibitor approved for use by the U.S. FDA for heavily treatment-experienced adults with multidrug-resistant HIV.\textsuperscript{6} Fostemsavir is an oral medication that after ingestion is hydrolyzed to its active form temsavir.\textsuperscript{6} In the only phase 3 trial completed with fostemsavir, serious side effects were rare; the most commonly observed mild-moderate side effects were observed nausea, and diarrhea.\textsuperscript{7}

Ibalizumab

Ibalizumab is a post-attachment entry inhibitor that is a humanized monoclonal IgG-4 antibody that prevents HIV cell entry by binding to the host CD4 receptor. Ibalizumab requires intravenous infusion. In clinical trials, the most common adverse effects associated with ibalizumab have been diarrhea, dizziness, nausea, and rash.\textsuperscript{8} Infusion reactions may also occur.

Maraviroc

Maraviroc is an entry inhibitor that exerts its action by directly binding to a host protein—the CCR5 co-receptor. Because maraviroc binds to a human protein, there has been concern it could have unique toxicity. Maraviroc can only be used in individuals who have R5-tropic virus, and thus a co-receptor tropism assay should be performed whenever the use of a CCR5 co-receptor antagonist is being considered.\textsuperscript{9} In clinical trials, most participants have tolerated maraviroc well.\textsuperscript{10,11}

- **Rash:** Maraviroc has been linked to at least one case of severe rash with systemic symptoms, although most cases of severe reactions (i.e. Stevens-Johnson syndrome, toxic epidermal necrolysis, drug reaction with eosinophilia and systemic symptoms) in patients taking maraviroc have involved patients who were also taking other drugs associated with these conditions.

- **Hepatotoxicity:** Several reports from clinical trials and postmarketing experience have noted sporadic cases of hepatotoxicity which may be preceded by severe rash and allergic symptoms in patients taking maraviroc. The FDA labeling now includes a black box hepatotoxicity warning for maraviroc. Careful monitoring of hepatic laboratory parameters, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), and bilirubin, in patients before and during treatment with maraviroc is recommended, and maraviroc should be used with caution in patients with underlying liver disease or coinfection with hepatitis B or C. Long-term follow-up of patients in the MERIT and MOTIVATE trials indicate no increased risk of hepatotoxicity in patients taking maraviroc over time.\textsuperscript{12,13}

- **Impact of Host Immune Function:** Maraviroc is the only antiretroviral drug that acts directly on a host (human) protein—the CCR5 coreceptor. The binding and impairment of the human CCR5 coreceptor by maraviroc has raised concerns for potential maraviroc-induced problems with host immune function or cancer surveillance, but trial data does not show an excess of infections or malignancies, with the exception that blockade of CCR5 receptor may increase the risk of developing symptomatic West Nile virus infection.\textsuperscript{10,14,15}
Integrase Strand Transfer Inhibitors

In general, the integrase strand transfer inhibitors (INSTIs) are well tolerated and cause minimal drug interactions. In clinical trials, the most frequent reported adverse effects were headache, nausea, diarrhea, insomnia, and fatigue, but generally were not significant enough to warrant stopping therapy.[1] Rare cases of mood changes or new onset of psychiatric disorders have been observed with INSTIs.[16,17]

Adverse Effects Observed with More than 1 INSTI

Weight Gain

Several studies have concluded that INSTIs (Figure 1), particularly dolutegravir (Figure 2), lead to greater weight gain than other classes of antiretrovirals, but the mechanism and clinical significance are unclear.[18,19,20,21] Dolutegravir-associated weight gain appears to be more pronounced when dolutegravir is combined with tenofovir alafenamide than with tenofovir DF (Figure 3).[22,23] Available data also suggest weight gain is a complication in persons taking bictegravir-tenofovir alafenamide-emtricitabine.[24]

Elevated Serum Creatinine

Dolutegravir and bictegravir causes a predictable modest increase in serum creatinine and a decrease in estimated creatinine clearance due to inhibition of active tubular secretion of creatinine via blockade of the organic cation transporter 2 (OCT2) (Figure 4).[25] In the kidney, OCT2 is an uptake transporter located on the basolateral (blood) membrane of renal proximal tubular cells, and it plays a role in transporting creatinine from the peritubular capillary blood cells into the renal tubular cells (tubular secretion of creatinine). Inhibition of OCT2 by dolutegravir causes more creatinine to remain in the bloodstream and an increase in serum creatinine. Iohexol clearance studies have shown that dolutegravir-related changes in serum creatinine do not reflect a reduction in true renal glomerular function.[26,27] Continued increases in serum creatinine after 2 to 3 months or an increase significantly greater than 0.2 mg/dL should prompt evaluation for a source of elevated creatinine other than bictegravir or dolutegravir.

Bictegravir

Bictegravir is an INSTI that is available only as a single-tablet regimen—bictegravir-tenofovir alafenamide-emtricitabine. In clinical trials, the most common adverse effects associated with bictegravir-tenofovir alafenamide-emtricitabine were diarrhea, nausea, and headache.[28,29,30] There are no known serious adverse effects associated with bictegravir. It is unknown whether bictegravir is safe to use in pregnancy. Effects of bictegravir on weight gain have not been as thoroughly studied as those with dolutegravir and are a topic of ongoing investigation. Available studies suggest the increases in serum creatinine associated with bictegravir are slightly less than with dolutegravir.[29,31]

Dolutegravir

Overall, dolutegravir is well tolerated and infrequently causes adverse effects. Dolutegravir is widely used in treatment-naïve and treatment-experienced individuals.

- **Elevated Serum Creatinine:** The dolutegravir associated elevations in serum creatinine are typically in the range of 0.1 to 0.2 mg/dL (mean change 0.15 mg/dL), occur within 4 weeks after starting dolutegravir, and remain stable thereafter (Figure 5).[32,33]
- **Insomnia:** In randomized trial settings, the incidence of insomnia in patients taking dolutegravir ranged from 3 to 15%.[33,34] Clinical experience has shown that some patients develop insomnia while taking dolutegravir, but this rarely requires discontinuation of dolutegravir.
- **Myopathy and Elevated Creatine Phosphokinase:** Rhabdomyolysis, myopathy, and myositis have been reported in very small numbers of clinical trial participants taking dolutegravir.[34,35]
Elvitegravir

Elvitegravir is an INSTI that is available a component of two single-tablet regimens: elvitegravir-cobicistat-tenofovir alafenamide-emtricitabine and elvitegravir-cobicistat-tenofovir DF-emtricitabine. Although elvitegravir itself causes few adverse effects, the cobicistat that it is combined with may lead to significant gastrointestinal symptoms and cause benign mild elevations in serum creatinine levels.[36,37]

Raltegravir

Raltegravir is the INSTI with which clinicians have the most clinical experience, and it has the fewest drug interactions among medications in the INSTI class. In general, it is a well-tolerated medication.

