

Antiviral Drug Allergy



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KEYWORDS

- Altered peptide repertoire • Abacavir • Nevirapine • Antiretroviral
- Telaprevir pharmacogenomics • Human leukocyte antigen
- Major histocompatibility complex

KEY POINTS

- Antiviral drugs successful in suppressing replication of human immunodeficiency virus (HIV) and hepatitis C (HCV) are common causes of delayed drug hypersensitivities for which an increasing number have more recently been shown to be human leukocyte antigen alleles (HLA) class I and/or II-restricted and T-cell-mediated.
- HLA-B*57:01 screening before abacavir prescription to prevent abacavir hypersensitivity is an example of a translational success story whereby a marker with 100% negative predictive value has now been implemented into guideline-based routine HIV clinical practice.
- Ancillary in vivo and ex vivo laboratory tests have been useful to define the true immunologically mediated phenotype of antiviral drug hypersensitivity (eg, patch testing for abacavir); however, the lower sensitivity of these tests for severe drug hypersensitivity syndromes means that clinical diagnosis remains the gold standard to guide management.
- Most allergic syndromes associated with antiviral medications consist of mild-to-moderate delayed rash without other serious manifestations (eg, fever, mucosal involvement, blistering rash, organ impairment). In these cases, treatment can be continued with careful observation and symptomatic management, and the discontinuation rate is low.

INTRODUCTION

Pharmacologically predictable adverse drug reactions and drug interactions have been commonly associated with anti-infective drugs and, particularly, antiretroviral agents. Immunologically mediated adverse drug reactions have also been commonly

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described in patients receiving drugs used to treat viral infections, including those used to treat human immunodeficiency virus (HIV) and hepatitis C infection.^{1–3} These hypersensitivity reactions associated with antiviral drugs can be classified by their immunologic mechanisms as well as their specific clinical manifestation or phenotype. Gell-Coombs types I–III (immediate drug allergy, antibody mediated, and immune complex mechanisms) are not commonly associated with antiviral drugs. Gell-Coombs type IV (T-cell-mediated) reactions, however, have been commonly associated with drugs used to treat viral infection.^{2–4} For instance, the antiretroviral drug, abacavir (ABC), causes a hypersensitivity syndrome, which has a distinct phenotype not shared by other drugs and is characterized by fever, malaise, and gastrointestinal symptoms. Mild-to-moderate skin rash is a late manifestation of ABC hypersensitivity, which occurs in 70% of cases.⁴ The antiretroviral drug, nevirapine, has been commonly associated with a delayed rash as well as more severe hypersensitivity reactions (drug reaction with eosinophilia and systemic symptoms [DRESS], also known as drug-induced hypersensitivity syndromes [DIHS], Stevens-Johnson syndrome/toxic epidermal necrolysis [SJS/TEN], and drug-induced liver disease [DILI]).⁵ Many drugs, such as the nonnucleoside reverse transcriptase inhibitor (NNRTI), efavirenz, and the anti-hepatitis C virus (HCV) NS3.4A serine protease inhibitor, telaprevir, are commonly associated with a nonspecific exanthem without systemic symptoms, which is not treatment limiting, and continued treatment is usually possible with symptom control.^{5–9} More severe reactions with fever and/or mucosal and/or severe cutaneous involvement and/or internal organ (eg, liver) involvement warrant immediate discontinuation and careful clinical monitoring. A major advance in pharmacogenomics has been the discovery that many immunologically mediated drug reactions are mediated through interactions with class I and/or class II human leukocyte antigen alleles (HLA) ([Table 1](#)). In the case of ABC, a strong association between HLA-B*57:01 was discovered by 2 independent groups in 2002 and HLA-B*57:01 is now used as a routine screening test with a proven 100% negative predictive value, before ABC prescription to exclude those at risk.^{10,11} Abacavir patch testing was also a useful research tool in this context that was used in clinical trials to identify those with true immunologically mediated ABC hypersensitivity reaction (HSR).^{21–23} ABC patch testing has a diagnostic sensitivity of 87% but there is currently no *in vivo* or *ex vivo* diagnostic test for antiviral drug hypersensitivity that has a 100% sensitivity or negative predictive value, and clinical diagnosis is used as the gold standard on which future recommendations are based. Drug hypersensitivity reactions associated with nevirapine have also been associated with class I and II HLA alleles, which seem to be ethnicity-dependent and phenotype-dependent, with associations that seem currently too complex to apply as a screening strategy in routine clinical practice (see [Table 1](#)).^{24–26} A major recent advance has been the elucidation of the science of ABC hypersensitivity, which has defined the specific mechanism by which ABC specifically interacts with HLA-B*57:01 and alters the repertoire of self-peptide ligands.^{22,27,28} Based on this work, the crystal structure of ABC-bound peptide-HLA-B*57:01 has been resolved and a new mechanistic paradigm for how drugs affect T-cell-mediated reactions was defined.²⁹ Future applications of this work could include preclinical strategies to determine drugs at high risk to cause immunologically mediated adverse drug reactions and hence inform drug design and development.

