Adverse Effects of Antiretroviral Medications

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Module 3: Antiretroviral Therapy
Lesson 2: Adverse Effects of Antiretroviral Medications

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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 as overt symptoms or initially only as laboratory abnormalities.[1] The spectrum of potential antiretroviral drug toxicity is broad, including renal toxicity, effects on bone mineralization, metabolic effects, gastrointestinal symptoms, cardiovascular effects, hypersensitivity, skin reactions, liver injury, insomnia, and neuropsychiatric manifestations.[2] In general, newer antiretroviral medications have a markedly improved safety profile compared with older antiretroviral medications, and this is reflected in the recommendations issued in the Adult and Adolescent ART Guidelines.[3] Clinicians who provide care to persons with HIV should have an understanding of the basic toxicity profile of antiretroviral medications and knowledge of recommended monitoring strategies, keeping in mind that most individuals tolerate antiretroviral medications well and experience only mild or no side effects. This Topic Review will explore antiretroviral-associated adverse effects by medication class and by specific medication. Issues related to drug interactions with antiretroviral medications are addressed in this same module in the lesson on 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 table below summarizes key baseline and safety laboratory studies recommended for individuals taking antiretroviral therapy.[4] Table 1.

Laboratory Monitoring for Antiretroviral Therapy-Related Toxicities*

Laboratory Study		ART Initiation	4-8 Weeks after ART Initiation or Modification	Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
HLA-B*5701	√ If considering ab						

Laboratory Study	ART Initiation		4-8 Weeks after ART Initiation or Modification		Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
	acavir							
Basic metabolic [a,b]	√	√		√		√		
ALT, AST, total bilirubin	√	√		√		√		
CBC with differential[c]	√		√ When monitoring CD4 count	√ When monitoring CD4 count	√ When no longer monitoring CD4 count	√		
Lipid [d]	√	Consider 1–3 months after ARV initiation or modification			√ If normal at baseline but with CV risk	If normal at baseline, every 5 years or if clinically indicated		
Random or fasting glucose[e]	√					√		
Urinalysis[f,g]	√				√ If on tenofovir DF or tenofovir alafenamide	√ E.g., in patients with chronic kidney disease or diabetes me		

Laboratory Study	ART Initiation	4-8 Weeks after ART Initiation or Modification	Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
						llitus
Pregnancy test[h]	√					√

*The information contained in this table is based on information in the table Laboratory Testing for Initial Assessment and Monitoring of People with HIV Receiving Antiretroviral Therapy.

[a]Serum Na, K, HCO3, Cl, BUN, creatinine, glucose, and Cr-based eGFR. Serum P should be monitored in patients with CKD who are on TDF-containing regimens.

[b]More frequent monitoring may be indicated for patients with evidence of kidney disease (e.g., proteinuria, decreased glomerular dysfunction) or increased risk of renal insufficiency (e.g., patients with diabetes, hypertension).

[c]CBC with differential should be done when a CD4 count is performed. When CD4 count is no longer being monitored, the recommended frequency of CBC with differential is once a year. More frequent monitoring may be indicated for people receiving medications that potentially cause cytopenia (e.g., TMP-SMX).

[d]If random lipids are abnormal, fasting lipids should be obtained. Consult the American College of Cardiology/American Heart Association's 2018 Guideline on the Management of Blood Cholesterol for diagnosis and management of patients with dyslipidemia.

[e]If random glucose is abnormal, fasting glucose should be obtained. HbA1C is no longer recommended for diagnosis of diabetes in people with HIV on ART.

[f]Consult the HIVMA/IDSA's Clinical Practice Guideline for the Management of Chronic Kidney Disease in Patients Infected with HIV for recommendations on managing patients with renal disease. More frequent monitoring may

Laboratory Study	ART Initiation	4-8 Weeks after ART Initiation or Modification	Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
be indicated for patients with evidence of kidney disease (e.g., proteinuria, decreased glomerular dysfunction) or increased risk of renal insufficiency (e.g., patients with diabetes, hypertension). [g]Urine glucose and protein should be assessed before initiating tenofovir alafenamide (TAF)- or tenofovir DF (TDF)-containing regimens and monitored during treatment with these regimens. [h]For women of childbearing potential.						

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 people with HIV receiving antiretroviral therapy. September 21, 2022. [HIV.gov]

Entry Inhibitors

Enfuvirtide

Enfuvirtide is the only fusion inhibitor medication approved for use by the United States Food and Drug Administration (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 more than 90% of patients in some studies) and include erythema, induration, cysts, nodules, and rarely more severe reactions.[5,6] 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. Usage of this drug in the United States has become rare due to the approval of other, better tolerated agents for salvage antiretroviral therapy.

Fostemsavir

Fostemsavir is the only attachment inhibitor approved for use by the U.S. Food and Drug Administration (FDA), and it is primarily used in heavily treatment-experienced adults with multidrug-resistant HIV.[7] Fostemsavir is an oral medication that, after ingestion, is hydrolyzed to the active drug—temsavir.[7] In the only phase 3 trial completed with fostemsavir, serious side effects were rare; the most commonly observed mild-moderate side effects were nausea and diarrhea.[8] Fostemsavir was shown to significantly prolong the QTc interval when given at a dose of 2,400 mg twice daily, which is 4 times the recommended daily dose.[9] Caution is thus advised if using fostemsavir in patients with a history of QTc prolongation, torsades de pointes, or if taking other medications known to prolong the QT interval.

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 and is dosed every 2 weeks. In clinical trials, the most common adverse effects associated with ibalizumab have been diarrhea, dizziness, nausea, and rash.[10] Infusion reactions may also occur. Although ibalizumab binds directly to a host cell receptor, there are no known adverse immunologic effects of this medication.

Maraviroc

Maraviroc is an entry inhibitor that exerts its action by directly binding to a host protein—the CCR5 coreceptor. In clinical practice and in clinical trials, maraviroc has been well tolerated, and serious toxicity has been quite rare.[11,12] Maraviroc has been linked to very rare cases of severe rash with systemic symptoms. In addition, there are rare cases of hepatotoxicity, which may be preceded by severe rash and allergic symptoms in patients taking maraviroc.[13,14] Since maraviroc binds directly to a host (human) CCR5 coreceptor, this initially raised concerns about potential maraviroc-induced problems with host immune function or cancer surveillance. Clinical trial data and clinical experience have not shown an excess of infections or malignancies, with the exception that maraviroc may increase the risk of developing symptomatic West Nile virus infection.[11,15,16]

Integrase Strand Transfer Inhibitors

In general, integrase strand transfer inhibitors (INSTIs) are well tolerated and cause minimal drug interactions. In clinical trials, the most frequently reported adverse effects were headache, nausea, diarrhea, insomnia, and fatigue; these side effects, however, were typically mild and not severe enough to warrant stopping therapy.[1] Rare cases of mood changes or new onset of psychiatric disorders have been observed with INSTIs.[2,17,18]

Adverse Effects Observed with Bictegravir and Dolutegravir

Weight Gain

Several studies have concluded that INSTIs, particularly dolutegravir, lead to greater weight gain than other classes of antiretrovirals; dolutegravir-associated weight gain appears to be more pronounced when dolutegravir is combined with tenofovir alafenamide than with tenofovir DF (Figure 1).[19,20,21,22] Available data also suggest weight gain is relatively greater in persons taking bictegravir-tenofovir alafenamide-emtricitabine than in persons taking antiretroviral therapy with other anchor drugs, such as boosted elvitegravir, a non-nucleoside reverse transcriptase inhibitor, or a boosted protease inhibitor.[23] Observations of excess weight gain after a switch to dolutegravir (or bictegravir), with or without a switch to tenofovir alafenamide, are complicated because studies also find associations between older antiretroviral agents (such as efavirenz and tenofovir DF) and suppression of weight gain, so removal of these agents may play a role in post-switch weight change. The mechanism and clinical significance are unclear. Research is ongoing to confirm whether INSTIs directly cause changes to appetite or weight or whether the associations are solely due to comparisons to drugs that suppress weight gain, like efavirenz. Ongoing studies are also evaluating the optimal strategy to address INSTI-associated excess weight gain, if it occurs. To date, guidelines do not recommend altering the choice of initial antiretroviral therapy due to the potential for weight gain and guidelines specify that it remains unclear whether switching from an INSTI to an alternate anchor drug leads to reversal of weight gain.[2]

Elevated Serum Creatinine

Dolutegravir and bictegravir cause a predictable, modest, benign increase in serum creatinine, and thereby, 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 2).[24] 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). Normally, approximately 15% of creatinine is secreted into the urine in the proximal tubule. 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.[25,26] These changes in serum creatinine caused by dolutegravir and bictegravir are usually small, occur in the first 2 to 3 months after starting the medication, and then plateau. 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.[27,28,29] There are no known serious adverse effects associated with bictegravir. Available studies suggest the increases in serum creatinine associated with bictegravir are slightly less than with dolutegravir the increases are benign.[28,30]

Cabotegravir

For HIV treatment, cabotegravir is available as a long-acting injectable combination of cabotegravir and rilpivirine. For HIV preexposure prophylaxis, long-acting injectable cabotegravir alone can be used. Oral cabotegravir can be used as a lead-in for approximately 1 month. The major adverse effects attributed to long-acting injectable cabotegravir are injection site reactions, including pain, nodules, induration, and swelling.[31,32,33] The injection site reactions typically become less frequent over time while receiving long-acting injectable cabotegravir.[32]

Dolutegravir

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

- **Insomnia**: In randomized trial settings, the incidence of insomnia in patients taking dolutegravir ranged from 3 to 15%.[34,35] Clinical experience has shown that some patients develop insomnia while taking dolutegravir, but this rarely requires discontinuation of dolutegravir.
- **Headache**: In clinical trials, aside from insomnia, headache was the most common side effect of moderate to severe intensity that occurred, though it was still uncommon (2% of participants in one of the phase 3 clinical trials).[35] In practice, it is a rare cause of intolerability of dolutegravir.
- **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 3).[35,36]

Elvitegravir

Elvitegravir is an INSTI that is available as 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.[37,38] Elvitegravir-based regimens are infrequently used now. Compared with boosted elvitegravir, dolutegravir or bictegravir are usually better tolerated and have fewer drug interactions.