- **Elevated Creatine Kinase**: Raltegravir has been reported to cause elevated creatine kinase enzyme levels in some patients and in some cases has been associated with rhabdomyolysis and myositis.[38,39] Concurrent use of a statin medication, which can also cause elevations in creatine kinase elevation, likely increases this risk.[39] Other risk factors include comorbid liver or kidney disease.
- **Proximal Myopathy**: Raltegravir has been reported to cause myalgias and proximal myopathy in the setting of normal creatine kinase levels, but the mechanism is unclear and there is no evidence to suggest that raltegravir causes polymyositis or dermatomyositis.[39]
- **Stevens-Johnson Syndrome/Toxic Epidermal Necrolysis**: Rash and severe systemic hypersensitivity reactions have rarely been reported in patients taking a regimen that included raltegravir.[40,41,42]
Nucleoside Reverse Transcriptase Inhibitors

Several of the older nucleoside reverse transcriptase inhibitors (NRTIs)—didanosine, stavudine, and zidovudine—can cause mitochondrial and metabolic adverse effects; these effects rarely occur with abacavir, emtricitabine, lamivudine, tenofovir alafenamide, or tenofovir DF. Any impact of the NRTIs on human mitochondria is important, since mitochondria play an essential role in producing energy for the cell in the form of adenosine triphosphate (Figure 6).[43,44] Mitochondrial toxicity caused by the NRTIs can result in a wide range of adverse effects, including lactic acidosis, hepatic steatosis, myopathy, cardiomyopathy, peripheral neuropathy, pancreatitis, and possibly lipodystrophy syndrome.[45,46] The mechanism of NRTI-induced mitochondrial toxicity occurs through inhibition of gamma-DNA polymerase-gamma, the key enzyme responsible for mitochondrial DNA replication; this inhibition can decrease cellular oxidative phosphorylation, increase intracellular lipids, and cause accumulation of lactate (Figure 7).[1,45,47] If NRTI-related peripheral neuropathy and/or lipoatrophy develops, it only partially reverses, or does not reverse at all, with discontinuation of the offending medication.[45]

Adverse Effects Observed with More than 1 NRTI

Hyperlactatemia and Lactic Acidosis

Elevated serum lactate level (hyperlactatemia) is a known complication of older NRTIs (which are now rarely used in the United States). This adverse effect is characterized by a venous lactate level greater than 2 mmol/L (18 mg/dL) and a normal arterial pH.[48,49] Lactic acidosis is a severe form of hyperlactatemia in which the serum lactate level is greater than 4 mmol/L and the pH less than 7.35 (or a bicarbonate level less than 20 mmol/L).[49] Lactic acidosis related to NRTIs is considered a life-threatening condition.[50] Of the NRTIs, stavudine, didanosine, and the combination of stavudine and didanosine carry the highest risk of hyperlactatemia and lactic acidosis.[50] The NRTIs abacavir, lamivudine, emtricitabine, tenofovir alafenamide, tenofovir DF, and zidovudine have minimal risk of causing hyperlactatemia and lactic acidosis. Lactic acidosis caused by NRTIs rarely occurs now in the United States.[49] The symptoms of hyperlactatemia can begin months or even years after starting antiretroviral therapy and may include nausea, vomiting, abdominal pain, lethargy, tachycardia, and tachypnea.

Peripheral Neuropathy

Stavudine and didanosine are the most likely of the NRTIs to cause peripheral neuropathy, especially when used in combination; other NRTIs rarely cause peripheral neuropathy. The time frame for developing peripheral neuropathy is controversial, with some studies indicating that risk is highest within the first 90 days of starting NRTI therapy and others suggesting NRTI-induced neurotoxicity results from cumulative exposure.[51,52] The risk of developing peripheral neuropathy is higher among older individuals and those with CD4 counts below 150 cells/mm³.

Hyperlipidemia

The effect of NRTIs on metabolic parameters, in particular lipid levels, are heterogeneous and study findings have been conflicting. Didanosine, stavudine, and zidovudine typically produce unfavorable changes in lipid levels, whereas tenofovir DF usually produces favorable lipid effects; abacavir, emtricitabine, lamivudine, and tenofovir alafenamide have relatively neutral effects on lipids.[53,54] The mechanism for adverse lipid effects associated with didanosine, stavudine, and zidovudine has not been well-defined, but switching from zidovudine or stavudine to a more lipid-friendly NRTI can improve lipid profiles.[55,56] Switching from tenofovir DF to tenofovir alafenamide, which is often done in clinical practice nowadays, may lead to a mild rise in all serum lipid parameters, but the clinical implications of this rise is unclear, and generally it is not considered a contraindication to switching.

Lipoatrophy
Use of the thymidine analogs (stavudine and zidovudine) has been associated with the development of lipoatrophy, which is characterized by generalized loss of subcutaneous fat, most prominently in the face, buttocks, legs, and arms.[57,58,59,60] Long-term use of thymidine analogs potentially cause mitochondrial dysfunction in adipocytes, which may result in adipocyte apoptosis.[57] Lipoatrophy is distinct from AIDS-related wasting syndrome, since the latter involves the loss of muscle in addition to fat tissue.[1] Additional risk factors for lipoatrophy syndromes include older age, male sex, lower body mass index, and advanced immunosuppression.[1,57,58] In 2002, James and coworkers published a facial lipoatrophy severity scale that included a range of severity from 1 to 4 (Figure 8).[61] The most important management strategy for patients with lipoatrophy is to discontinue thymidine analog medications (generally by updating them to a newer antiretroviral option).[62,63,64] Multiple types of injectable facial filler agents have been used for esthetic treatment of the facial volume loss caused by lipoatrophy.[65] A systematic review performed in 2015 concluded that poly-L-lactic acid was the only facial filler to receive a grade B recommendation.[65] The administration of facial fillers should be performed by an expert who has experience and training with this procedure.

Abacavir

Abacavir is an NRTI that is also available in the fixed-dose combination drugs abacavir-lamivudine, abacavir-lamivudine-zidovudine, and dolutegravir-abacavir-lamivudine. Abacavir in any form should only be used in persons who are HLA-B*5701 negative.[2]

Hypersensitivity Reaction

The abacavir hypersensitivity reaction is a potentially life-threatening reaction to abacavir that occurs in up to 5% of individuals who do not undergo HLA-B*5701 screening; this reaction is highly associated with positivity for the HLA-B*5701 allele, which stimulates a self-directed immune response (Table 2).[66,67] Signs and symptoms of abacavir hypersensitivity typically develop within 6 weeks of starting abacavir (the median onset of symptoms is at 11 days), and may include fever, rash, malaise, gastrointestinal effects, and respiratory symptoms.[67,68] The reaction occurs more frequently in Caucasians than African Americans, due to a higher HLA-B*5701 allele frequency in Caucasians. The HLA-B*5701 test is highly useful for identifying persons who have a significantly increased risk of developing the abacavir hypersensitivity. Screening for HLA-B*5701 is required before prescribing abacavir, and any person with a positive HLA-B*5701 screening test should not receive abacavir.[2,3]

Cardiovascular Risk

Abacavir has been associated with cardiovascular disease in some studies, but the data on this issue are conflicting. In the Strategies for the Management of Antiretroviral Therapy (SMART) trial,[69] a sub-analysis found that patients taking abacavir had a higher rate of cardiovascular disease than persons taking other NRTIs.[70] In addition, a Danish cohort study showed a 2-fold relative risk of hospitalization for myocardial infarction after initiation of abacavir compared with other NRTIs.[71] and a large cohort study of veterans with HIV found a significant association between abacavir use and cardiovascular disease.[72] The Data Collection on Adverse Events of Anti-HIV Drugs (D:A:D) cohort study also found an elevated risk of myocardial infarction in persons taking abacavir.[73,74,75] In contrast, a meta-analysis that included data from more than 9,000 persons with HIV in randomized controlled trials concluded abacavir does not confer a higher risk of cardiovascular events relative to comparator abacavir-sparing regimens.[76] In light of these concerning but conflicting findings, most experts recommend avoiding use of abacavir in persons with cardiovascular disease (or significant risk factors for cardiovascular disease).