IMMUNOPATHOGENESIS AND PHARMACOGENOMICS OF ANTIVIRAL DRUG ALLERGY

Models that have been proposed to define the immunopathogenesis of drug allergy and hypersensitivity syndromes include the prehapten/hapten hypothesis, the

Table 1
Pharmacogenomics of antiviral drugs

Clinical Phenotypes and Drug	Alleles	Populations
DRESS/DIHS		
Abacavir	B*57:01	European, African ^{10,11}
Nevirapine (hepatitis)	DRB1*01:01 (CD4% $\geq$ 25) and DRB1*01:02	Australian, European, South African ¹²⁻¹⁴
Nevirapine (DRESS/DIHS with rash)	Cw*8 or Cw*8-B*14 haplotype	Italian, Japanese ^{15,16}
	Cw*4	White, Black, Asian Han Chinese ^{13,16}
	B*35	Asian ¹³
	B*35:05	Asian (Thai) ¹⁵
	B*35:01	European/Australia ¹⁷
	CYP2B6 516 G $\rightarrow$ T+C*04	White, Black, Asian ¹³
	CYP2B6 (rs2054675, rs3786547, rs3745274)	White, Black, Asian ¹³
Delayed rash (nonsystemic)		
Efavirenz	DRB1*01	French ⁵
Nevirapine	DRB1*01	French ⁵
	Cw*04	African, Asian, European, Thai ^{13,18}
	B*35:05; rs1576*G CCHR1 status (GWAS)	Thai ^{15,16}
SJS/TEN		
Nevirapine	HLA-C*04:01 ?CYP2B6 983 T $\rightarrow$ C	African (Malawian) ¹⁹ Mozambique ²⁰

pharmacologic-interaction (P-I) model, and most recently, the altered peptide repertoire model. The hapten hypothesis suggests that a drug or a reactive metabolite irreversibly binds to and covalently modifies self-proteins, leading to a neo-antigen.²⁷ The P-I model suggests that drugs induce T-cell activation by directly interacting with immune receptors on a pharmacologic level and noncovalently binding with HLA alleles and/or T-cell receptors.^{28,30} New evidence now exists that many drugs, including the nucleoside reverse transcriptase inhibitor and antiretroviral drug ABC, mediate hypersensitivity through the altered peptide repertoire model whereby it is proposed that drugs bind noncovalently with HLA, occupy anchor sites within the antigen-binding cleft, and thereby alter the repertoire of self-peptide ligand bound and presenting to T cell, creating a form of altered T-cell immunity based on alteration of immunologic self by a drug. Multiple groups have now reproduced evidence demonstrating that ABC binds noncovalently to the F-binding pocket of HLA-B*57:01 to specific residues that define this allele and shifts the repertoire of self-peptides presented and the crystal structure of ABC bound to HLA-B*57:01 and peptide has been solved.³¹⁻³³ Because the altered peptide model does not explain why only 55% of HLA-B*57:01-positive patients experience ABC hypersensitivity, additional models are needed.²¹ Other models for drug hypersensitivity include the heterologous immune model, suggesting that these reactions could be mediated by cross-reactive memory T-cell responses to chronic prevalent viruses, such as human herpes viruses (HHV) and/or mediated through restricted T-cell receptor repertoire usage as recently demonstrated for carbamazepine.³¹ Reactivation of chronic persistent HHV, such as HHV 6/7, cytomegalovirus (CMV), and Epstein-Barr virus (EBV), has also been

described as complications of DRESS/DIHS; however, this has not been a described feature of hypersensitivity associated with ABC or other antivirals.^{34–36}

In 2002, 2 independent groups reported a strong association between the HLA class I allele, HLA-B*57:01, and ABC hypersensitivity syndrome.^{10,11} The nonspecific nature of the clinical syndrome of ABC hypersensitivity characterized by fever, rash, gastrointestinal symptoms, and sometimes respiratory symptoms led to a high rate of false positive clinical diagnosis and the suggestion that the HLA-B*57:01 allele lacked sensitivity and 100% negative predictive value for ABC hypersensitivity, particularly in races with a low prevalence of HLA-B*57:01 carriage. A randomized controlled clinical trial that compared prospective HLA-B*57:01 screening versus ABC initiation without screening and used ABC patch testing (Fig. 1) as a co-primary endpoint to clinical diagnosis to identify true immunologically mediated ABC hypersensitivity clarified the 100% negative predictive value of HLA-B*57:01 for ABC hypersensitivity and, hence, its utility in clinical practice.²¹ A follow-up study in Whites and African Americans also confirmed the generalizability of this 100% negative predictive value to non-White ethnicities.³⁷ Since 2008, international guidelines have recommended the use of HLA-B*57:01 screening before ABC prescription, and HLA-B*57:01 is now one of the most widely used genetic screening tests in clinical practice today.²⁴

Early in the postmarketing phase of ABC's development, ABC hypersensitivity was defined as an HLA-B*57:01-restricted CD8+ T-cell-mediated reaction with long-lasting immunity, as demonstrated by patch testing and ex vivo studies.^{22,38,39} The Prospective Randomized Evaluation of DNA Screening in a Clinical Trial (PREDICT-1) study demonstrated that 55% of those carrying HLA-B*57:01 will develop ABC hypersensitivity and, although to date no other HLA has been associated with ABC hypersensitivity, the mechanism of HLA-B*57:01-positive ABC tolerance has not been determined.²¹ Despite this incomplete positive predictive value, ABC-specific CD8+