Raltegravir

Raltegravir is generally well-tolerated and has the fewest drug interactions among medications in the INSTI class. In current clinical practice, dolutegravir or bictegravir are usually favored over raltegravir, because raltegravir has a lower barrier to resistance and higher pill burden. Most individuals tolerate raltegravir well. The potential toxicities listed below have been reported, but rarely occur in clinical practice.

- **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.[39,40] Concurrent use of a statin medication, which can also cause elevations in creatine kinase, likely increases this risk.[40]
- **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.[40]
- **Stevens-Johnson Syndrome/Toxic Epidermal Necrolysis**: Rash and severe systemic hypersensitivity reactions have rarely been reported in patients taking a regimen that included raltegravir.[41,42,43]

Nucleoside Reverse Transcriptase Inhibitors

Adverse Effects Observed with More than 1 NRTI

Mitochondrial Toxicity

Several of the older nucleoside reverse transcriptase inhibitors (NRTIs)—didanosine, stavudine, and zidovudine—can cause mitochondrial adverse effects; these effects rarely occur with abacavir, emtricitabine, lamivudine, tenofovir alafenamide, or tenofovir DF. 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, lipoatrophy, and possibly lipodystrophy syndrome.[44,45,46,47] Since didanosine, stavudine, and zidovudine are rarely used in current clinical practice (and manufacturing of didanosine and stavudine has been discontinued), these adverse effects will not be reviewed in further detail. If NRTI-related peripheral neuropathy and/or lipoatrophy develops, it usually only partially reverses or does not reverse at all, when discontinuing the offending medication.[44]

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.[48,49] 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.[50,51] Switching from tenofovir DF to tenofovir alafenamide, which is often done in clinical practice, may lead to a slight rise in all serum lipid parameters; the cause of the increase in lipids is at least partly due to the removal of the mild lipid-lowering effects of tenofovir DF and the long-term clinical consequences have not been confirmed.

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 have a negative HLA-B*5701 screening test.[3]

- **Cardiovascular Risk**: Abacavir has been associated with cardiovascular disease in some studies, but the data on this issue are conflicting.[52,53,54,55] In the Strategies for the Management of Antiretroviral Therapy (SMART) trial, a sub-analysis found that patients taking abacavir had a higher rate of cardiovascular disease than persons taking other NRTIs.[52] 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.[56,57] 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.[55] In light of these concerning but conflicting findings, most experts recommend avoiding abacavir in persons with cardiovascular disease (or significant risk factors for cardiovascular disease). The mechanism by which abacavir may increase the risk of ischemic cardiovascular events has been proposed to relate to platelet activation and aggregation.[58,59,60]
- **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 .[61,62] Signs and symptoms of abacavir hypersensitivity typically develop within 6 weeks of starting abacavir and include fever, rash, malaise, gastrointestinal effects, and respiratory symptoms.[62,63] The HLA-B*5701 test is highly useful for identifying persons who have a significantly increased risk of developing 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.[3,4]

Table 2.

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

Population Group	HLA-B*5701 Carrier Frequency Range (%)
European	1.4 – 10.2
South American	1.1– 3.1
African	0.0 – 3.2
Middle Eastern	0.5– 6.0
Mexican	0.0 – 4.0
Asian	0.0 – 6.7
Southwest Asian (Indian)	3.8 – 19.6

Source:

- Martin MA, Kroetz DL. Abacavir pharmacogenetics--from initial reports to standard of care. Pharmacotherapy. 2013;33:765-75. [PubMed Abstract]

Emtricitabine and Lamivudine

Emtricitabine and lamivudine have the best tolerability and safety profile among all the NRTIs.[64,65,66] 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, though these effects seem to be rare in clinical practice.[67]

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 4).[68,69,70,71] Switching from tenofovir DF to tenofovir alafenamide results in improved glomerular filtration rate, glomerular and tubular proteinuria, and bone mineral density.[72,73] Overall, in clinical trials, tenofovir alafenamide was well tolerated, except for mild gastrointestinal effects (nausea, vomiting, diarrhea). Increases in certain lipid parameters (total cholesterol and HDL) are more likely to occur with tenofovir alafenamide than with tenofovir DF.[71,74] Some clinical trials and retrospective data suggest that use of tenofovir alafenamide leads to more weight gain than the use of tenofovir DF, but the mechanism and clinical significance are not known.[21,75]

- **Renal Monitoring on Tenofovir alafenamide**: Persons receiving tenofovir alafenamide should have serum creatinine obtained at baseline, 4-8 weeks after starting therapy, and every 6 months thereafter.[4] Tenofovir alafenamide is not recommended in persons who have an estimated creatinine clearance less than 30 mL/min. Urine glucose and protein should be obtained at baseline and repeated at least annually.[4]

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.[37,76] The main adverse effects associated with tenofovir DF are decreases in bone mineral density and renal toxicity.[71,77] Tenofovir DF may also suppress weight gain or induce weight loss, though the mechanism has not been confirmed, and further research into this observational finding is needed.[78]

- **Bone Demineralization**: Multiple studies have specifically implicated tenofovir DF use as a risk factor for reduced bone mineral density.[37,71,79] Although the mechanism for this effect is incompletely understood, tenofovir DF may affect bone indirectly through proximal tubular toxicity, leading to phosphate wasting and bone turnover.[80] There is also evidence that tenofovir DF may affect bone turnover through effects on parathyroid hormone levels or by direct effects on osteoclasts or osteoblasts.[81,82] There are no specific recommendations for bone mineral density screening for individuals taking tenofovir DF, but use of tenofovir DF should be considered a risk factor for osteopenia and osteoporosis.
- **Nephrotoxicity**: Tenofovir DF-associated renal toxicity may include gradual declines in glomerular filtration rate (GFR), phosphate wasting, proteinuria, glycosuria, and Fanconi syndrome (generalized proximal tubule dysfunction manifesting as type 2 renal tubular acidosis and phosphate wasting).[26] According to the FDA package insert, the dosing frequency of tenofovir DF can be reduced if the creatinine clearance falls to below 50 mL/min, but most clinicians would instead choose an alternate antiretroviral agent in this setting (both to reduce the risk of inducing further renal insufficiency and because the recommended dosing of tenofovir DF in this situation may be difficult to adhere to, such as dosing every 48 or every 72 to 96 hours). For persons taking HIV PrEP, tenofovir DF is not recommended if the creatinine clearance is less than 60 mL/min.
- **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.[83,84] 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. Concomitant use of nephrotoxic, non-antiretroviral medications may also increase the risk of tenofovir DF-associated renal adverse effects.
- **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.[26] Additional available guidelines for monitoring patients for renal dysfunction are in the Adult and Adolescent ART Guidelines.[4] More frequent monitoring may be indicated in certain clinical situations, including the presence of risk factors for renal dissease. The following summarizes the recommendations from these guidelines:
    - Monitoring serum creatinine and GFR should be performed at baseline, 4 to 8 weeks after starting therapy, and every 6 months thereafter. More frequent monitoring may be indicated in persons with chronic kidney disease risk factors.
    - Urinalysis (including urine glucose and protein) should be performed at baseline when starting tenofovir-DF and monitored at least annually.
    - If the urinalysis is performed and 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.
- **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 5).[26] 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 calculating the 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.[26] A result between 10 and 20% is considered indeterminate. 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 to 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 a decline in renal function. Tests that quantify proteinuria are useful in this scenario, and 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.[26] New or worsening proteinuria may indicate a need to change tenofovir DF, particularly if associated with a decline in renal function.

- **Discontinuing or Switching Tenofovir DF because of Nephrotoxicity**: 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 m^2), 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).[26] In clinical practice, if tenofovir DF appears to be inducing renal adverse effects, one may consider switching it to an alternate agent or changing the regimen to one that avoids NRTIs altogether or avoids both tenofovir DF and tenofovir alafenamide. In this setting, if tenofovir DF is stopped, the renal dysfunction tends to improve over time, but sometimes improvement is slow and in rare cases the renal toxicity effects persist.[85]

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.[86,87] In most circumstances, a person taking zidovudine should have their antiretroviral regimen updated to a new regimen that does not include zidovudine.

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.[3] Delavirdine is no longer manufactured in the United States and will not be discussed further.

Doravirine

Doravirine is an NNRTI that is very well tolerated and has been associated with very few adverse effects.[88,89] In clinical trials, doravirine, when compared with efavirenz, had fewer cutaneous and neuropsychiatric adverse effects.[90] 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.[90]

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. Due to the neuropsychiatric risks and other side effects described below, clinicians should choose other options than efavirenz for starting antiretroviral therapy and should have a low threshold to recommend a change of efavirenz to a newer, safer option for individuals still taking this agent.

- **Cardiac QTc Interval Prolongation**: Prolonged QTc intervals have been reported with the 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.[91,92] This issue is particularly important when patients are taking medications other than efavirenz that may cause QT prolongation.
- **Dyslipidemia**: Efavirenz has also been shown to increase lipid parameters.[51,93] It is unclear, though, what impact efavirenz-induced dyslipidemia has on cardiovascular disease risk, especially given that HDL levels increase with efavirenz, and these HDL changes may potentially confer a protective effect.[94,95]
- **Hepatotoxicity**: Reports have documented rare cases of fulminant hepatitis in persons receiving efavirenz, progressing in some cases to hepatic failure that required liver transplantation, or resulted in death.[96,97,98] 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, depression, and risk of suicide.[99,100] Efavirenz should be avoided in persons with preexisting mental health conditions. Pharmacokinetic studies have shown that higher plasma efavirenz levels correlate with central nervous system adverse effects (Figure 6).[101] Taking efavirenz with food significantly increases efavirenz plasma levels when compared with taking it without food and thus it is recommended to take efavirenz on a relatively empty stomach.
- **Rash**: Clinical trials have demonstrated that approximately 15% of patients (range 10 to 25%) treated with efavirenz develop a rash (Figure 7), which is significantly higher than reported rates of rash with doravirine, etravirine, or rilpivirine.[90,102,103] 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.
- **Hypovitaminosis D**: Efavirenz has also been noted in studies to interfere with vitamin D metabolism, causing low vitamin D levels (sometimes leading to severely low levels and associated alkaline phosphatase elevations).[104,105,106]

Etravirine

Etravirine is an NNRTI that is primarily used for 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.[107] There are rare reports (less than 0.1%) of severe rash, including Stevens-Johnson syndrome, toxic epidermal necrosis, erythema multiforme, and DRESS (drug rash with eosinophilia and systemic symptoms) syndrome.