Didanosine

Didanosine is rarely used now given the potential for multiple adverse effects and serious complications, including pancreatitis, lactic acidosis, and peripheral neuropathy.[77,78] Several studies have identified
enhanced risk of didanosine-associated pancreatitis when didanosine is used in combination with stavudine, with incidence rates as high as 60 per 1,000 person-years.\[77\]

**Emtricitabine and Lamivudine**

Emtricitabine and lamivudine have the best tolerability and safety profile among all the NRTIs.\[79,80,81\] In clinical trials, discoloration of the skin, nails, and tongue was the only side effect that was more common among people taking emtricitabine compared with other antiretroviral medications.\[82\]

**Stavudine**

Stavudine is no longer recommended for use in the United States due to an array of adverse effects, including peripheral neuropathy, lactic acidosis, and facial and body lipoatrophy.\[59\] In addition, cases of severe neuromuscular weakness have been described.\[83\]

**Tenofovir alafenamide**

Tenofovir alafenamide is available as a component of multiple fixed-dose combination tablets. When compared with tenofovir DF, tenofovir alafenamide generates significantly lower serum tenofovir levels, which may offer a relatively better renal and bone safety profile (Figure 10).\[84,85,86,87,88\] Switching from tenofovir DF to tenofovir alafenamide results in improved glomerular filtration rate, glomerular and tubular proteinuria, and bone mineral density.\[89,90\] Overall, in clinical trials, tenofovir alafenamide was well tolerated, except for mild gastrointestinal effects (nausea, vomiting, diarrhea). Tenofovir alafenamide is more likely than tenofovir DF to increase certain lipid parameters (total cholesterol and HDL) but not others (total cholesterol/HDL ratio, triglycerides).\[88,91\] Tenofovir alafenamide is not recommended in persons who have an estimated creatinine clearance less than 30 mL/min. Some clinical trial and retrospective data suggest that use of tenofovir alafenamide leads to more weight gain than use of tenofovir DF, but the mechanism and clinical significance are not known.\[22,92\]

- **Monitoring on Tenofovir alafenamide:** Persons receiving tenofovir alafenamide should be monitored for renal toxicity as follows:[3]
  - Serum creatinine should be obtained at baseline, 2-8 weeks after starting therapy, and every 3-6 months thereafter.
  - Urinalysis (including urine glucose and protein) should be obtained at baseline and every 6 months.
  - If the urinalysis shows proteinuria of 1+ or higher, then a quantitative follow-up test is indicated, either an albumin-to-creatinine ratio or a protein-to-creatinine ratio.
  - Monitoring of serum phosphorus is indicated if the patient has chronic kidney disease.
  - More frequent monitoring may be indicated in patients with risk factors for renal disease.

**Tenofovir disoproxil fumarate (Tenofovir DF)**

Tenofovir DF is available as a single drug and in multiple fixed-dose combinations. Several studies have shown that persons receiving tenofovir DF had improved lipid profiles when compared with persons receiving abacavir or tenofovir alafenamide.\[36,93\] The main adverse effects associated with tenofovir DF are decreases in bone mineral density and renal toxicity.\[88,94\]

**Bone Demineralization**

Initiation of antiretroviral therapy accelerates bone demineralization by as much as 6% in the first two years (independent of the specific antiretroviral regimen selected) although this process is not progressive, and bone mineral density stabilizes and may even improve over time.\[57,95,96,97,98\] Multiple studies have
specifically implicated tenofovir DF use as a risk factor for reduced bone mineral density.[36,88] In AIDS Clinical Trials Group (ACTG) trial 5224s, investigators compared the long-term impact on bone mineral density of tenofovir DF-emtricitabine and abacavir-lamivudine and found that participants treated with tenofovir DF-emtricitabine had significantly greater decreases in bone mineral density at the spine and hip.[97] Although the mechanism is incompletely understood, tenofovir DF may affect bone indirectly through proximal tubular toxicity, leading to phosphate wasting and bone turnover.[98]

- **Evaluation for Decreases in Bone Mineral Density**: There are no specific recommendations for bone mineral density screening for individuals taking tenofovir DF, but the HIVMA/IDSA Primary Care Guidance advise bone mineral density screening with DXA for all postmenopausal women with HIV infection and for men with HIV who are 50 years of age and older.[99]

**Nephrotoxicity**

Tenofovir DF-associated renal toxicity includes gradual declines in glomerular filtration rate (GFR), phosphate wasting, and Fanconi syndrome (generalized proximal tubule dysfunction manifesting as type 2 renal tubular acidosis and phosphate wasting).[27] Reports have also described a unique form of tenofovir-associated interstitial nephritis secondary to a diffuse infiltrative lymphocytosis syndrome.[100] Tenofovir DF is not recommended for use in persons who have a creatinine clearance less than 60 mL/min. Individuals with tenofovir DF-associated nephrotoxicity may present with declining GFR or new proteinuria on routine screening.

- **Risk Factors for Nephrotoxicity**: Risk factors for tenofovir DF-associated nephrotoxicity include low CD4 cell count, hepatitis C coinfection, diabetes, older age, and baseline hepatic or renal dysfunction.[101,102] Some studies have shown that the risk of nephrotoxicity also increases when tenofovir DF is used with a ritonavir-boosted protease inhibitor or with unboosted atazanavir (when compared with tenofovir DF plus a non-nucleoside reverse transcriptase inhibitor); other studies, however, have shown that use of ritonavir-boosted protease inhibitors and unboosted atazanavir independently predicts chronic kidney disease to a similar degree as use of tenofovir DF.

- **Monitoring for Tenofovir DF-Associated Nephrotoxicity**: The 2014 HIVMA CKD Clinical Practice Guideline recommends routine monitoring of kidney function in order to allow timely identification of tenofovir DF-related nephrotoxicity.[27] This guideline is the most thorough with respect to monitoring and evaluating renal dysfunction in persons with HIV infection. Additional available guidelines for monitoring patients for renal dysfunction include the 2013 HIVMA/IDSA Primary Care Guidance and the Adult and Adolescent ARV Guidelines.[3,99] When clinically indicated, more frequent monitoring may be indicated. The following summarizes recommendations from these guidelines:
  - Monitoring serum creatinine and GFR should be performed at baseline, 2 to 8 weeks after starting therapy, and every 3 to 6 months thereafter.
  - Urinalysis (including urine glucose and protein) should be performed at baseline when starting tenofovir-DF and every 6 months thereafter.
  - If the urinalysis is performed shows proteinuria of 1+ or higher, then a quantitative follow-up test is indicated, either an albumin-to-creatinine ratio or a protein-to-creatinine ratio.
  - More frequent monitoring may be indicated in patients with risk factors for renal disease.