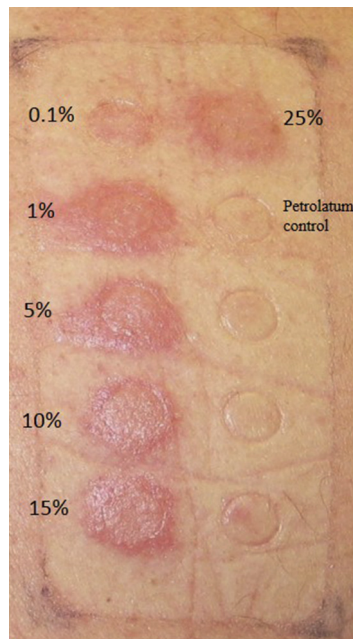


Fig. 1. ABC patch test: 24-hour reading ABC in concentrations of 0.1, 1, 5, 10, 15, and 25% in petrolatum and petrolatum control are applied to the skin and left undisturbed for 24 hours.

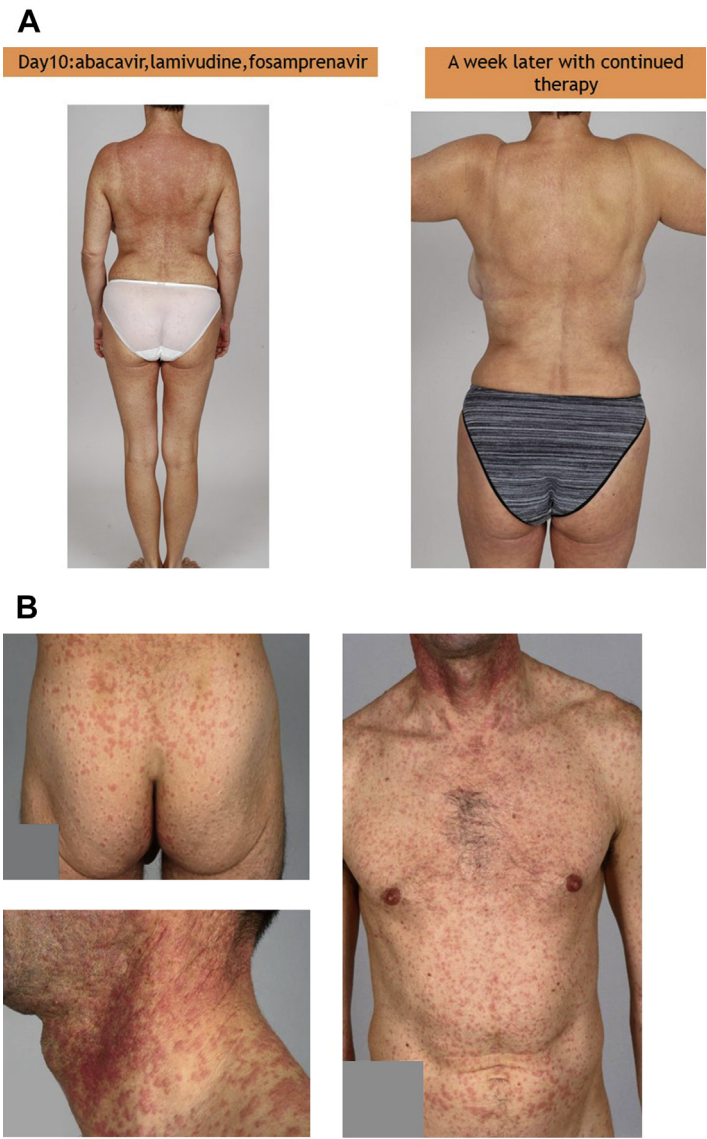
T-cell responses can be reproduced in 10- to 12-day culture from 100% of HLA-B*57:01-positive ABC-naïve healthy blood donors.³⁹

Nevirapine is a NNRTI used to treat HIV, the major treatment limiting toxicity of which is a drug hypersensitivity syndrome. The phenotypes of nevirapine hypersensitivity vary from exanthem without other symptoms, DRESS/DIHS, hepatitis (DILI), and SJS/TEN (Fig. 2B–D). More recently, each of these phenotypes has been associated with different class I and class II HLA associations across different ethnicities (see Table 1).^{5,12–18} An early study in a Western Australian cohort suggested that nevirapine hypersensitivity associated with rash and hepatitis was a CD4+ T-cell-dependent HLA-DRB1*01:01-restricted process.¹²