Nevirapine

Nevirapine confers a risk of serious adverse effects. Earlier in the HIV epidemic, nevirapine was commonly used in antiretroviral regimens, but its use has dramatically declined and it is no longer recommended or used to any extent in clinical practice.

- **Hypersensitivity Reaction:** Nevirapine has an FDA black box warning for possible life-threatening rash and hepatotoxicity, which can occur together or separately (Figure 8).[108] If hepatotoxicity develops, it usually occurs as either an immune-mediated reaction, manifesting within the first 4 weeks of therapy, or as a nonimmune-mediated reaction that develops later (typically after 18 weeks of initiating therapy). Nevirapine-related hypersensitivity reactions occur more commonly in women and in persons with higher CD4 cell counts.[109,110] 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.[2]

Rilpivirine

Rilpivirine is available alone, as part of several oral single-tablet regimens (rilpivirine-tenofovir DF-emtricitabine, rilpivirine-tenofovir alafenamide-emtricitabine, and dolutegravir-rilpivirine), and as a component of the long-acting injectable cabotegravir plus rilpivirine. Multiple studies comparing oral rilpivirine with efavirenz (each given with two NRTIs) have shown lower rates of drug discontinuation of rilpivirine due to fewer adverse effects than with efavirenz.[100,102,111]

- **Cardiac QTc Interval Prolongation**: Studies performed with high-dose rilpivirine (3 to 12 times higher than the 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.[112]
- **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.[111]
- **Neuropsychiatric**: Rilpivirine has the potential to cause neuropsychiatric side effects, including depression, insomnia, headaches, and dizziness, but the risk is significantly lower than with efavirenz.[102,113]
- **Injection Site Reactions**: With the long-acting injectable rilpivirine, which is given in combination with long-acting injectable cabotegravir, the major adverse effect has been injection site reactions; in clinical trials, most of these reactions were graded as mild to moderate, and the vast majority resolved within 7 days. The most frequent type of reaction was pain, followed much less frequently by nodules, induration, and swelling.[33]

Pharmacologic Boosters

General Considerations

Ritonavir and cobicistat are pharmacokinetic enhancers that 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 protease inhibitor (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 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).[114,115] 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 the actual glomerular filtration rate.[116] 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.[37,116] For patients taking cobicistat-containing regimens, changes in serum creatinine greater than 0.4 mg/mL from baseline may indicate another cause and should prompt an evaluation.[115] In clinical trials, cobicistat was also associated with gastrointestinal symptoms, primarily nausea and diarrhea.[115]

Protease Inhibitors

The following discussion pertains to the adverse effects of protease inhibitors (PIs) used to treat HIV, not the PIs used to treat hepatitis C virus (HCV), SARS-CoV-2, or other infections. In addition, the following will not include a discussion of the adverse effects of amprenavir, fosamprenavir, indinavir, nelfinavir, saquinavir, or tipranavir, since these PIs have either been discontinued or are very rarely used in clinical practice.[2] In modern clinical practice, when a PI is used, it is usually darunavir (boosted with either cobicistat or ritonavir).

Adverse Effects Observed with More than One PI

Gastrointestinal Adverse Effects

Gastrointestinal side effects (mainly diarrhea but also nausea, vomiting, and abdominal pain) were common with early PIs, particularly 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.[117,118,119] 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 gastrointestinal intolerability.[120,121,122]

Cardiovascular Risk

Protease inhibitors have been associated with dyslipidemia, insulin resistance, premature atherosclerosis, and myocardial infarction.[123] 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.[124] 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.[56]

Cardiac Conduction Abnormalities

Several studies have revealed PR prolongation as a potential cardiac conduction complication of ritonavir-boosted PIs, including ritonavir-boosted atazanavir and lopinavir-ritonavir.[2,125] 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.

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) have 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), an enzyme responsible for converting unconjugated bilirubin to conjugated bilirubin (Figure 9).[126] The inhibition of UGT1A1 by atazanavir causes an increase in indirect bilirubin and potentially jaundice, but it does not cause liver damage. The degree of hyperbilirubinemia typically fluctuates and will return to normal when atazanavir is discontinued.[2] .
- **Nephrolithiasis**: Atazanavir-induced kidney stones develop in approximately 1% of persons taking ritonavir-boosted atazanavir.[127,128,129] The onset of nephrolithiasis occurs, on average, 2 years after starting atazanavir.[130] The urine sediment may show rod-shaped crystals, and the actual

stones are often composed of atazanavir and/or calcium phosphate. Atazanavir stones are typically radiolucent and therefore not evident on plain film radiograph or non-contrast computed tomography (CT).[131] 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 an approximately two-fold increased risk of developing cholelithiasis.[132,133,134] A separate study, however, failed to show an increased risk of cholelithiasis with ritonavir-boosted atazanavir when compared with other protease inhibitors.[128,129]

Darunavir

Although darunavir is no longer recommended as initial antiretroviral therapy for most individuals with HIV (unless an individual has received injectable cabotegravir for HIV PrEP prior to the diagnosis of 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.[119,135] The incidence of rash is approximately 10%, with most cases of mild severity.[119,135] The mild rash typically begins during the first 4 weeks of treatment and resolves even with the continuation of darunavir. Severe skin rash has been reported in less than 1% of persons taking darunavir, which can be accompanied by fever and/or increases in hepatic aminotransferase levels.[119,135] 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.

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.[3]

- **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 controlled trial comparing the 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.[136] Standard dosing of the lopinavir-ritonavir liquid solution requires taking 10 mL once daily or 5 mL twice daily.[136] The liquid lopinavir-ritonavir solution should not be administered with disulfiram. 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.

Capsid Inhibitors

Lenacapavir

The FDA has approved one agent in the capsid inhibitor class, lenacapavir, which is approved as part of antiretroviral therapy for heavily treatment-experienced individuals with multiclass drug resistance. The drug is administered as a subcutaneous injection every 6 months (along with a brief oral lead-in, given either as two days of oral pills starting on the same day as the first subcutaneous injection, or given as oral pills on days 1, 2, and 8, followed by an initial injection on day 15).[137] In clinical trials, the most common adverse effects of lenacapavir injections were nausea and injection site reactions; most injection site reactions were mild and did not necessitate discontinuation of the drug.[138] The most common types of injection site reactions were pain, swelling, erythema, nodule formation, and induration. Otherwise, the most common adverse effects were nausea (experienced by 13% of participants), constipation (experienced by 11%), and diarrhea (experienced by 11%); again, most side effects were mild and did not lead to discontinuation of the lenacapavir.

Summary Points

- Antiretroviral therapy has overwhelming benefits and has transformed HIV infection into a manageable chronic disease for most patients, but antiretroviral therapy may have some adverse effects.
- Fostemsavir is generally well tolerated but should be used with caution in individuals with QTc prolongation or risk factors for that condition. The other entry inhibitors, like maraviroc and ibalizumab, are also typically well tolerated, though ibalizumab requires regular infusions and does have a small risk of infusion reactions. 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 the active tubular secretion of creatinine, but these drugs do not typically impact the actual glomerular filtration rate.
- Dolutegravir can cause headaches and insomnia. Bictegravir and dolutegravir have been associated with greater weight gain than other INSTIs and other classes of antiretrovirals.
- Abacavir can cause hypersensitivity syndrome in persons who are HLA-B*5701 positive and use of this medication requires a baseline HLA-B*5701 screening test. Abacavir may also increase the risk of myocardial infarction compared with other NRTIs.
- Tenofovir DF can cause nephrotoxicity, including progressive chronic kidney disease and Fanconi syndrome (generalized proximal tubule dysfunction), which manifests as proteinuria, type 2 renal tubular acidosis, and phosphate wasting. Tenofovir DF has also been linked to decreased bone density. Tenofovir alafenamide has significantly lower adverse renal and bone mineral density effects than tenofovir DF.
- Efavirenz may cause significant neuropsychiatric side effects, including suicidality, and it is no longer a recommended antiretroviral for most individuals with HIV..
- Atazanavir often causes unconjugated hyperbilirubinemia, which is not dangerous and improves with a switch to another antiretroviral medication. Atazanavir is also associated with nephrolithiasis and cholelithiasis.
- The most common side effects of darunavir (boosted with cobicistat or ritonavir) 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.
- The most common complication of lenacapavir is injection site reactions, which typically are mild and resolve within a few days. Injection site reactions are also the most common adverse effect with long-acting, intramuscular cabotegravir and rilpivirine.

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Figures

Figure 1 (Image Series) - Dolutegravir-Associated Weight Gain (Image Series) - Figure 1 (Image Series) - Dolutegravir-Associated Weight Gain
Image 1A: 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 on elvitegravir, and 63 on raltegravir).

Source: Bourgi K, Rebeiro PF, Turner M, et al. Greater Weight Gain in Treatment-naive Persons Starting Dolutegravir-based Antiretroviral Therapy. Clin Infect Dis. 2020;70:1267-74.