- **Evaluation of Suspected Tenofovir DF-Associated Nephrotoxicity**: For persons with HIV who develop renal dysfunction in the setting of tenofovir DF use, it can be challenging to determine whether tenofovir DF is the cause of the renal dysfunction. Measuring markers of proximal tubular dysfunction may be helpful in this scenario since these markers can distinguish proximal tubular disease (most likely, tenofovir-induced) from glomerular disease (Figure 9).[27] Two indicators have high specificity as markers for tubular dysfunction: (1) glycosuria with normal serum glucose, and (2) urinary phosphorus wasting with low serum phosphorus.
  - **Fractional Excretion of Phosphate**: Phosphorus wasting can be determined by fractional excretion of phosphate. Normal fractional excretion of phosphate is generally defined as less than 10% and impaired fractional excretion of phosphate is defined as above 20%; thus, a fractional excretion of phosphate above 20% raises the likelihood of tenofovir DF-related
toxicity, whereas a result below 10% makes tenofovir DF toxicity unlikely.[27] The fractional excretion of phosphate can be determined with a Fractional Excretion of Phosphate (FePO4) calculator, and it requires a serum phosphate, urine phosphate, serum creatinine, and urine creatinine (see the FePO4 Calculator in the Tools and Calculators section of this website).

- **Proteinuria**: Although proteinuria is not specific for proximal tubular dysfunction it should also be included in the workup. New onset or worsening proteinuria may be evidence of tenofovir DF-induced proximal tubular wasting (if there is no alternate explanation and if other results suggest proximal tubulopathy) and should prompt additional evaluation for tenofovir DF renal toxicity. New or worsening proteinuria may indicate a need to discontinue tenofovir DF, particularly if associated with decline in renal function. Tests that quantify proteinuria are useful in this scenario and data also suggest that a urine albumin-to-protein ratio of less than 0.4 may be useful in distinguishing proteinuria due to proximal tubular dysfunction (secondary to tenofovir DF toxicity) from proteinuria due to glomerular disease.[27]

**Discontinuing or Switching Tenofovir DF Because of Nephrotoxicity**: New or worsening proteinuria may indicate a need to change tenofovir DF, particularly if associated with a decline in renal function. Continuing tenofovir DF in the setting of ongoing renal dysfunction, particularly if the dose is not reduced when indicated, can result in severe renal failure. The 2014 HIVMA CKD Clinical Practice Guideline recommends discontinuing tenofovir DF in patients who have a significant reduction in GFR (greater than 25% decrease from baseline and to a level less than 60 mL/minute/1.73 m²), particularly when additional evaluation shows evidence of proximal tubular dysfunction (new onset or worsening of proteinuria, increased urinary phosphorous excretion and hypophosphatemia, euglycemic glycosuria, or increased urinary phosphorous excretion and hypophosphatemia).[27] In a study that enrolled adults with reduced renal function (estimated creatinine clearance of 30 to 69 mL/min) on a tenofovir DF-containing regimen, participants switched to elvitegravir-cobicistat-tenofovir alafenamide-emtricitabine had improvement in proteinuria and minimal change in GFR.

### Zidovudine

In the current antiretroviral era, zidovudine is rarely used, primarily because of poor tolerance and substantial risk of long-term adverse effects. An array of adverse effects have been associated with zidovudine use, including fatigue, headache, gastrointestinal upset, lipoatrophy, bone marrow suppression, and myopathy.

- **Bone Marrow Suppression**: Zidovudine is a well-established cause of reversible anemia and leucopenia. The anemia often occurs within the first 6 months after starting zidovudine and can be severe.[103] Significant decreases in hemoglobin are more likely to occur in patients with advanced immunosuppression (low CD4 cell count), lower baseline hemoglobin levels, and those with coexisting medical conditions. Zidovudine predictably causes an increase in red blood cell mean corpuscular volume (MCV) values.[104] In contrast with its effects on other hematologic cell lines, zidovudine does not typically lower platelet count levels.

- **Myopathy**: Chronic zidovudine use has been associated with myopathy in up to 17% of patients and is marked by progressive generalized muscle pain, weakness, and fatigue; patients may have muscle atrophy and elevated creatine kinase levels. [105] There are several proposed mechanisms for zidovudine-induced myopathy, including zidovudine-induced oxidative stress and mitochondrial depletion of L-carnitine.[105] Virtually all patients experience resolution of myopathy once zidovudine therapy is stopped (assuming zidovudine was the cause of the myopathy).
Non-Nucleoside Reverse Transcriptase Inhibitors

There are six non-nucleoside reverse transcriptase inhibitors (NNRTIs) that have been FDA approved for use: delavirdine, doravirine, efavirenz, etravirine, nevirapine, and rilpivirine.\[2\] Note that delavirdine is no longer manufactured in the United States and will not be discussed further.

Doravirine

Doravirine is an NNRTI that has been very well tolerated in clinical trials and has been associated with very few adverse effects.[106,107] In clinical trials, doravirine had an improved safety profile compared with efavirenz, with respect to cutaneous and neuropsychiatric adverse effects.[108] Approximately 1% of individuals discontinued doravirine because of neuropsychiatric adverse effects. Compared with ritonavir-boosted darunavir or efavirenz, doravirine clearly had a favorable lipid profile.[108]

Efavirenz

Efavirenz is a highly potent NNRTI, but it is no longer recommended as a component of preferred antiretroviral regimens, primarily due to neuropsychiatric adverse effects. Efavirenz is predominantly eliminated by the cytochrome p450 enzyme CYP2B6 and persons with the CYP2B6*6 allele have reduced clearance of efavirenz and thus greater risk for efavirenz-related toxicity.

- **Cardiac QTc Interval Prolongation:** Prolonged QTC intervals have been reported with administration of efavirenz and one study has shown that persons homozygous for CYP2B6*6 have an increased risk for developing efavirenz-induced prolongation of QTc.[109,110] This issue is particularly important when patients are taking medications other than efavirenz that may cause QT prolongation; in that situation, consideration should be given to switching efavirenz to another antiretroviral medication.
- **Dyslipidemia:** Efavirenz has also been shown to increase lipid parameters, including total cholesterol, triglycerides, LDL, and HDL.[56,111] Studies have consistently demonstrated that efavirenz causes more unfavorable lipid changes than the other NNRTI medications.[56] It is unclear, though, what impact efavirenz-induced dyslipidemia has on cardiovascular disease risk, especially given that HDL levels and HDL particle size both increase with efavirenz and these HDL changes may potentially confer a protective effect.[112] One cohort study and a small nested case-control study using Québec’s public health insurance database showed an increased odds ratio of myocardial infarction associated with any exposure to efavirenz (compared to no exposure).[113] whereas the very large D:A:D cohort study with over 180,000 patient-years did not find an association between efavirenz and myocardial infarction.
- **Hepatotoxicity:** Reports have documented fulminant hepatitis in persons receiving efavirenz; in some cases the hepatitis has progressed to hepatic failure that required liver transplantation, or resulted in death.[114,115,116] Efavirenz is not recommended for use in patients with hepatic insufficiency (Child-Turcotte-Pugh class B or C).
- **Neuropsychiatric:** Efavirenz has significant potential neuropsychiatric side effects that limit its use. These neuropsychiatric side effects include nightmares, impaired concentration, hallucinations, irritability, and depression.[117] Further, efavirenz may also worsen or unmask underlying or preexisting psychiatric conditions and has been associated with increased risk for suicidal ideation, attempted suicide, and suicide completion.[118] Accordingly, efavirenz should be avoided in persons with preexisting psychiatric conditions. Pharmacokinetic studies have shown that higher plasma efavirenz levels correlate with central nervous system adverse effects (Figure 11) and (Figure 12).[119] Individual variation in drug metabolism, as well as food-drug interactions, impact peak efavirenz levels. Taking efavirenz with food significantly increases efavirenz plasma levels compared with taking it without food. Taking efavirenz on an empty stomach at bedtime is recommended to minimize adverse effects.
- **Rash:** Clinical trials have demonstrated that approximately 15% of patients (range 10 to 25%) treated
with efavirenz develop a rash (Figure 13), which is significantly higher than reported rates of rash with doravirine, etravirine, or rilpivirine. The rash typically presents as a mild-to-moderate erythematous, maculopapular exanthem without systemic involvement, though severe reactions including Stevens-Johnson syndrome and toxic epidermal necrolysis have occurred.