With regards to phenotype specific class I HLA associations and nevirapine hypersensitivity syndromes this includes HLA-B*35:05 and cutaneous hypersensitivity in Southeast Asians and HLA-Cw4 in association with cutaneous phenotypes across multiple ethnicities, but, in particular, in association with CYP2B6 516 G>T in Blacks.¹² In a South African population, HLA-B*58:01 and HLA-DRB1*01:02 have recently been associated with grade 3/4 hepatitis on nevirapine, and HLA-C*04:01 was associated with SJS/TEN in a Malawian population. HLA-DRB1*01 was also previously reported with cutaneous hypersensitivity in association with nevirapine and another NNRTI, efavirenz.⁵ Severe drug-induced liver injury has been reported in 3.4% of an HIV Ethiopian population started on efavirenz and associated with higher efavirenz plasma levels and CYP2B6*6 as well as advanced HIV and pretreatment liver disease. It is unclear from the report whether the hepatitis was toxic, immunologic, or a mixture of both.⁴⁰ Rash and pruritus have been associated with up to 50% or more of patients receiving combination regimens, including the direct-acting hepatitis C antiviral (NS3/4A protease inhibitor) telaprevir, resulting in treatment discontinuation in 6% of patients.⁴¹ Severe hypersensitivity (DRESS/DIHS) or severe cutaneous adverse reactions including SJS/TEN are uncommon, occurring in less than 1% of patients.⁴² A case control study of 187 telaprevir-treated patients of whom 114 had developed rash (59 severe) was conducted to explore a potential association between telaprevir rash and HLA class I and II alleles. HLA-B*44:02 and HLA-DQB1*02:02 were the top-ranked alleles associated with severe skin rash; however, these associations did not hold up after correction for multiple comparisons.^{41,43}

HYPERSENSITIVITY SYNDROMES ASSOCIATED WITH ANTIRETROVIRAL TREATMENT

Those living with HIV have increased exposure to drugs more likely to cause drug hypersensitivity and immune dysregulation. Many delayed and likely T-cell-mediated drug hypersensitivity reactions have been reported to occur more commonly in HIV-infected populations. In the first decade of HIV treatment, these mainly involved drugs used to treat HIV-related infections, but now primarily include drugs used to treat HIV.⁴⁴ The most common cutaneous drug reactions in HIV-infected patients are maculopapular exanthemas (MPE). These eruptions are characterized by widespread erythematous macules and papules that usually affect the trunk and proximal extremities; these rashes are often accompanied by pruritus without fever. Initial macules and papules can be increasing in size and lead to confluence or be followed by maculopapular, pustular, or vesicular lesions. MPE usually appear between 2 and 10 weeks after primary exposure to antiretroviral therapy (ART) and within 1 to 2 days of rechallenge. Most of these exanthema are benign and resolve within 2 weeks without sequelae. The patient should be evaluated carefully for the presence of signs of severity, such as edema, skin detachment, erosions, mucosal involvement, fever or systemic symptoms that alert to a more severe drug reaction, such as DRESS/DIHS or SJS/TEN. Usually rash severity is graded



Nevirapine-associated rash – Day 10

Fig. 2. (A) (*left*) Patient on day 10: abacavir, lamivudine, fosamprenavir and (*right*) improvement a week later with continued therapy. (B) Patient displays Nevirapine-associated rash at Day 10. (C) Patient with Nevirapine-associated Toxic Epidermal Necrolysis. (D) Patient with Nevirapine-induced DRESS 15 days after the initiation of treatment. (E) Patients displaying Telaprevir-induced rashes of varying severity. Part A shows Grade 1 (mild): treatment is continued. Part B shows Grade 2 (moderate): treatment is continued. Part C shows Grade 3 (severe): treatment is stopped.



Fig. 2. (continued)

in 4 levels (Box 1). Other allergic syndromes, such as Gell-Coombs type I (IgE-mediated) reactions or delayed urticarial eruptions, are infrequently seen in association with ART.

SJS/TEN

SJS and TEN represent acute life-threatening conditions with high morbidity and mortality with an incidence estimated at 1 to 2 cases/million population/year. The histologic hallmark of these diseases is necrosis with detachment of the epidermis. Patients are classified according to the percentage of the body surface area exhibiting epidermal detachment (BSA%), which is less than 10% in SJS, more than 30% in TEN, and 10% to 30% in SJS/TEN overlap syndrome.^{45,46} The mortality of SJS and TEN has recently been estimated to be about 22%,⁴⁷ correlating with the extent of detachment and age of the patient and thus elements of the prognostic score called SCORTEN⁴⁸: seven independent risk factors: age greater than 40 years, malignancy, tachycardia greater than 120 per minute, initial BSA% greater than 10%, serum urea greater than 10 mmol per liter, serum glucose greater than 14 mmol per liter, and bicarbonate less than 20 mmol per liter. TEN usually develops 1 to 3 weeks after the administration of the responsible drug. The clinical diagnosis is based on the presence of characteristic eruptions of mucosal extensive erosions, typical targetoid lesions, erythematous confluent maculae, and bullae, with a positive Nikolsky’s sign (detachment of epidermis to finger pressure). Histopathology is characterized by keratinocyte apoptosis followed by necrosis, which creates the basis for the epidermal erosion and detachment. Infection is the most common acute complication and cause of death in SJS/TEN patients. Recovery may require 3 to 6 weeks and is often followed by pigmentation disorders and pathologic scarring at mucosal sites. More than 50% of patients surviving SJS/TEN suffer from long-term complications primarily located in the eyes, such as vision loss in some cases.^{44,46} To date, there is no established treatment for SJS/TEN. Symptomatic treatment (dressings, maintenance of thermoregulation, fluid and electrolyte balance, nutritional support, prevention of infections) and immediate cessation of the suspected causative drug are the key to the management of SJS/TEN. Patients benefit from being under the care of a dermatologist in an intensive care or burns unit.