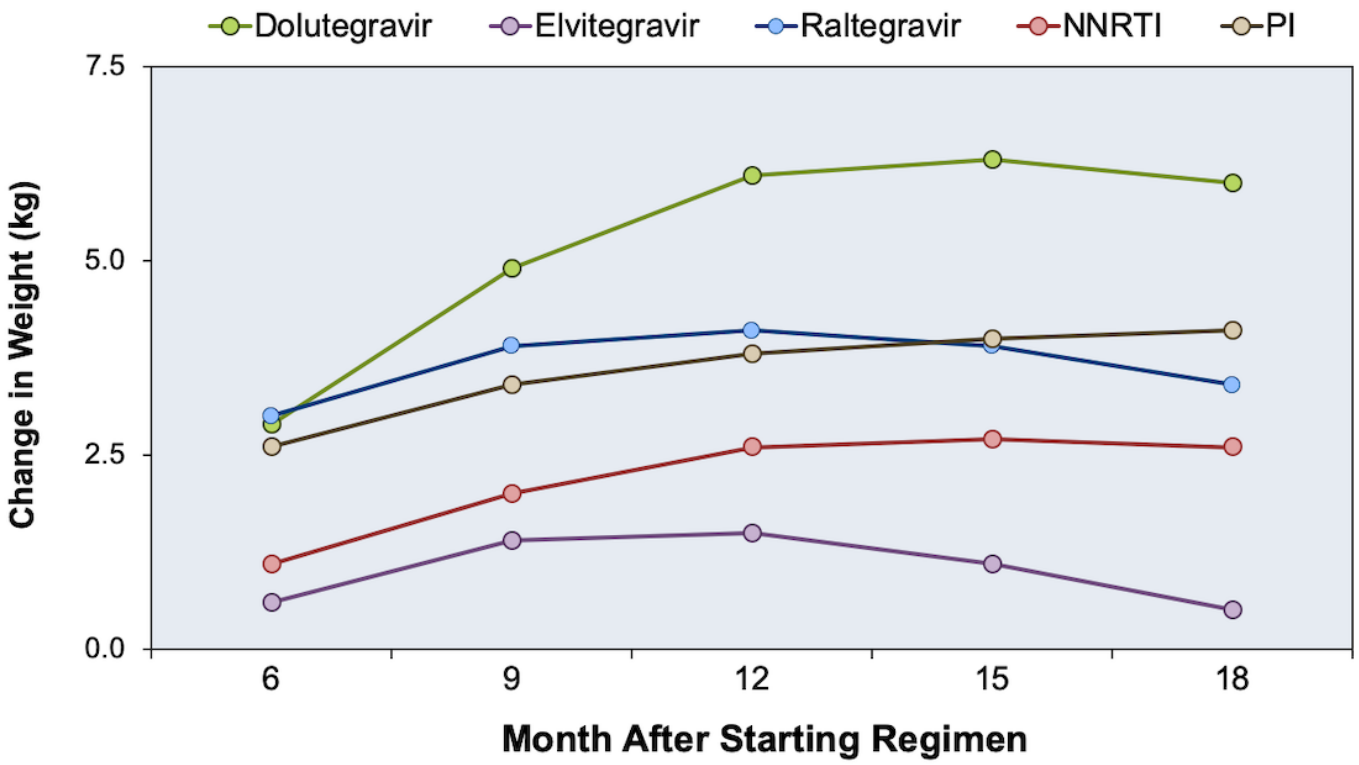

Figure 1 (Image Series) - Dolutegravir-Associated Weight Gain
Image 1B: Weight Gain in NA-ACCORD Study by INSTI-Based Regimen

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

Source: Bourgi K, Jenkins CA, Rebeiro PF, et al. Weight gain among treatment-naïve persons with HIV starting integrase inhibitors compared to non-nucleoside reverse transcriptase inhibitors or protease inhibitors in a large observational cohort in the United States and Canada. J Int AIDS Soc. 2020;23:e25484.

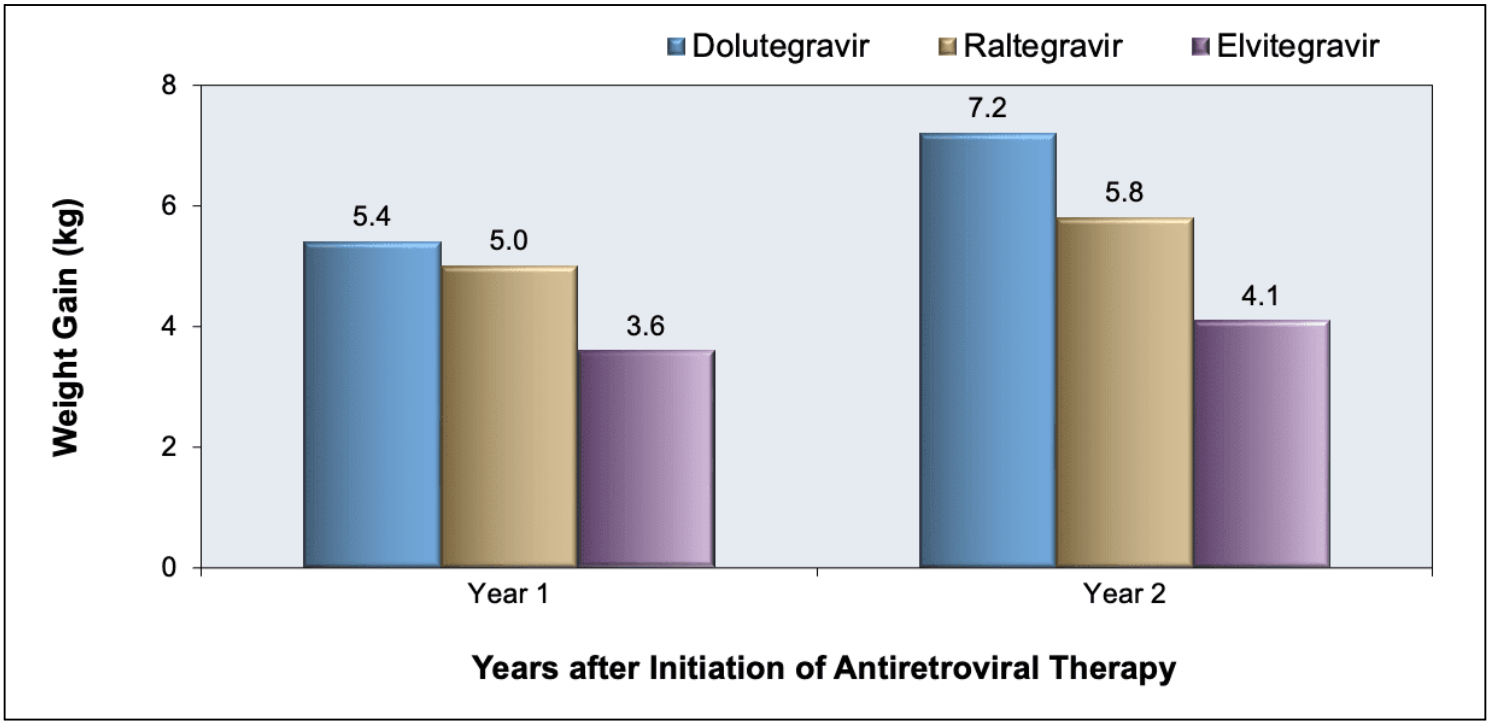

Figure 1 (Image Series) - Dolutegravir-Associated Weight Gain
Image 1C: Impact of NRTI on Dolutegravir-Related Weight Gain

This graph shows weight gain at week 48 after starting antiretroviral therapy, based on the regimen used. The combination of dolutegravir with tenofovir alafenamide-emtricitabine was associated with the most weight gain.
Abbreviations: DTG = dolutegravir; EFV = efavirenz; TDF = tenofovir DF; TAF = tenofovir alafenamide; FTC = emtricitabine

Source: Venter WDF, Moorhouse M, Sokhela S, et al. Dolutegravir plus Two Different Prodrugs of Tenofovir to Treat HIV. N Engl J Med. 2019;381:803-15

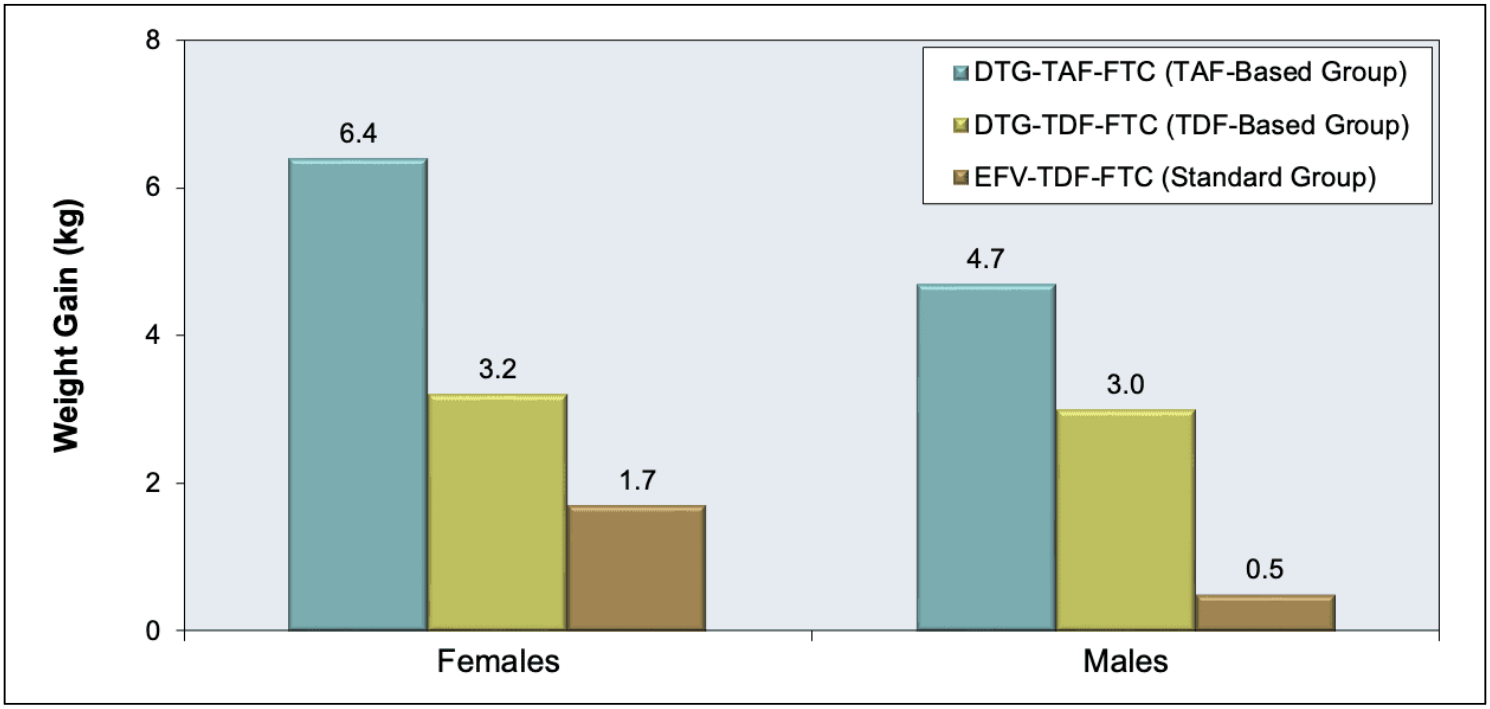

Figure 2 (Image Series) - Inhibition of Tubular Secretion of Creatinine (Image Series) - Figure 2 (Image Series) - Inhibition of Tubular Secretion of Creatinine
Image 2A: Renal Tubule and Promial Tubular Secretion of Creatinine

Approximately 15% of creatinine is actively secreted into the urine by the proximal tubule. Dolutegravir can inhibit the urine organic cation transporter 2 (OCT2), a protein involved in renal tubular secretion of creatinine.