**Etravirine**

Etravirine is an NNRTI that is primarily used in treatment-experienced individuals who have resistance to another NNRTI. The most common side effect of etravirine is rash, which occurs in approximately 5 to 10% of persons (more commonly in women than men) and is typically mild-to-moderate in severity, with only about 2% of persons needing to discontinue etravirine because of rash.[122] Rare (less than 0.1%) of cases of severe rash, including Stevens-Johnson syndrome, toxic epidermal necrosis, erythema multiforme, and DRESS (drug rash with eosinophilia and systemic symptoms) syndrome, have been reported.

**Nevirapine**

Nevirapine confers a risk of serious adverse effects and it may be less potent than other available agents. Earlier in the HIV epidemic, nevirapine was commonly used in antiretroviral regimens, but its use has dramatically declined and it is no longer a recommended or alternative medication for initial therapy.

- **Hypersensitivity Reaction:** Nevirapine has an FDA black box warning for possible life-threatening rash and hepatotoxicity, which can occur together or separately (Figure 14).[123] Rash may be accompanied by fever, general malaise, fatigue, myalgias, arthralgias, blisters, oral lesions, conjunctivitis, facial edema, eosinophilia, granulocytopenia, lymphadenopathy, or renal dysfunction.[124] If hepatotoxicity develops, it usually occurs as either an immune-mediated reaction manifesting within the first 4 weeks of therapy, or a nonimmune-mediated reaction that develops later (typically after 18 weeks of initiating therapy). Nevirapine-related hypersensitivity reactions occurs more commonly in women and in persons with higher CD4 cell counts.[125,126] Expert guidelines, recommend against initiating nevirapine in women with a CD4 count greater than 250 cells/mm$^3$ or in men with a CD4 count greater than 400 cells/mm$^3$.[124] Starting nevirapine at a lower dose, and increasing to full dose after two weeks, is a strategy that reduces the risk of rash and possibly hepatotoxicity.[124] Coadministration of corticosteroids is not recommended.[127,128]

**Rilpivirine**

Three studies—ECHO, THRIVE, and STaR—compared rilpivirine with efavirenz (given with two background NRTIs) that showed lower rates of drug discontinuation due to adverse effects in patients taking rilpivirine than in those taking efavirenz.[118,120,129]

- **Cardiac QTc Interval Prolongation:** Studies performed with high-dose rilpivirine (3 to 12 times higher than recommended dose) in volunteers without HIV demonstrated QTc prolongation (10.7 msec increase with a 75 mg daily dose and 23.3 msec with a 300 mg once-daily dose); it is recommended to consider using an alternative to rilpivirine in a patient receiving another medication that has known risk for causing torsades de pointes.[130]
- **Elevated Serum Creatinine:** In several trials, rilpivirine caused mild elevations in serum creatinine related to inhibition of tubular secretion of creatinine, but this did not represent a true reduction in renal function, nor did it require discontinuation of rilpivirine.[129]
- **Neuropsychiatric:** Rilpivirine has potential to cause neuropsychiatric side effects, including depression, insomnia, headaches, and dizziness, but the risk is significantly lower than with efavirenz.[120,131]
Pharmacologic Boosters

General Considerations

Ritonavir and cobicistat are pharmacokinetic enhancers to boost the concentration of other antiretroviral agents used in the treatment of HIV. Both medications work by interacting with the hepatic metabolism of antiretroviral drugs through the cytochrome P450 (CYP450) system. As would be expected, both of these medications can significantly impact the levels of other coadministered medications that are metabolized via the cytochrome P450 system, potentially leading to clinically significant (and occasionally unpredictable) drug interactions and potential adverse effects.

Ritonavir

Ritonavir is a PI that was previously used at high doses as an independent antiretroviral medication, but due to side effects it is no longer used as a PI. It inhibits the liver enzyme CYP450 3A (CYP3A) and now is used exclusively at lower doses for its boosting effect. The main symptoms associated with ritonavir consist of gastrointestinal effects, including diarrhea, nausea, vomiting, and abdominal pain. These side effects are greater with higher doses of ritonavir.

Cobicistat

Cobicistat is also a CYP34A inhibitor and was developed specifically as a pharmacokinetic enhancer of atazanavir and darunavir; it is also now available in combination form as a booster for elvitegravir. Cobicistat does not have any intrinsic activity against HIV. Cobicistat reduces tubular secretion of creatinine via competitive inhibitor of the multidrug and toxin extrusion protein 1 (MATE1).[132,133] In the kidney, MATE1 is located in the luminal (urine) membrane of renal tubular cells and MATE1 can transport creatinine from the renal tubular cell into the renal tubule lumen. The inhibition of MATE1 by cobicistat causes reduced tubular secretion of creatinine and results in a benign increase in serum creatinine. This inhibition correlates with a decrease in the estimated glomerular filtration rate (eGFR), but iohexol clearance studies have shown that cobicistat does not impact actual glomerular filtration rate.[134] The rise in serum creatinine, which typically is about 0.10 to 0.15 mg/dL, occurs within the first 8 weeks of starting antiretroviral therapy and then stabilizes.[36,134] For patients on cobicistat-containing regimens, changes in serum creatinine greater than 0.4 mg/mL from baseline may indicate another cause and should prompt evaluation.[132] In clinical trials, cobicistat was also associated with gastrointestinal symptoms, primarily nausea and diarrhea.[132]
Protease Inhibitors

There are currently 10 FDA-approved HIV protease inhibitors (PIs), but in the Adult and Adolescent ARV Guidelines none are designated in the category of Recommended Initial Regimens for Most People with HIV.\(^2\) The following discussion pertains to PIs used to treat HIV infection, not the PIs used to treat hepatitis C virus.