Box 1

Grading of rash severity

Grade 1 (mild): localized skin eruption and/or limited skin eruption with or without pruritus

Grade 2 (moderate): diffuse eruption involving up to 50% of BSA with or without superficial skin peeling, pruritus, or mucous membrane involvement and no ulceration

Grade 3 (severe): generalized rash involving EITHER $\geq 50\%$ of BSA OR rash presenting with any of the following characteristics:

- Vesicles or bullae
- Superficial ulceration of mucous membranes
- Typical or atypical target lesions
- Palpable purpura/nonblanching erythema

Grade 4 (life-threatening reactions)

- DRESS/DIHS
- SJS/TEN

DRESS/DIHS

DRESS/DIHS is a severe drug-induced adverse manifestation that occurs in most patients 2 to 6 weeks after drug administration. Clinical and biologic manifestations of DRESS are characteristic: high fever, facial edema, erythroderma followed by an exfoliative dermatitis, diffuse lymphadenopathy, eosinophilia, atypical circulating lymphocytes, and abnormal results of liver function tests. Numerous systemic manifestations may occur (hepatitis, pneumonitis, pancreatitis, renal failure, neurologic symptoms, and many others). In contrast to SJS and TEN, involvement of the mucous membranes is rare.^{45,46} Reactivation of HHV, including EBV and HHV-6 and HHV-7, has been described in association with many drug-induced DRESS/DIHS syndromes, however, interestingly, not with ART-associated DRESS/DIHS. The detection of HHV-6 reactivation has even been recently proposed as a diagnostic marker for DRESS/DIHS.^{27,28,30} To define more accurately the DRESS syndrome, a scoring system—the RegiSCAR scoring—has been designed to grade DRESS cases as “no,” “possible,” “probable,” or “definite” case.⁴⁸ This condition must be recognized early to immediately stop the suspected drugs, but the persistence or aggravation of symptoms despite the discontinuation of the culprit drug is possible. Topical high-potency corticosteroids or systemic corticosteroids are usually required for a full recovery.

Cutaneous adverse drug reactions, although reported with all ART, are more prevalent with specific ART drugs and drug classes, particularly the NNRTI ([Table 2](#)).

PROTEASE INHIBITORS

All protease inhibitors have been associated with mild-to-moderate maculopapular rashes; these are typically observed within the first 2 weeks of treatment and are mild without need for treatment discontinuation (see [Fig. 2A](#)). They are uncommonly associated with severe reactions, such as DRESS/DIHS or SJS/TEN. The rate of rash in patients treated with a protease inhibitors has been recently estimated as around 5%. The newest protease inhibitors are more commonly responsible with variable rates, respectively, up to 6%, 10%, 16%, and 19% for atazanavir, tipranavir, darunavir, and fosamprenavir.⁴⁴ Darunavir and fosamprenavir are sulfa antimicrobials, and there is concern for cross-reactivity with sulfamethoxazole and other sulfa antimicrobials. For darunavir, patients with a history of sulfa antimicrobial hypersensitivity were not excluded from clinical trials.

NNRTIS

NNRTIs in clinical use include the first-generation drugs, nevirapine and efavirenz, and second-generation drugs, etravirine and rilpivirine. Cutaneous problems and hepatotoxicity are the main side effects induced by NNRTIs. In most patients, rashes are mild-to-moderate MPE that occur within the first 1 to 2 weeks of treatment and resolve with continued treatment (see [Fig. 2B](#)). Rashes associated with nevirapine (4%–38%) and efavirenz (4.6%–20%) are frequent (see [Table 2](#)). SJS/TEN has most frequently been reported with nevirapine (0.3%–1%) (see [Fig. 2C](#)) and less frequently with efavirenz (0.1%).⁴⁹ DRESS/DIHS syndrome is well documented with nevirapine occurring in up to 5% of patients (see [Fig. 2D](#)) but is uncommonly attributed to efavirenz.⁵⁰ Female sex, ethnicity (Hispanic, Chinese, and African), and individuals with higher CD4+ T-cell count and uncontrolled HIV viremia in early studies seemed to be at higher risk for nevirapine-related rash.⁵¹ An initial 2-week lead-in period at half the recommended dose has been shown to reduce the risk of skin rashes with nevirapine by at least 50%. The prophylactic use of corticosteroids or antihistamines to prevent hypersensitivity