Illustration by Casandra Mack and David H. Spach, MD

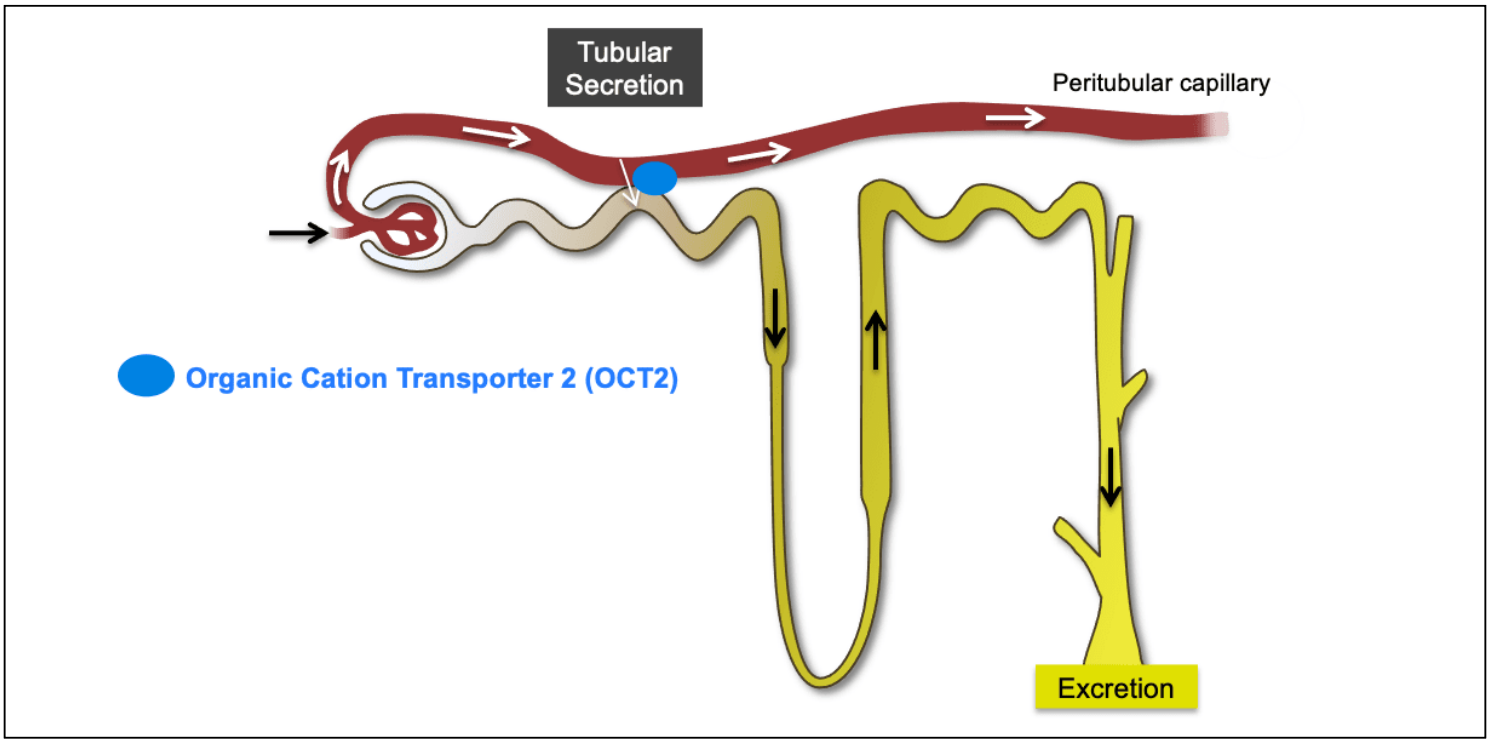

Figure 2 (Image Series) - Inhibition of Tubular Secretion of Creatinine
Image 2B: Organic Cation Transporter 2 (OCT2) and Normal Tubular Secretion of Creatinine

Organic cation transporter 2 (OCT2 is 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.

Illustration: David H. Spach, MD

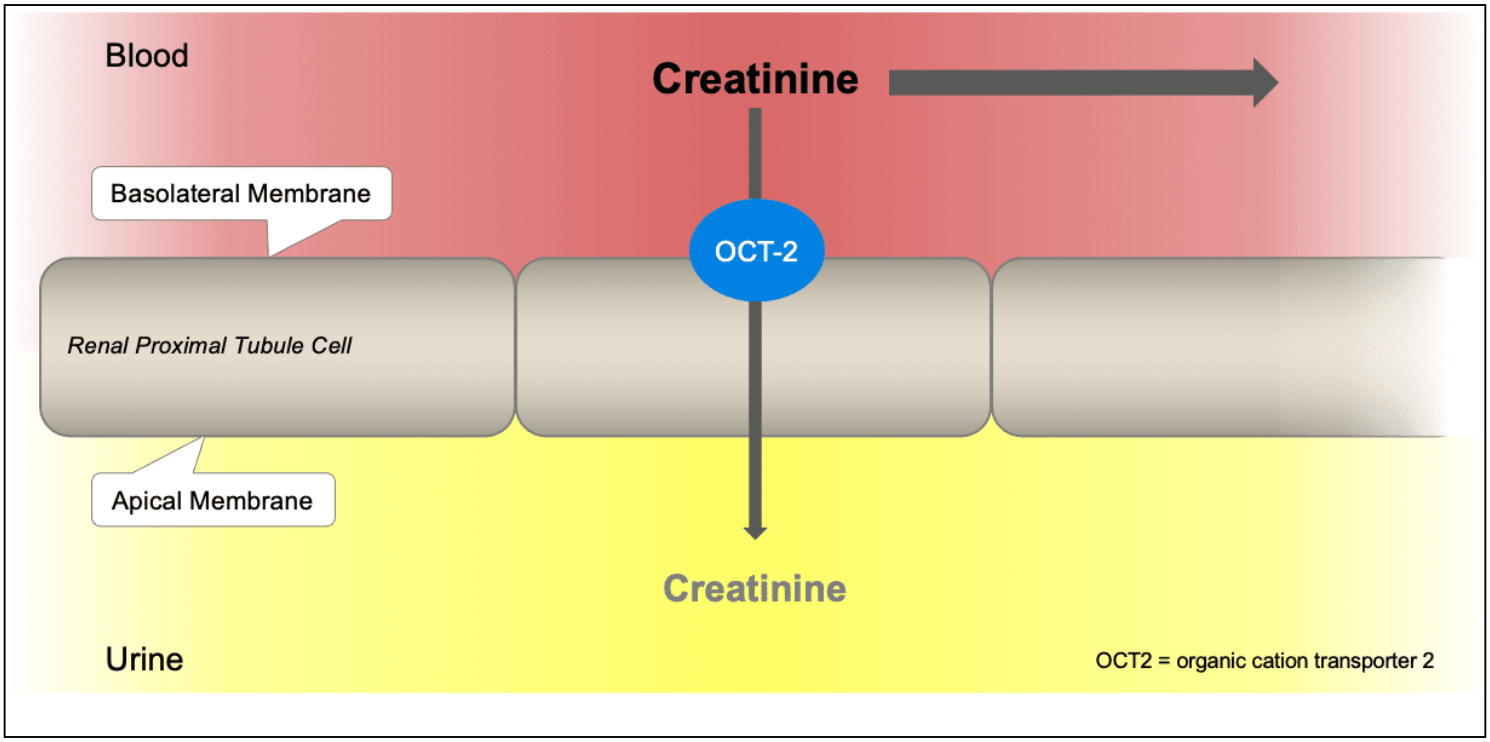

Figure 2 (Image Series) - Inhibition of Tubular Secretion of Creatinine
Image 2C: Inhibition of Tubular Secretion of Creatinine by Bictegravir and Dolutegravir

Bictegravir and dolutegravir can inhibit OCT2, which 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: David H. Spach, MD