Gastrointestinal Adverse Effects

Gastrointestinal side effects (mainly diarrhea but also nausea, vomiting, and abdominal pain) were common with early PIs, particularly nelfinavir and PIs given with high doses of ritonavir for pharmacokinetic boosting; these adverse effects are less frequent and less severe with more recently developed PIs and when lower doses of ritonavir are used for boosting (100 mg/day versus 200 mg/day).\(^1\) In several trials, boosted darunavir and boosted atazanavir demonstrated lower rates of gastrointestinal side effects compared with the combination of lopinavir-ritonavir.\(^{135,136,137}\) Nevertheless, PIs overall are linked to higher rates of gastrointestinal side effects than other drug classes, such as the INSTIs or NNRTIs, and even modern PIs can cause some gastrointestinal intolerability.\(^{138,139,140}\)

Cardiovascular Risk

Protease inhibitors have been associated with dyslipidemia, insulin resistance, premature atherosclerosis, and myocardial infarction.\(^{141}\) The large, prospective observational D:A:D study found that the incidence of myocardial infarction increased from 1.53 per 1000 person-years in those not exposed to PIs to 6.01 per 1000 person-years in those exposed to PIs for longer than 6 years, with much of this risk attributable to elevated lipid levels.\(^{142}\) When the D:A:D study results were stratified according to exposure to individual drugs, only indinavir and lopinavir-ritonavir were associated with a statistically significant increased risk of myocardial infarction.\(^{73}\)

Cardiac Conduction Abnormalities

Several studies have revealed prolonged PR interval as a potential complication of both boosted and unboosted PIs, with the effect being more pronounced with ritonavir-boosted atazanavir, lopinavir, and saquinavir.\(^{143}\) Although all ritonavir-boosted PIs may potentially prolong the QTc interval, this effect is generally considered minimal, except with the combination of saquinavir with ritonavir.\(^{144}\) Some persons taking PIs have developed symptomatic atrioventricular (AV) block. Accordingly, ritonavir-boosted PIs should be used with caution in persons who have underlying conduction defects or in patients taking other medications that can prolong the PR interval.

Bleeding Risk in Persons with Hemophilia

Several case studies and case series have reported an increased risk of spontaneous bleeding episodes among persons with hemophilia and HIV who take HIV PIs.\(^{145,146}\) In some of these cases, the bleeding was severe. The biologic mechanism remains unknown but may involve platelet dysfunction.\(^{147}\) Reports have documented individuals with HIV and hemophilia who have safely taken HIV PIs without bleeding complications.\(^{148}\) In addition, clinical experience has shown that most persons with HIV infection with hemophilia can be safely treated with HIV PIs. Thus, the use of PIs in persons with hemophilia is not contraindicated, but those started on protease inhibitors should be warned about this potential complication and monitored closely.

Lipoaccumulation

Prior use of some first-generation protease inhibitors, particularly indinavir and saquinavir, in combination with thymidine analog NRTIs, has been associated with the development of abnormal central fat
accumulation, most often from excessive visceral fat.[45,149] Clinically, the abnormal fat accumulation has manifested as marked increases in abdominal girth, breast enlargement, and development of a dorsocervical fat pad—often referred to as a buffalo hump (Figure 15) and (Figure 16).[149] The risk of developing lipoaccumulation has markedly declined in the current antiretroviral era since regimens now rarely include thymidine analogs ( stavudine or zidovudine) or first-generation PIs.

**Atazanavir**

Although atazanavir was a preferred, first-line agent for many years, relatively lower potency and the potential disadvantage of hyperbilirubinemia (which causes cosmetic concern for many patients) has limited its use compared with newer antiretroviral therapy options.

- **Hyperbilirubinemia**: Atazanavir can block the normal glucuronidation of bilirubin through inhibition of the liver enzyme uridine diphosphate glucuronosyltransferase 1A1 (UGT1A1).[150] The UGT1A1 enzyme is responsible for converting unconjugated bilirubin to conjugated bilirubin (Figure 17).[150] This inhibition of UGT1A1 by atazanavir causes an increase in indirect bilirubin. It does not cause or reflect liver damage but can lead to icterus and jaundice; this is reversible with discontinuation of atazanavir. Discontinuation of atazanavir is sometimes necessary if the icterus is distressing to the person taking atazanavir.[124] The degree of hyperbilirubinemia typically fluctuates, often with a waxing and waning course.

- **Nephrolithiasis**: Atazanavir-induced kidney stones develop in approximately 1% of persons taking ritonavir-boosted atazanavir.[151,152,153] The onset of nephrolithiasis occurs, on average, two years after starting atazanavir.[154] Risk factors identified for atazanavir-induced nephrolithiasis include high atazanavir blood levels (due to slower atazanavir metabolism and/or pharmacologic boosting), high bilirubin levels, alkaline urine (atazanavir is less soluble in an alkaline environment), and prior hepatic or renal disease.[154] The urine sediment may show rod-shaped crystals and the actual stones often are composed of atazanavir and/or calcium phosphate. Atazanavir stones are typically radiolucent so will not be evident on plain film radiograph or non-contrast computed tomography (CT).[155] Crystal nephropathy can also occur in the absence of stones and should be suspected in persons with rising creatinine levels or sterile pyuria.

- **Cholelithiasis**: Several reports have been published that suggest ritonavir-boosted atazanavir is associated with the development of cholelithiasis.[156] In one study, cumulative treatment with ritonavir-boosted atazanavir for 2 years or longer has been associated with a two-fold increased risk of cholelithiasis compared to shorter term use or treatment with other protease inhibitors, including ritonavir-boosted darunavir or ritonavir-boosted lopinavir.[100,157] A separate study, however, failed to show an increased risk of cholelithiasis with ritonavir-boosted atazanavir when compared with other protease inhibitors.[152,153] Thus, if atazanavir is associated with the development of cholelithiasis, it is an uncommon or rare occurrence.

**Darunavir**

Although darunavir is no longer recommended as initial antiretroviral therapy for most individuals with HIV, it remains a cornerstone of second-line and salvage antiretroviral therapy. Abdominal pain and diarrhea are the most common darunavir-related symptoms, occurring in approximately 5 to 14% of persons.[135,158] The incidence of rash is approximately 10%, with most cases of mild severity.[135,158] The mild rash typically begins during the first 4 weeks of treatment and resolves, even with continuation of darunavir. Severe skin rash has been reported in less than 1% of persons taking darunavir, and it can be accompanied by fever and/or increases in hepatic aminotransferase levels.[135,158] Darunavir should promptly be discontinued if a severe skin rash develops. Darunavir contains a sulfonamide moiety and persons with a history of skin reaction to a sulfa medication have an increased risk of developing rash when taking darunavir. A history of sulfa allergy is not considered a darunavir contraindication, but darunavir should be used with caution in this situation, especially if the prior sulfa reaction was severe.
**Indinavir**

Indinavir is an older protease inhibitor that is now rarely used in clinical practice due to an increased risk of nephrotoxicity and requirement for twice-daily dosing. Indinavir is classically associated with a wide range of urologic and renal abnormalities, including dysuria, flank pain, renal colic, hematuria, crystalluria, nephrolithiasis, acute renal failure, chronic renal failure, and papillary necrosis. Nephrolithiasis, or kidney stones, occurred in about one-fifth of patients treated with indinavir and some of these individuals developed significant renal insufficiency. In these cases, renal function typically improved upon withdrawal of indinavir.[2]

**Lopinavir-Ritonavir**

Lopinavir is a protease inhibitor that is available only as the coformulated product lopinavir-ritonavir. Although this combination medication was used frequently in the past (including during pregnancy), it is now infrequently used because of its larger pill burden and greater toxicity than with many other currently available antiretroviral medication options.[2]

- **Hyperlipidemia**: Lopinavir-ritonavir frequently causes elevations in lipid levels, particularly total cholesterol and triglycerides. In randomized controlled trials, lopinavir-ritonavir led to more substantial lipid abnormalities than either atazanavir or darunavir; in switch-studies, patients experienced an improvement in lipid parameters when they switched off lopinavir-ritonavir to atazanavir, raltegravir, etravirine, or nevirapine.