Class	Agent	Reaction	Incidence	Discontinuation
Antiretroviral treatments				
Protease inhibitors	Atazanavir	Rash	≤6%	<1%
	Darunavir	Rash	≤10%	<1%
		SJS/TEN/DIHS/DRESS	<1%	100%
	Fosamprenavir	Rash	≤19%	<1%
		Moderate-severe	—	<1%
	Lopinavir/Ritonavir	Rash	2%	<1%
NNRTIs	Efavirenz	Rash	4.6%–20%	<2%
		SJS/TEN	0.1%	100%
		DRESS/DIHS	—	—
	Etravirine	Rash	≤10%	<2%
		DRESS/DIHS, SJS/TEN	<0.1%	100%
	Nevirapine	Rash	4%–38%	6%
		DRESS/DIHS	Up to 5%	100%
		SJS/TEN	0.3%–1%	—
Fusion inhibitors	Enfuvirtide	Rash	2%	<1%
		Hypersensitivity reaction	<1%	Mostly for subcutaneous reactions, not HSR
NRTIs	Tenofovir	Rash	5%–7%	<1%
	Abacavir	Hypersensitivity reaction (fever, gastrointestinal symptoms, rash in 70%)	5%–8%	100%, hypotension, severe morbidity on rechallenge
		Rash only	3%	<1%
		Pruritus, rash	17%–30%	<1%
Integrase inhibitors	Raltegravir	Pruritus, diaphoresis, rash	2%–7%	<1%
		DRESS/DIHS/SJS/TEN	<1%	100%
CCR5 inhibitors	Maraviroc	Pruritus	3.8%	<1%
Direct-acting hepatitis C treatments	Telaprevir	Mild to moderate eczematous rash	50%	<10%
		DRESS/DIHS	5%	100%
		SJS/TEN	<1%	—

reactions to nevirapine has not been shown to be of benefit and may even increase risk.^{52,53} Risk factors for efavirenz-induced rash are less well-described. Nevirapine-associated hypersensitivity syndromes have a pharmacogenomic basis and have been associated with various class I and II HLA alleles as described above.

Etravirine is the first of the second-generation NNRTIs that has showed efficacy in controlling HIV replication in treatment-experienced patients, in combination with other active agents. In clinical trials, rash was reported in 16.9% of the etravirine-treated patients compared with 9.3% in placebo (see [Table 2](#)). Most rashes were of mild or moderate severity, occurring within the first few weeks of treatment (median 14 days) and resolved with continued treatment (only 2.2% of patients discontinued etravirine). In clinical trials, women developed more rash than men. There was no relationship between rash and

etravirine pharmacokinetic exposure, CD4+ T-cell count, nor history of other NNRTI-related rash. DRESS/DIHS and SJS/TEN were reported in less than 0.1% of the etravirine-treated patients during clinical trials. In 2009, the manufacturer issued a drug warning regarding the safety of etravirine in light of postmarketing reports of severe skin and hypersensitivity reactions. Cases included life-threatening and fatal reports of DRESS/DIHS and SJS/TEN.⁵⁴ Another second-generation NNRTI, rilpivirine, has been associated with a low incidence (2%) of mild-to-moderate rash in clinical trials (see [Table 2](#)).⁵⁵

FUSION INHIBITORS

Enfuvirtide was the first of a class of antiretroviral medications called fusion inhibitors and the only one currently available as an injectable formulation. Most cutaneous side effects are injection site reactions. Hypersensitivity reaction has an incidence rate of less than 1% of patients in clinical trials.⁵⁶

NUCLEOSIDE REVERSE TRANSCRIPTASE INHIBITORS

Nucleoside reverse transcriptase inhibitors (NRTIs) were the first medication approved for the treatment of HIV. Currently, the nucleoside analogues commonly used as part of combination ART include Lamivudine (2',3'-dideoxy-3'-thiacytidine, commonly called 3TC), emtricitabine (3TC), tenofovir (nucleotide analogue), and ABC. Because of the inconvenience of dosing and long-term toxicities, Zidovudine (INN)/azidothymidine (AZT), Didanosine (2',3'-dideoxyinosine, ddI, DDI), and Stavudine (2',3'-dideoxy-2',3'-dideoxythymidine, d4T) are currently much less commonly used in the developed world. Rash has been less commonly associated with tenofovir and a hypersensitivity syndrome has been rarely reported (see [Table 2](#)).⁴⁴

ABC

ABC can be associated with a drug hypersensitivity syndrome that is distinct from DRESS/DIHS. In early studies, ABC hypersensitivity was reported to occur within the first 6 weeks of exposure, although most cases occur in the second week of first exposure at a median of 8 to 9 days. It is characterized by fever, malaise, gastrointestinal symptoms, and internal organ involvement in approximately 5% to 8% of patients who begin therapy with ABC.⁴