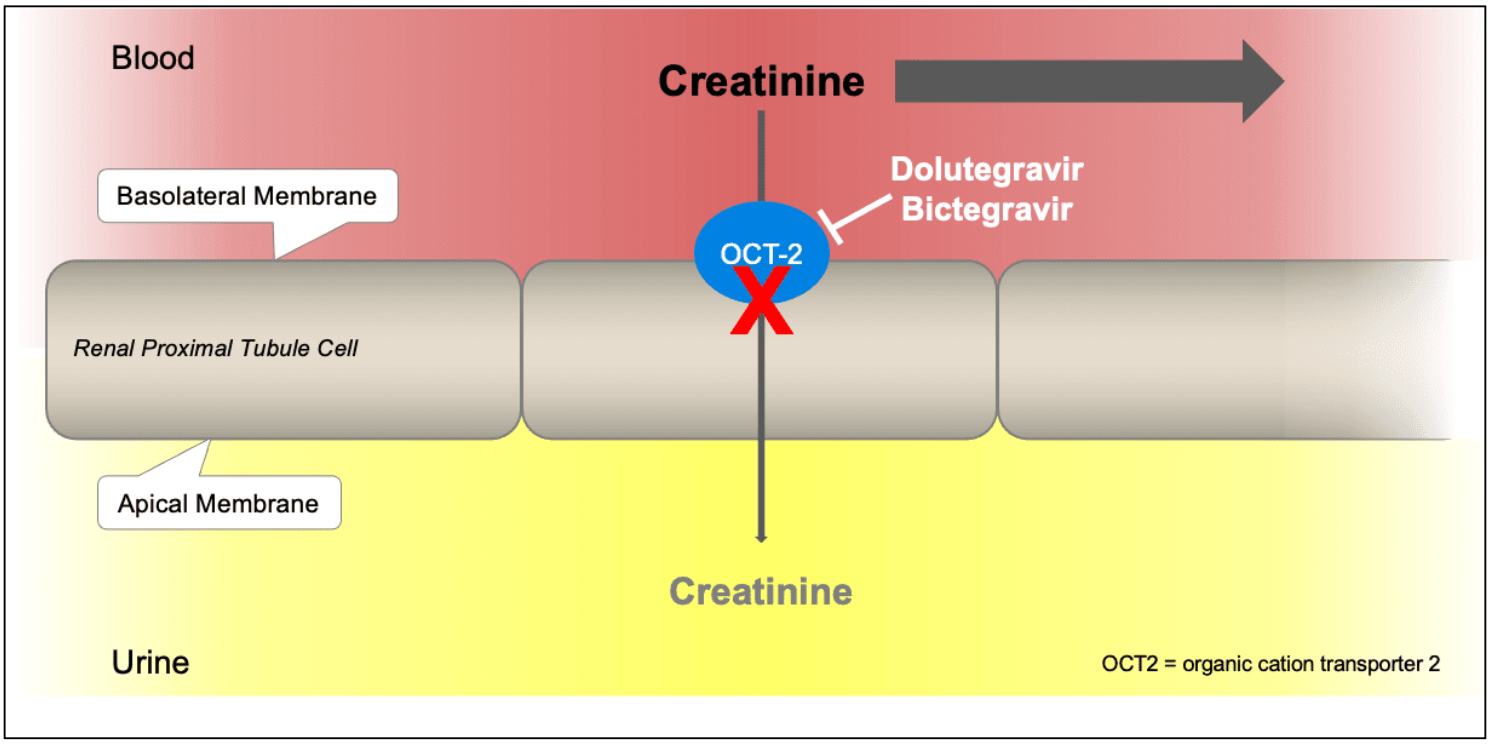

Figure 3 Dolutegravir-Related Changes in Serum Creatinine Level

This graph shows the mean change in serum creatinine levels from baseline for two antireretroviral regimens: 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.

Source: Walmsley SL, Antela A, Clumeck N, et al. Dolutegravir plus abacavir-lamivudine for the treatment of HIV-1 infection. N Engl J Med. 2013;369:1807-18. ©2013 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

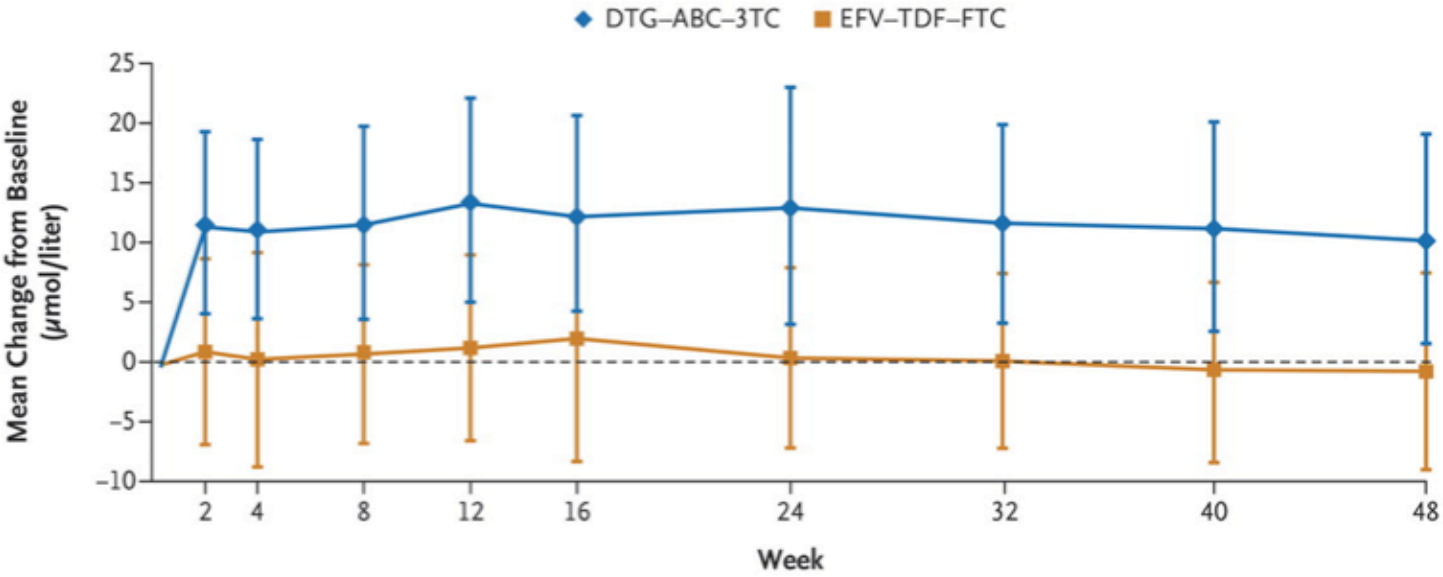

Figure 4 Metabolism of Tenofovir DF and Tenofovir Alafenamide Cellular Activation

A 25 mg dose of tenofovir alafenamide has 90% lower circulating plasma tenofovir levels when compared with a 300 mg dose of tenofovir DF.

Illustration: David H. Spach, MD

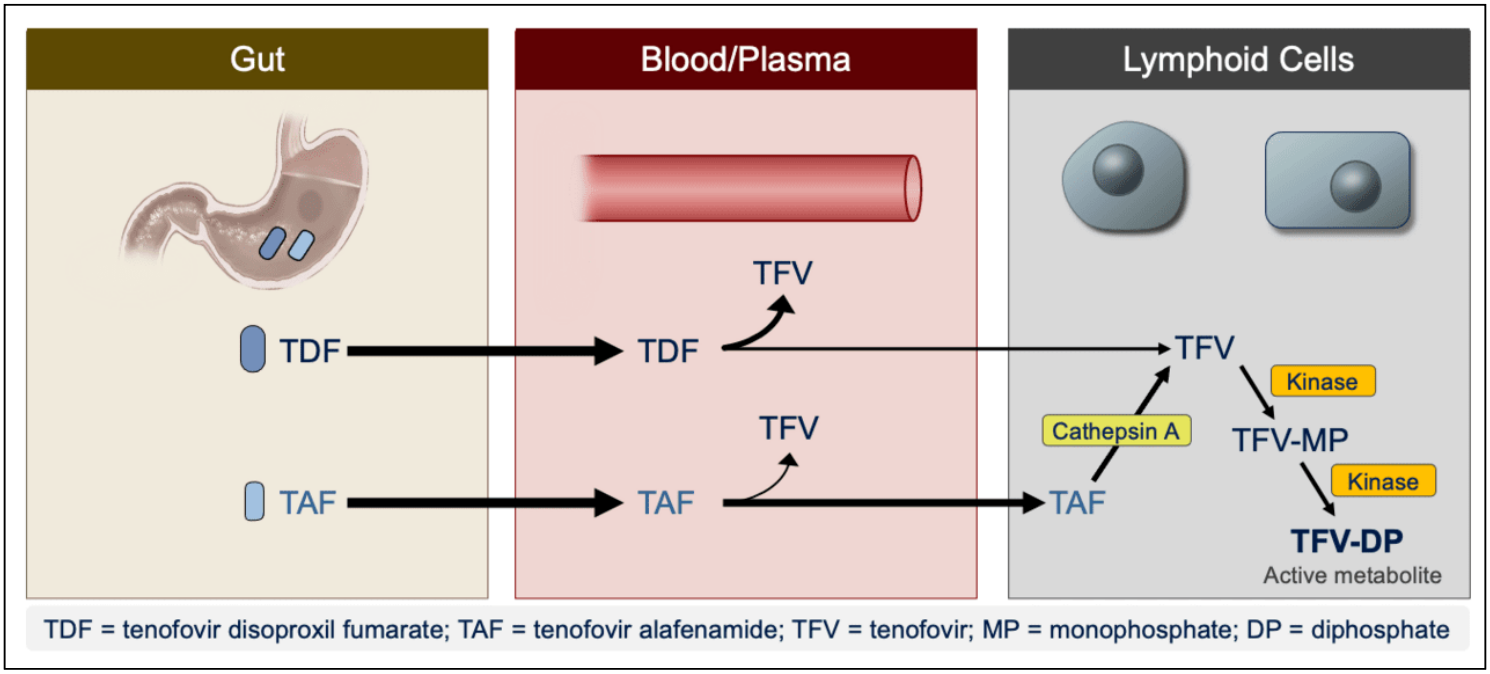

Figure 5 Common Laboratory Indicators of Proximal Tubule Dysfunction

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.

Source: modified from Lucas GM, Ross MJ, Stock PG, et al. Clinical practice guideline for the management of chronic kidney disease in patients infected with HIV: 2014 update by the HIV Medicine Association of the Infectious Diseases Society of America. Clin Infect Dis. 2014;59:e96-138.