- **Diarrhea**: Gastrointestinal side effects may occur with any protease inhibitor, but they are more prevalent with lopinavir-ritonavir than with atazanavir or darunavir. In a head-to-head randomized control trial comparing efficacy and safety of twice-daily lopinavir-ritonavir with once-daily atazanavir, diarrhea was reported in 11% of subjects in the lopinavir-ritonavir arm compared with 2% of subjects in the atazanavir arm, and subjects in the lopinavir-ritonavir arm also reported higher rates of nausea compared with the atazanavir arm (8% versus 4%).

- **Alcohol in Liquid Formulation**: The liquid solution of lopinavir-ritonavir contains 42.3% alcohol by volume.[160] Standard dosing of liquid solution of lopinavir-ritonavir requires taking 10 mL once daily or 5 mL twice daily.[160] The liquid lopinavir-ritonavir solution should not be administered with disulfiram or with any medication that may cause a disulfiram reaction, such as metronidazole. In addition, because the liquid solution of lopinavir-ritonavir contains alcohol, it should not be administered to pregnant women. Use of oral liquid ritonavir solution alone also has 42.3% alcohol by volume and thus has the same alcohol-related issues as lopinavir-ritonavir.

**Saquinavir**

Saquinavir is rarely used in current clinical practice due to the high pill burden, poor tolerability, and potential for serious adverse effects. The combination of saquinavir and ritonavir may cause prolongation of the cardiac QTc and PR intervals, which increases the risk for serious cardiac arrhythmias, including heart block and polymorphic ventricular tachycardia (torsades de pointes). Identified risks for saquinavir-induced QTc prolongation include an underlying heart condition, preexisting prolonged QTc or arrhythmia, older age, female sex, and concomitant use of other medications that prolong the QTc interval.[144] The FDA issued a recommendation that the combination of saquinavir and ritonavir should not be used in persons taking other medications known to prolong the QTc interval or in patients with a history of prolonged QTc interval.[161] All persons who are still taking saquinavir should be switched to a more modern and less toxic agent.

**Tipranavir**

Tipranavir is almost never used now because of the high pill burden and the potential for serious complications, including intracranial hemorrhage and hepatotoxicity, and the drug carries a black box warning for both conditions.[162] Tipranavir should be avoided in persons at risk for intracranial hemorrhage,
and it is contraindicated in persons with Child-Turcotte-Pugh Class B or C hepatic insufficiency.
Summary Points

- Antiretroviral therapy has overwhelming benefits and has transformed HIV infection to a manageable chronic disease for most patients, but antiretroviral therapy may confer adverse effects and sometimes these may be serious.
- Enfuvirtide, the only drug in the fusion inhibitor class, causes injection site reactions (both acute inflammatory responses and persistent sclerotic lesions) in most patients who take it.
- Bictegravir, dolutegravir, rilpivirine, and the pharmacokinetic enhancer cobicistat can increase serum creatinine and decrease estimated creatinine clearance by inhibiting active tubular secretion of creatinine, but these drugs do not typically impact actual glomerular filtration rate.
- Dolutegravir can cause headache and insomnia and has been associated with greater weight gain than other INSTIs and other classes of antiretrovirals.
- The older nucleoside reverse transcriptase inhibitors (NRTIs) were associated with mitochondrial toxicity, which encompasses lactic acidosis, hepatic steatosis, myopathy, cardiomyopathy, peripheral neuropathy, pancreatitis, and lipoatrophy, but these adverse effects are rare with newer, recommended NRTIs.
- Abacavir can cause a hypersensitivity syndrome in persons who are HLA-B*5701 positive. Abacavir may increase the risk of myocardial infarction compared with other NRTIs.
- Tenofovir alafenamide has significantly lower adverse renal and bone mineral density effects than tenofovir DF.
- Tenofovir DF can cause nephrotoxicity, including progressive chronic kidney disease and Fanconi syndrome (generalized proximal tubule dysfunction), which manifests as type 2 renal tubular acidosis and phosphate wasting. Tenofovir DF has also been linked to decreased bone density.
- Efavirenz may cause significant neuropsychiatric side effects, including suicidality, and it is no longer a recommended antiretroviral for most individuals with HIV.
- Protease inhibitors have been traditionally linked to higher rates of gastrointestinal effects, though newer PIs with lower ritonavir-boosting doses are generally better tolerated than older PI options.
- Atazanavir often causes unconjugated hyperbilirubinemia, which is not dangerous but may be cosmetically bothersome and which improves with a switch to another antiretroviral medication. Atazanavir is also associated with nephrolithiasis and cholelithiasis.
- The most common side effects of darunavir include gastrointestinal symptoms (diarrhea, abdominal pain, vomiting) and rash; the rash usually self-resolves and requires discontinuation of the drug in less than 1% of cases.
Citations


3. 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. Laboratory testing: laboratory testing for initial assessment and monitoring of patients with HIV receiving antiretroviral therapy. December 18, 2019. [HIV.gov] -


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[PubMed Abstract] -

[PubMed Abstract] -

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**Figures**

**Figure 1 Weight Gain following Initiation of Antiretroviral Therapy**

This retrospective observational cohort study analyzed data from 1,152 persons following their initiation of antiretroviral therapy. This included 351 persons receiving an integrase strand transfer inhibitor (135 on dolutegravir, 153 elvitegravir, and 63 raltegravir).

Figure 2 Weight Gain in NA-ACCORD Study by INSTI-Based Regimen

These data from the North American AIDS Cohort Collaboration on Research and Design (NA-ACCORD) show the greatest weight gain at year 1 and 2 with regimens containing dolutegravir when compared to those with raltegravir or elvitegravir.

Figure 3 Impact of NRTI in Dolutegravir Related Weight Gain

This graph shows weight gain at week 48 after starting antiretroviral therapy, based on the regimen used. In both females and males, the combination of dolutegravir with tenofovir alafenamide-emtricitabine was associated with the most weight gain.

Figure 4 Dolutegravir and Inhibition of Tubular Secretion of Creatinine

Dolutegravir can inhibit the urine organic cation transporter 2 (OCT2), a protein involved in renal tubular secretion of creatinine. The OCT2 transporter protein is located on the basolateral (blood) membrane of the renal tubular cell. The inhibition of OCT2 blocks the secretion of creatinine from the basolateral membrane of the peritubular capillary blood cell into the renal tubular cell. As a result, more serum creatinine remains in the blood and serum creatinine increases.