The syndrome can be accompanied by a mild-to-moderate rash in 70% of patients with ABC hypersensitivity and is associated with severe hypotension and possible death on rechallenge, in contrast to the complete abrogation of symptoms 72 hours after withdrawal of the drug. Once the hypersensitivity syndrome reaction has been diagnosed, ABC therapy should be discontinued immediately and permanently. Corticosteroids, given prophylactically, do not seem to reduce the severity or frequency of the ABC hypersensitivity syndrome.⁵³ There is a strong association with ABC hypersensitivity and the presence of the HLA-B*57:01 allele^{7,8,57} and genetic testing to prevent ABC HSR is currently one of the best examples of integrating pharmacogenetic testing into clinical practice. Mild-to-moderate rash without other symptoms of ABC hypersensitivity is known to occur in 3% of those starting ABC. This MPE is not known to be associated with HLA-B*57:01 and is not treatment limiting. SJS/TEN has only rarely been suspected in association with ABC therapy.⁵⁸ ABC patch testing (see [Fig. 1](#)) has been used as a research tool to identify true immunologically mediated ABC hypersensitivity; however, it has a diagnostic sensitivity of 87% and in view of the severe rechallenge reactions (hypotension, shock) that have occurred in patients

with ABC hypersensitivity on second exposure to ABC, a negative patch test alone should never be used as the sole basis for ABC reintroduction.^{23,24,59}

Emtricitabine

Emtricitabine is used to prevent the replication of HIV and hepatitis B virus. The skin rashes most commonly reported in emtricitabine trials were pruritus, maculopapular rash, urticaria, vesiculobullous, and pustular rash, observed in 17% to 30% of the patients. These reactions were mild or moderate; only 1% of the patients discontinued treatment because of rash (see [Table 2](#)).⁴⁴

INTEGRASE INHIBITORS

Most rash events in raltegravir-treated subjects in the clinical trials were mild to moderate in intensity, and no discontinuations were reported. However, many of the rash events have been confounded by the use of concomitant medications associated, such as NNRTIs, ABC, and Protease inhibitors. More recently, there have been cases of raltegravir-associated DRESS/DIHS and SJS/TEN with 3 separate case publications of raltegravir-associated DRESS/DIHS syndrome all in women of African descent.^{60–62} A newly approved integrase inhibitor, dolutegravir, has not been associated with rash.

INHIBITORS OF THE CCR5 CHEMOKINE RECEPTOR

Maraviroc is the first human chemokine receptor 5 (CCR5) co-receptor antagonist approved for HIV treatment. Information about the cutaneous adverse events and hypersensitivity syndromes associated with maraviroc is scarce; however, pruritus occurred in 3.8% of the patients receiving maraviroc in clinical trials (see [Table 2](#)).⁶³

HYPERSENSITIVITY SYNDROMES ASSOCIATED WITH TREATMENT OF HCV

HCV is a major global health problem with an estimated 170 million people chronically infected.⁶⁴ It may lead to chronic liver disease, cirrhosis, and hepatocellular carcinoma, with high morbidity and mortality.⁶⁵ Standard combination treatment with pegylated interferon- α (PegIFN) and ribavirin (RBV) results in a virological response in only about 45% of patients.⁶⁶ New direct-acting antiviral drugs, such as telaprevir and boceprevir that are inhibitors of the HCV NS3.4A serine protease, have thus become of great interest for improving the efficacy of anti-HCV treatment. Telaprevir has been recently developed for the treatment of chronic genotype 1 HCV infection in combination with RBV and PegIFN.⁶⁷ Telaprevir-associated rash has occurred in up to 50% or more of the patients on combination treatment with RBV and PegIFN since its first evaluation in clinical studies (see [Fig. 2E](#), [Table 2](#)). More than 90% of these eruptions are mild and moderate eczematous dermatitis (grades 1 and 2) that does not require telaprevir discontinuation and are usually well controlled by antihistamine therapy, emollients, and topical steroids (see [Fig. 2E](#)).² Approximately 5% of these skin eruptions are potentially severe with cases of DRESS/DIHS and SJS/TEN reported.^{8,9,41} There has been no association between the pharmacokinetics of PegIFN, RBV, and telaprevir and incidence of rash.⁴¹ The safety data of the combination of boceprevir with PegIFN and RBV were assessed in phase 2 and 3 placebo-controlled clinical trials. The most common adverse events observed were anemia, dysgeusia, and cutaneous side effects. Rashes were noted in 14% to 22% of cases and dry skin in 18% to 22% of cases, which was noted more significantly compared with PegIFN and RBV alone in treatment-experienced patients; however, no patient receiving boceprevir discontinued the treatment because of skin eruption.⁶⁸ Severe cutaneous syndromes are

uncommon with boceprevir, with one recently published case of DRESS/DIHS associated with boceprevir.⁶⁹ For mild-to-moderate skin rash without systemic symptoms or mucosal involvement, appropriate skin-care management usually facilitates continuation of antiviral therapy (see [Table 2](#)),⁷⁰ which emphasizes the importance of close collaboration between dermatologists and hepatologists.

DIAGNOSIS AND TREATMENT

The diagnosis and treatment of drug hypersensitivity to antivirals, as per any drugs, are still largely based on clinical assessment of the specific syndrome involved. As per other drugs, the presence of mild-to-moderate rash without systemic symptoms, or internal organ or mucosal involvement, is commonly associated with many antiviral drugs. Given the need to continue uninterrupted antiretroviral and hepatitis C treatment, it is reasonable in these mild cases to continue treatment with careful observation with the expectation that the rash will remit, although the mechanism of immunologic tolerance is not clear.

Desensitization or graded reintroduction of drug has also been used to reintroduce an antiviral whereby the original reaction consisted of an isolated mild-to-moderate skin rash.⁸ ABC patch testing showed great utility as a research tool in the PREDICT-1 and Study of Hypersensitivity to Abacavir and Pharmacogenetic Evaluation (SHAPE) studies to define the specific syndrome of immunologically mediated ABC hypersensitivity.^{11,21} From the PREDICT-1 study, the diagnostic sensitivity of ABC patch testing was 87%, giving it one of the highest sensitivities of patch testing for drug hypersensitivity. However, given the severity and potential for morbidity and mortality associated with rechallenge with ABC in patients who have already experienced ABC hypersensitivity syndrome, patch testing alone should never be used as the basis for rechallenge and clinical judgment should always take precedent.⁷¹ In general, patch testing has shown diagnostic utility for other drug hypersensitivity syndromes, such as DRESS/DIHS, acute generalized exanthematous pustulosis (AGEP), and fixed drug eruption, and less so for SJS/TEN; however, in general, the sensitivity of patch testing for drugs other than ABC has been less than 50% and is very drug-specific.^{72,73} Patch testing for syndromes such as DRESS/DIHS/SJS/TEN for specific antivirals such as nevirapine appears to have low sensitivity and utility.^{59,72} For efavirenz, a type of photoallergic dermatitis has been described and there have been case reports of positive photopatch, whereby the drug is applied for 48 hours followed by low-dose ultraviolet A application for 24 hours.^{73–75} More recently, direct-acting drugs against hepatitis C, such as telaprevir, have been associated with a very high incidence of delayed rash; however, treatment is largely supportive and most patients do not have associated systemic symptoms or signs and can continue treatment.⁴¹ Specific ex vivo tests such as ELISpot have reproducibly shown γ -interferon responses to the parent drug for several years after the acute ABC hypersensitivity reaction, but seem less reliable for other drugs, such as nevirapine, whereby responses have been shown to wane quickly over months to years. In general, the management of antiviral drug hypersensitivity is similar to other drugs and includes use of prednisone or other immunosuppressants in cases of DRESS/DIHS with severe organ involvement of SJS/TEN, respectively. The long half-life of nevirapine is a risk factor for poor outcome associated with SJS/TEN, and nevirapine should be stopped immediately after onset of symptoms/signs suggestive of SJS/TEN.⁷⁶

HLA-B*57:01 has had great utility as a screening test with 100% negative predictive value generalizable across different ethnicities to identify patients at risk to develop ABC hypersensitivity.^{21,77,78} The complexity of HLA associations across different

phenotypes and ethnicities with other drugs such as nevirapine is such that currently HLA testing has limited utility as a screening strategy to prevent nevirapine hypersensitivity syndromes before nevirapine prescription.

SUMMARY AND FUTURE DIRECTIONS

Antiviral drugs are common causes of delayed T-cell-mediated drug reactions for which the immunopathogenesis has been more recently defined to be largely HLA class I and/or class II restricted and T-cell-mediated. Fortunately, most of these reactions are benign and consist of a mild-to-moderate delayed skin rash, which is not treatment limiting and resolved with continued dosing. Although these drugs may share structure, such as a shared sulfa antimicrobial group in the case of darunavir and fosamprenavir, or shared mechanism of action and propensity to develop skin rash, as for the HIV NNRTI, clinical and immunologic cross-reactivity between antiviral drugs is uncommon in clinical practice. The association between HLA-B*57:01 and ABC hypersensitivity represents an successful example of where a genetic marker with 100% negative predictive value and generalizable across different ethnicities has been used as a screening test in the routine clinical setting to prevent a specific antiviral drug hypersensitivity syndrome. Many other HLA class I and II associations have been described between various phenotypes of nevirapine hypersensitivity, which have shed further light on the immunopathogenesis of antiviral hypersensitivity syndromes; however, the complexity of these associations and the lack of generalizability across all ethnicities make it unlikely they these will be used in the routine clinical setting. A paradigm shift has occurred in the science of drug hypersensitivity with definition of the crystal structure of ABC bound to peptide-HLA-B*57:01 and evidence for an altered peptide model of drug hypersensitivity. From recent research, it is likely that this altered peptide repertoire model applies to many other phenotypes of severe T-cell-mediated drug reactions, including DIHS/DRESS and SJS/TEN.^{24,27} The altered peptide repertoire model does not explain why in general only a small fraction of patients carrying a specific HLA class I and/or II risk allele will develop a drug hypersensitivity syndrome and other models are needed. Some evidence now exists to suggest that hypersensitivity reactions to drugs like ABC, where symptoms can occur within 1 to 2 days of first exposure, may occur secondary to a pre-existing memory T-cell response. This pre-existing memory T-cell response may be targeted against a prevalent persistent viral pathogen, such a human herpes virus representing a heterologous immune model of drug hypersensitivity. The convergence of structural, biochemical, and functional immunologic approaches to define interactions between antiviral drugs and HLA molecules offers promise for being able to predict drug hypersensitivity risk in the preclinical stage of drug development and positively impact the efficacy, safety, and efficiency of antiviral drug development and design.

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