Common Laboratory Indicators of Proximal Tubular Dysfunction	
Abnormality	**Definition of Abnormality**
Serum Abnormalities	
Hypokalemia	Serum potassium concentration below laboratory reference range
Low serum bicarbonate	Serum bicarbonate concentration below laboratory reference range
Hypophosphatemia	Serum phosphorous concentration below laboratory reference range
Urine abnormalities	
Urine glucose on dipstick	Glycosuria in the absence of diabetes, or in diabetics with well-controlled blood glucose
Fractional excretion of phosphate	<10% is normal and >20% is abnormal
Tubular maximum for phosphate corrected for GFR	Lower than reference value (normal, 2.8–4.4 mg/dL)
Fractional excretion of uric acid	<15% is normal and >20% is abnormal
Urine albumin-to-protein ratio	uAPR <0.4 suggests predominantly tubulointerstitial disease, whereas uAPR >0.4 suggests predominantly glomerular disease
Abbreviations: GFR = glomerular filtration rate; uAPR, urine albumin-to-protein ratio;	

Figure 6 Central Nervous System Toxicity Related to Plasma Efavirenz Levels

This study involved an analysis of 130 adults taking an efavirenz-based antiretroviral regimen. Blood samples for efavirenz levels were drawn at an average of 14 hours after efavirenz intake.

Source: Marzolini C, Telenti A, Decosterd LA, Greub G, Biollaz J, Buclin T. Efavirenz plasma levels can predict treatment failure and central nervous system side effects in HIV-1-infected patients. AIDS. 2001;15:71-5.

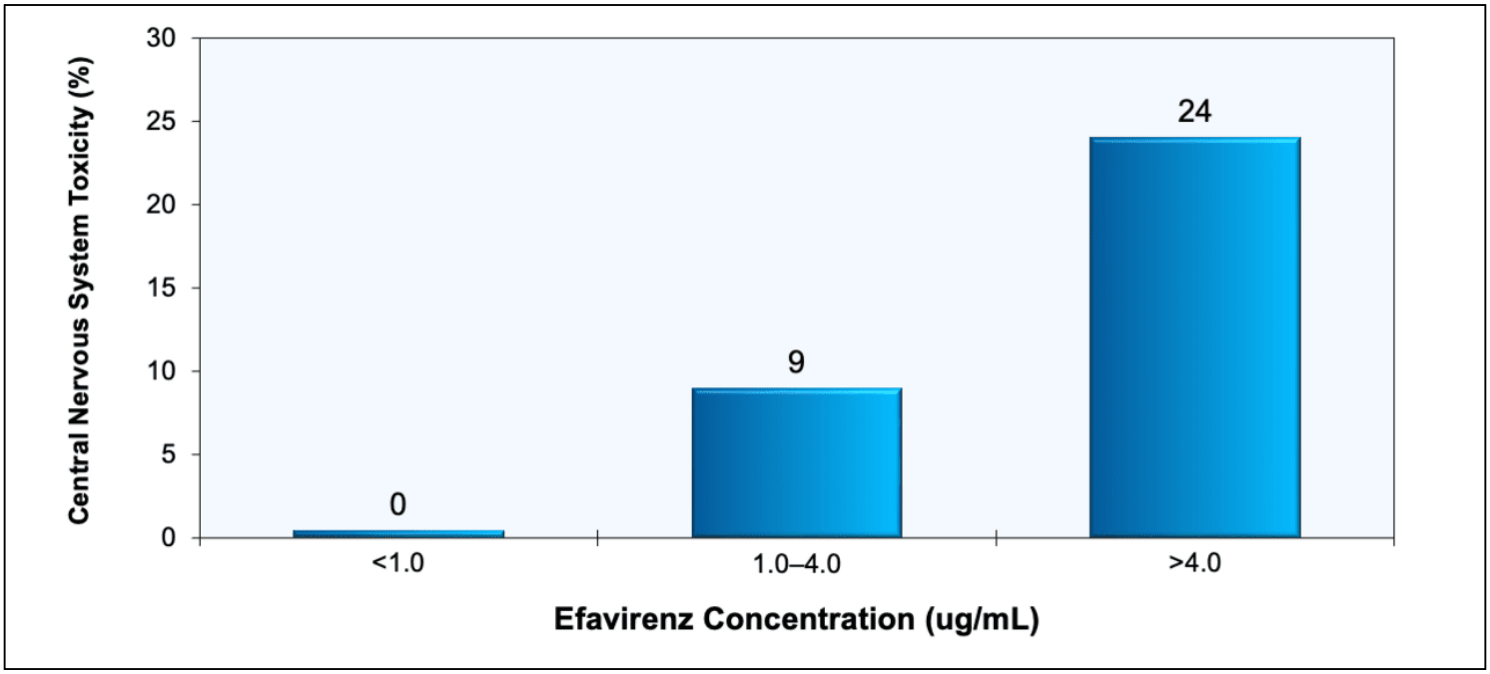

Figure 7 Efavirenz-Associated Rash

Photograph by David H. Spach, MD

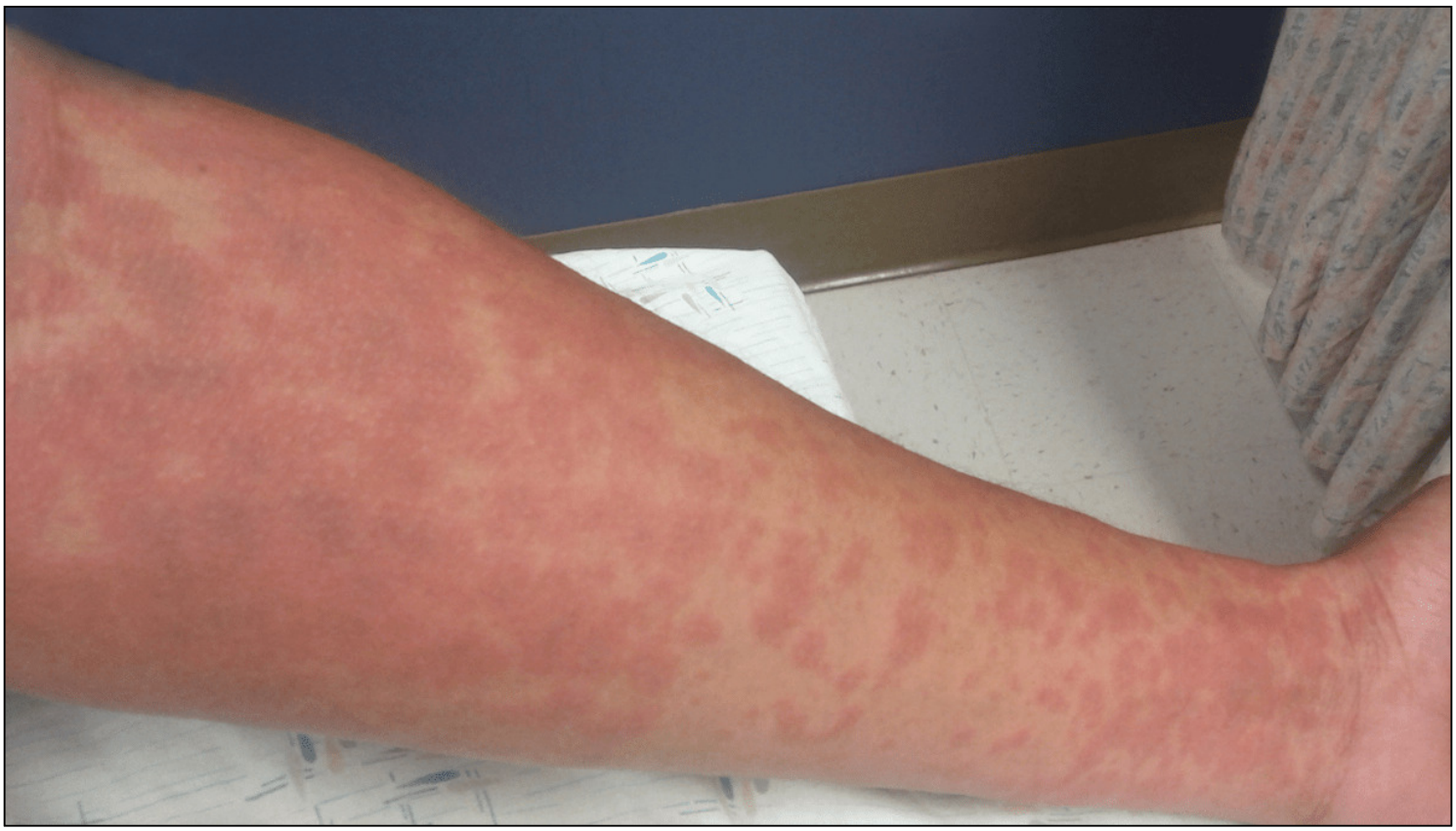

Figure 8 Nevirapine-Associated Rash

Photograph by David H. Spach, MD

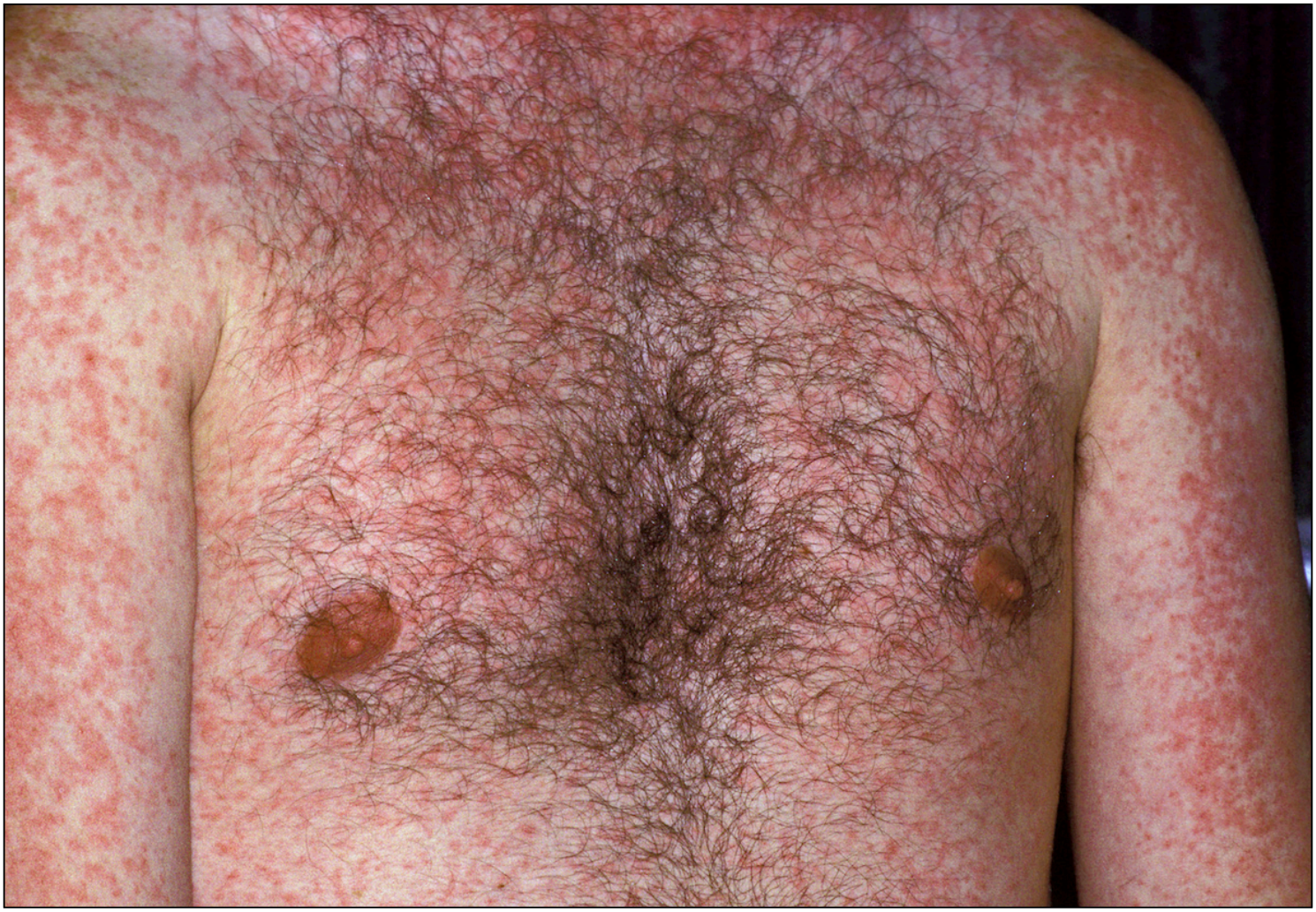

Figure 9 Mechanism for Atazanavir-Associated Increase in Serum Bilirubin

Abbreviation: UGT1A1 = uridine diphosphate glucuronosyltransferase 1A

Illustration: David Spach, MD

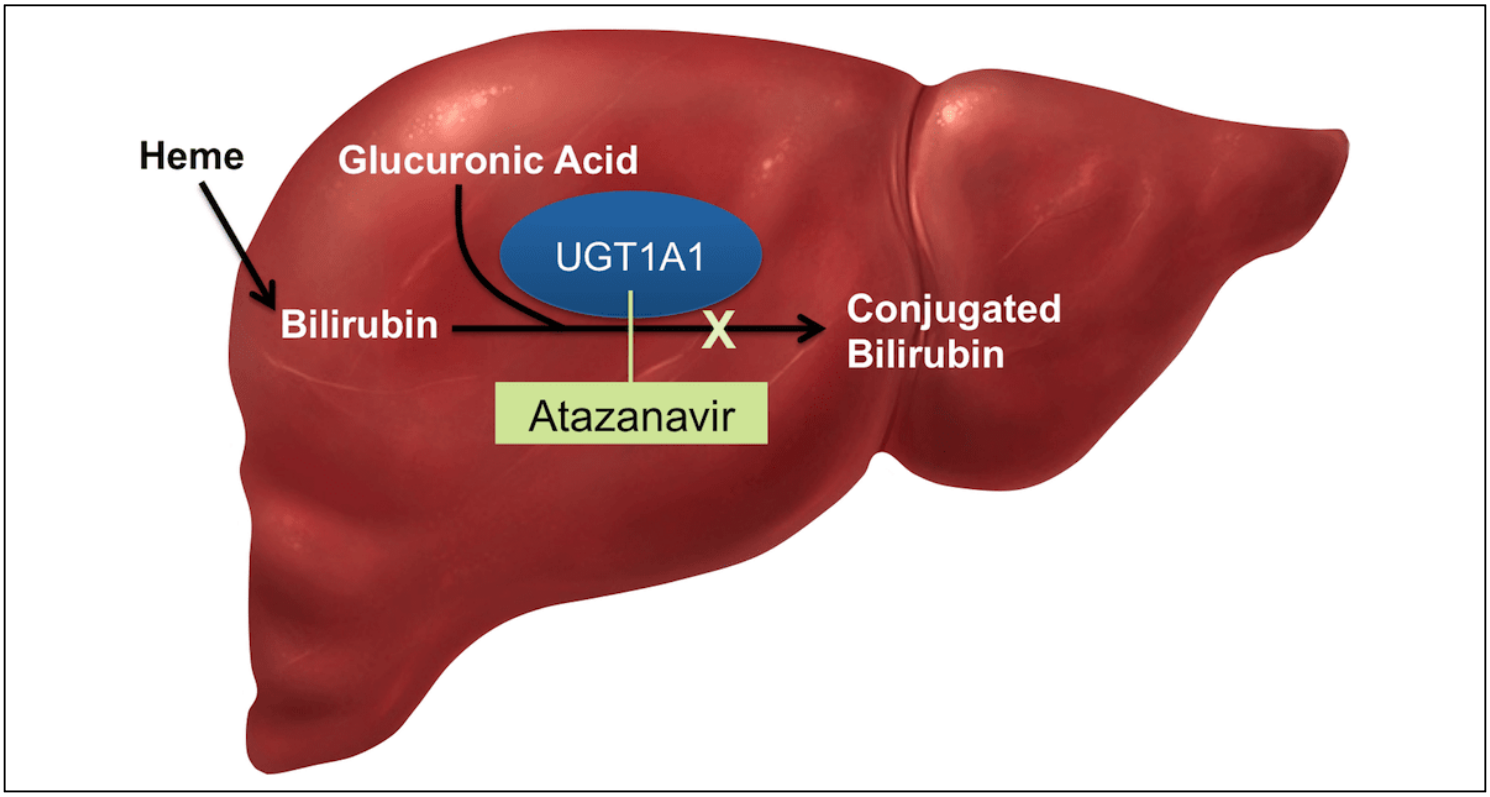

Table 1.

Laboratory Monitoring for Antiretroviral Therapy-Related Toxicities*

Laboratory Study	ART Initiation	4-8 Weeks after ART Initiation or Modification	Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
HLA-B*5701	√ If considering abacavir					
Basic metabolic panel[a,b]	√	√		√		√
ALT, AST, total bilirubin	√	√		√		√
CBC with differential[c]	√		√ When monitoring CD4 count	√ When monitoring CD4 count	√ When no longer monitoring CD4 count	√
Lipid profile[d]	√	Consider 1–3 months after ARV initiation or modification			√ If normal at baseline but with CV risk	If normal at baseline, every 5 years or if clinically indicated
Random or fasting glucose[e]	√					√
Urinalysis[f,g]	√				√ If on tenofovir DF or tenofovir alafenamide	√ E.g., in patients with chronic kidney disease or diabetes mellitus
Pregnancy test[h]	√					√

*The information contained in this table is based on information in the table Laboratory Testing for Initial Assessment and Monitoring of People with HIV Receiving Antiretroviral Therapy.
[a]Serum Na, K, HCO3, Cl, BUN, creatinine, glucose, and Cr-based eGFR. Serum P should be monitored in patients with CKD who are on TDF-containing regimens.
[b]More frequent monitoring may be indicated for patients with evidence of kidney disease (e.g., proteinuria, decreased glomerular dysfunction) or increased risk of renal insufficiency (e.g., patients with diabetes, hypertension).
[c]CBC with differential should be done when a CD4 count is performed. When CD4 count is no longer being monitored, the recommended frequency of CBC with differential is once a year. More frequent monitoring may be indicated for people receiving medications that potentially cause cytopenia (e.g., TMP-SMX).
[d]If random lipids are abnormal, fasting lipids should be obtained. Consult the American

Laboratory Study	ART Initiation	4-8 Weeks after ART Initiation or Modification	Every 3 Months	Every 6 Months	Every 12 Months	Clinically Indicated
College of Cardiology/American Heart Association's 2018 Guideline on the Management of Blood Cholesterol for diagnosis and management of patients with dyslipidemia. [e]If random glucose is abnormal, fasting glucose should be obtained. HbA1C is no longer recommended for diagnosis of diabetes in people with HIV on ART. [f]Consult the HIVMA/IDSA's Clinical Practice Guideline for the Management of Chronic Kidney Disease in Patients Infected with HIV for recommendations on managing patients with renal disease. More frequent monitoring may be indicated for patients with evidence of kidney disease (e.g., proteinuria, decreased glomerular dysfunction) or increased risk of renal insufficiency (e.g., patients with diabetes, hypertension). [g]Urine glucose and protein should be assessed before initiating tenofovir alafenamide (TAF)- or tenofovir DF (TDF)-containing regimens and monitored during treatment with these regimens. [h]For women of childbearing potential.						

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 people with HIV receiving antiretroviral therapy. September 21, 2022. [HIV.gov]

Table 2.

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

Population Group	HLA-B*5701 Carrier Frequency Range (%)
European	1.4 – 10.2
South American	1.1– 3.1
African	0.0 – 3.2
Middle Eastern	0.5– 6.0
Mexican	0.0 – 4.0
Asian	0.0 – 6.7
Southwest Asian (Indian)	3.8 – 19.6

Source:

- Martin MA, Kroetz DL. Abacavir pharmacogenetics--from initial reports to standard of care. Pharmacotherapy. 2013;33:765-75. [PubMed Abstract]