Illustration by Casandra Mack and David H. Spach, MD
Figure 5 Dolutegravir-Related Changes in Serum Creatinine Level

This graph shows the mean change from baseline in serum creatinine levels for the two arms dolutegravir plus abacavir-lamivudine and efavirenz-tenofovir DF-emtricitabine. The I bars indicate 1 standard deviation. To convert the values for creatinine to milligrams per deciliter, divide by 88.4.

Each cell has multiple mitochondria and each mitochondrion contains multiple copies of its own DNA (mtDNA). The enzyme DNA polymerase γ catalyzes the formation of new mtDNA.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
The new mtDNA encodes for mtRNA that in turn encodes for proteins that function as subunits for 4 of the 5 oxidative phosphorylation complexes. These complexes subsequently become part of the oxidative phosphorylation system.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 6 (Image Series) - Human Mitochondrial Function
Image 6C: Oxidative Phosphorylation System

At the inner mitochondrial membrane, the oxidative phosphorylation complex subunits synthesized from mtDNA join those complexes synthesized from nuclear DNA and comprise the five enzyme complexes of the oxidative phosphorylation system. The system also includes two electron carriers (not shown).

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 6 (Image Series) - Human Mitochondrial Function
Image 6D: \( H^+ \) Gradient and Conversion of ADP to ATP

Electrons (e\(^-\)) and \( H^+ \) are generated from the oxidation of NADH and FADH\(_2\). The electrons are passed down the electron transport system and H\(^+\) ions are pumped into the intermembrane space to form an \( H^+ \) gradient. Transport of H\(^+\) back into the mitochondria releases energy for the conversion of ADP to ATP.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 6 (Image Series) - Human Mitochondrial Function
Image 6E: Transport of ATP to Cytosol via Adenine Nucleotide Transporter

The conversion of the ADP to ATP within the mitochondria is followed by the transport of the ATP from the mitochondria to the cytosol via the adenine nucleotide transporter. This transporter shuttles ATP and ADP across the mitochondrial membrane. Within the cytosol, the conversion of ATP to ADP generates energy for the cell.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
The process of glycolysis in the cytosol and β-oxidation in the mitochondria generate acetyl Co-A, which then enters the Krebs cycle, causing a series of redox reactions that reduce electron carrying agents (NAD+ to NADH and FAD to FADH₂). The NADH and FADH₂ play a critical role in the oxidation phosphorylation process.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 6 (Image Series) - Human Mitochondrial Function
Image 6G: Conversion of Glucose to Pyruvate or Lactate

Conditions within the cell determine the fate of pyruvate. Aerobic conditions favor a higher NAD$^+$ to NADH ratio and thus a flow of lactate to pyruvate. Anaerobic conditions (or disruption of the oxidative phosphorylation system) favor conversion of pyruvate to lactate because of a higher NADH to NAD$^+$ ratio.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Some NRTIs have the potential to significantly inhibit DNA polymerase $\gamma$ and impact mtDNA synthesis. This effect is most prominent with stavudine and didanosine. The decrease in mtDNA synthesis in turn leads to diminished mtRNA, resulting in decreased synthesis of some oxidative phosphorylation system subunits.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 7 (Image Series) - NRTI and Increased NADH
Image 7B: Diminished Conversion of NADH to NAD$^+$ and FADH$_2$ to FAD.

The decreased synthesis of mitochondrial components of the oxidative phosphorylation system results in a dysfunctional oxidative phosphorylation system, which leads to diminished conversion of NADH to NAD$^+$ and FADH$_2$ to FAD.

Illustration by David Ehler, Cognition Studio and David Spach, MD
Figure 7 (Image Series) - NRTI and Increased NADH
Image 7C: Increased NADH leads to Shunting of Pyruvate to Lactate

The drop off in conversion of NADH to NAD$^+$ results in an increased NADH to NAD$^+$ ratio. The NADH reacts with pyruvate to form lactate. Thus, the overall effect of the increased NADH levels is to shift the cytosolic conversion of pyruvate to lactate.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
Figure 8 Facial Lipoatrophy Severity Scale

Facial lipoatrophy most often has been associated with long-term receipt of stavudine, didanosine, or the combination of stavudine plus didanosine.

Figure 9 Common Laboratory Indicators of Proximal Tubule Dysfunction

Additional nonspecific indicators include proteinuria/albuminuria and hematuria. Investigational markers with limited clinical availability include aminoaciduria, urinary alfa-1 microglobulin, urinary beta-2 microglobulin, urinary retinol binding protein, urinary cytochrome C, and urinary cystatin C.

**Figure 10 Metabolism of Tenofovir DF and Tenofovir alafenamide**

A 25 mg dose of tenofovir alafenamide has 90% lower circulating plasma tenofovir levels when compared with a 300 mg dose of tenofovir DF.
Figure 11 Central Nervous System Toxicity Related to Plasma Efavirenz Levels

This study involved an analysis of 130 adult on an efavirenz-based antiretroviral regimen. Blood samples for efavirenz levels were drawn at an average of 14 hours after efavirenz intake. The bar graph shows the percentage of patients with central nervous system toxicity based on efavirenz levels. Patients with levels greater than 4.0 µg/ml had an approximately three-fold greater incidence of central nervous system toxicity than patients with levels in the 1.0-4.0 µg/mL range.

**Figure 12 Plasma Efavirenz Levels: Virologic Response and Toxicity**

This graph shows a correlation of plasma efavirenz levels and probability of CNS adverse effects. The probability of viral suppression is shown by the purple line and the central nervous system adverse effects are shown by the blue line. The data shown as stepped lines represent the observed frequency in predefined concentration ranges and the curved lines represent the fitted regression model. The grey box in the middle represents the optimal efavirenz concentration range of 1000-4,000 μg/L (equivalent to 1-4 μg/mL).

Figure 13 Efavirenz-Associated Rash

Photograph by David H. Spach, MD
Figure 14 Nevirapine-Associated Rash

Photograph by David H. Spach, MD
Figure 15 Fat Redistribution

This patient developed marked enlargement of the abdominal girth and breasts while taking a regimen of indinavir plus stavudine plus lamivudine.

Photograph by David H. Spach, MD
Figure 16 Fat Redistribution: Neck

Note the dorsocervical fat pad enlargement. This has often been referred to as a buffalo hump.

Photograph by David H. Spach, MD
Figure 17 Mechanism for Atazanavir-Associated Increase in Serum Bilirubin

Atazanavir can increase serum total bilirubin through inhibition of the liver enzyme uridine diphosphate glucuronosyltransferase 1A1 (UGT1A1); this enzyme is a key enzyme in the normal glucuronidation of bilirubin.

Illustration by David Ehlert, Cognition Studio and David Spach, MD
<table>
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<th>Laboratory Study</th>
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* The information contained in this table is based on information in the Laboratory Testing Schedule for Monitoring HIV-Infected Patients Before and After Initiation of Antiretroviral Therapy.

Source:
- 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. Laboratory testing: laboratory testing for initial assessment and monitoring of patients with HIV receiving antiretroviral therapy. December 18, 2019. [HIV.gov]
Table 2.

**Allele Frequency of HLA-B*5701 in Various Population Groups**

<table>
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<th>Population Group</th>
<th>HLA-B*5701 Carrier Frequency Range (%)</th>
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Source: