MAYO CLINIC LABORATORIES

Pharmacogenomic Association Tables

Disclaimer: The included tables are for educational purposes and should not be used for making clinical decisions. The genes included are found in the US Food and Drug Administration (FDA) Table of Pharmacogenetic Associations (Tables 1–3), Clinical Pharmacogenetic Implementation Consortium (CPIC) guidelines, and/or guidelines produced by the Dutch Pharmacogenomics Working Group. Additional genes with a lower level of evidence (often based on limited literature) are provided in gray, non-bold font.

This list is not comprehensive of all drugs in the pharmacopeia, but focuses on commonly used drugs where some evidence for a pharmacogenomic association exists. Other genes and their encoded enzymes, not described here, may also be relevant, but do not have a well-established pharmacogenomic association. Regardless of pharmacogenomic associations, all medications require careful clinical judgment and monitoring, and should be selected and dosed based on the overall clinical context.

See Appendix 1 for guidance to identify reliable sources for more in-depth information or to review the most current information for additional drugs and/or genes.

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Table 1: Pharmacogenomic Associations

Note: Associations with genes in **black bold font** are based on information provided in the FDA Table of Pharmacogenetic Associations (Tables 1–3), CPIC Guidelines, and/or Dutch Pharmacogenomics Working Group Guidelines. However, in some cases, variation in the genes listed may impact pharmacokinetics and not necessarily require a dose adjustment. Associations with genes in gray font (not bold) are based on either limited literature or may be theoretical (eg, if strong inhibitors of an enzyme are mentioned in the FDA-approved drug label, a genetic variant leading to significantly decreased enzyme activity may be expected to have a similar impact on drug metabolism). In some instances, activation of a pro-drug by an enzyme occurs and this is indicated by the word "activates" behind the gene name. The genes listed here may be considered; however, it is not recommended to act on these associations alone. Consult the medication label and CPIC guidelines for more details on use of the patient's specific genetic test results related to these genes.

Drug	Genes and/or HLA Alleles
abacavir (Ziagen)	***HLA-B*57:01***
allopurinol (Aloprim, Zyloprim)	***HLA-B*58:01***
alprazolam (Xanax)	*CYP3A4, CYP3A5*
amifampridine (Firdapse)	***NAT2***
amitriptyline (Elavil)	***CYP2D6, CYP2C19***
amoxapine (Asendin)	***CYP2D6***
amphetamine	***CYP2D6***
aripiprazole (Abilify)	***CYP2D6,*** *CYP3A4*
asenapine (Saphris)	*CYP1A2*
atazanavir (Reyataz)	***UGT1A1***
atomoxetine (Strattera)	***CYP2D6***
atorvastatin (Lipitor)	***SLCO1B1***
avatrombopag (Doptelet)	***CYP2C9***
azathioprine (Azasan)	***TPMT, NUDT15***
belinostat (Beleodaq)	***UGT1A1***

Drug	Genes and/or HLA Alleles
belzutifan (Welireg)	***CYP2C19, UGT2B17***
brexpiprazole (Rexulti)	***CYP2D6,*** *CYP3A4*
brivaracetam (Briviact)	***CYP2C19***
buprenorphine (Buprenex, Butrans, Probuphine)	*CYP3A4, OPRM1*
bupropion (Wellbutrin)	*CYP2B6* activates
buspirone (BuSpar)	*CYP3A4*
capecitabine (Xeloda)	***DPYD***
carbamazepine (Carbatrol, Tegretol)	***HLA-B*15:02, HLA-A*31:01,*** *SCN1A, EPHX1*
cariprazine (Vraylar)	*CYP3A4*
carisoprodol (Soma)	***CYP2C19***
carvedilol (Coreg)	***CYP2D6***
celecoxib (Celebrex)	***CYP2C9***
cevimeline (Evoxac)	***CYP2D6***
chlorpromazine (Thorazine)	*CYP1A2, CYP2D6*

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Pharmacogenomic Association Tables (continued)

Table 1: Pharmacogenomic Associations (continued)

Drug	Genes and/or HLA Alleles
citalopram (Celexa)	***CYP2C19,*** *SLC6A4, HTR2A, GRIK4*
clobazam (Onfi)	***CYP2C19***
clomipramine (Anafranil)	***CYP2D6, CYP2C19***
clonazepam (Klonopin)	*CYP3A4*
clopidogrel (Plavix)	***CYP2C19* activates**
clozapine (Clozaril)	***CYP2D6,*** *CYP1A2, CYP3A4, ANKK1*
codeine	***CYP2D6* activates**
dapsone (Aczone)	***G6PD***
darifenacin (Enablex)	***CYP2D6***
desipramine (Norpramin)	***CYP2D6***
deutetrabenazine (Austedo)	***CYP2D6***
dexlansoprazole (Dexilant)	***CYP2C19***
diazepam (Valium)	***CYP2C19,*** *CYP3A4*
dolutegravir (Tivicay)	***UGT1A1***
donepezil (Aricept)	***CYP2D6***
doxepin (Sinequan)	***CYP2D6, CYP2C19***
dronabinol (Marinol, THC)	***CYP2C9***
duloxetine (Cymbalta)	*CYP1A2, CYP2D6*
efavirenz (Sustiva)	***CYP2B6***
elagolix (Orilissa)	***SLCO1B1***
eliglustat (Cerdelga)	***CYP2D6***
erdafitinib (Balversa)	***CYP2C9***
escitalopram (Lexapro)	***CYP2C19,*** *SLC6A4, HTR2A, GRIK4*
esomeprazole (Nexium)	***CYP2C19***
eszopiclone (Lunesta)	*CYP3A4*
fesoterodine (Toviaz)	***CYP2D6***
flecainide (Tambocor)	***CYP2D6***
flibanserin (Addyi)	***CYP2C19***
fluorouracil (Efudex, Fluoroplex, Tolak)	***DPYD***
fluoxetine (Prozac)	***CYP2D6***
flurbiprofen (Ocufen)	***CYP2C9***
fluvastatin (Lescol)	***SLCO1B1, CYP2C9***
fluvoxamine (Luvox)	***CYP2D6***

Drug	Genes and/or HLA Alleles
fosphenytoin (Cerebyx)	***CYP2C9, HLA-B*15:02***
galantamine (Razadyne)	***CYP2D6***
gefitinib (Iressa)	***CYP2D6***
haloperidol (Haldol)	***CYP2D6***
hydralazine	***NAT2***
ibuprofen	***CYP2C9***
iloperidone (Fanapt)	***CYP2D6,*** *CYP3A4*
imipramine (Tofranil)	***CYP2D6, CYP2C19***
irinotecan (Camptosar)	***UGT1A1***
isoniazid	***NAT2***
lansoprazole (Prevacid)	***CYP2C19***
levomilnacipran (Fetzima)	*CYP3A4*
lofexidine (Lucemyra)	***CYP2D6***
lorazepam (Ativan)	*UGT2B15*
lornoxicam (chlortenoxicam)	***CYP2C9***
lovastatin (Altoprev)	***SLCO1B1***
lurasidone (Latuda)	*CYP3A4*
maprotiline (Ludiomil)	*CYP2D6*
meclizine (Medi-Meclizine, Bonine, Motion Sickness, Verticalm)	***CYP2D6***
meloxicam (Mobic)	***CYP2C9***
mercaptopurine (Purixan)	***TPMT, NUDT15***
methadone (Methadose, Diskets, Dolophine)	*CYP2B6, COMT*
methylene blue (ProvayBlue)	***G6PD***
metoclopramide (Reglan)	***CYP2D6***
metoprolol (Toprol, Lopressor)	***CYP2D6***
midazolam	***CYP3A***
mirabegron (Myrbetriq)	***CYP2D6***
mirtazapine (Remeron)	*CYP2D6, CYP3A4*
naltrexone (Revia, Vivitrol)	*OPRM1*
nebivolol (Bystolic)	***CYP2D6***
nicotine replacement therapy	*CHRNA3*
nilotinib (Tasigna)	***UGT1A1***
nitrofurantoin (Furadantin, Macrobid, Macrodantin)	***G6PD***

Pharmacogenomic Association Tables (continued)

Table 1: Pharmacogenomic Associations (continued)

Drug	Genes and/or HLA Alleles
nortriptyline (Pamelor)	***CYP2D6***
olanzapine (Zyprexa)	*CYP1A2, ANKK1*
oliceridine (Olinvyk)	***CYP2D6***
omeprazole (Prilosec, Zegerid, OmePPi)	***CYP2C19***
ondansetron (Zuplenz, Zofran)	***CYP2D6***
oxazepam (Serax)	*UGT2B15*
oxcarbazepine (Trileptal)	***HLA-B*15:02, HLA-A*31:01***
pantoprazole (Protonix)	***CYP2C19***
paroxetine (Paxil)	***CYP2D6***
pazopanib (Votrient)	***HLA-B*57:01, UGT1A1***
PEG interferon-alpha	***IFNL3 (IL28B)***
perphenazine (Trilafon)	***CYP2D6***
phenytoin (Phenytek, Dilantin)	***CYP2C9, HLA-B*15:02***
pimozide (Orap)	***CYP2D6,*** *CYP1A2, CYP3A4*
piroxicam (Feldene)	***CYP2C9***
pitavastatin (Livalo)	***SLCO1B1***
pitolisant (Wakix)	***CYP2D6***
pravastatin (Pravachol)	***SLCO1B1***
primaquine	***G6PD***
procainamide	***NAT2***
propafenone (Rythmol)	***CYP2D6***
propranolol (Inderal, Innopran)	***CYP2D6***
protriptyline (Vivactil)	***CYP2D6***
quetiapine (Seroquel)	*CYP3A4, CYP3A5, ANKK1*
rabeprazole (AcipHex)	***CYP2C19***
raltegravir (Isentress)	***UGT1A1***
rasburicase	***G6PD***
risperidone (Risperdal)	***CYP2D6,*** *DRD2, ANKK1*
rosuvastatin (Crestor)	***SLCO1B1, ABCG2***
sacituzumab govitecan-hziy (Trodelvy)	***UGT1A1***

Drug	Genes and/or HLA Alleles
sertraline (Zoloft)	***CYP2C19, CYP2B6***
simvastatin (FloLipid, Zocor)	***SLCO1B1***
siponimod (Mayzent)	***CYP2C9***
sulfamethoxazole/trimethoprim (Bactrim, Sulfatrim)	***NAT2***
sulfasalazine (Azulfidine)	***NAT2***
tacrolimus (Envarsus, Protopic, Astagraf)	***CYP3A5***
tafenoquine	***G6PD***
tamoxifen (Nolvadex, Soltamox)	***CYP2D6* activates**
tamsulosin (Flomax)	***CYP2D6***
tegafur	***DPYD***
tenoxicam (Mobiflex)	***CYP2C9***
tetrabenazine (Xenazine)	***CYP2D6***
thioguanine (Tabloid)	***TPMT, NUDT15***
thioridazine (Mellaril)	***CYP2D6***
tolterodine (Detrol)	***CYP2D6***
toluidine blue	***G6PD***
tramadol (Ultram, ConZip)	***CYP2D6* activates**
trazodone (Desyrel)	*CYP3A4*
triazolam (Halcion)	*CYP3A4*
trimipramine (Surmontil)	***CYP2D6, CYP2C19***
tropisetron	***CYP2D6***
valbenazine (Ingrezza)	***CYP2D6,*** *CYP3A4* **activates**
venlafaxine (Effexor)	***CYP2D6***
vilazodone (Viibryd)	*CYP3A4*
viloxazine (Qelbree)	***CYP2D6***
voriconazole (Vfend)	***CYP2C19***
vortioxetine (Trintellix)	***CYP2D6***
warfarin (Coumadin, Jantoven)	***CYP2C9, VKORC1, CYP4F2, rs12777823***
ziprasidone (Geodon)	*CYP3A4*
zolpidem (Ambien)	*CYP3A4*

Table 2: Inducers and Inhibitors of Cytochrome P450 (CYP) Enzymes

Note: The extent of induction or inhibition is not well-defined for all medications. This is intended to be an educational guide, not an exhaustive list of all inhibitors and inducers. This information, which is based on the FDA drug labels and literature, should be confirmed prior to use in a clinical setting.

Drug	Induces	Inhibits
abiraterone (Yonsa, Zytiga)		CYP2C8, CYP2D6
amiodarone (Nexterone, Pacerone)		CYP1A2, CYP2C9, CYP2D6, and CYP3A
aprepitant (Emend)	CYP3A4, CYP2C9	CYP3A4
armodafinil (Nuvigil)	CYP1A2, CYP3A	CYP2C19
atazanavir (Reyataz)		CYP3A, UGT1A1, CYP2C8
barbiturates	CYP3A4/5	
brigatinib (Alunbrig)	CYP3A	
broccoli	CYP1A2	
brussel sprouts	CYP1A2	
buprenorphine (Belbuca, Probuphine, Buprenex)		CYP3A4 (strong), CYP2D6
bupropion (Wellbutrin, Aplenzin)		CYP2D6 (strong)
cannabidiol (CBD)		CYP1A2, CYP2C9, CYP2C19, CYP3A
capecitabine (Xeloda)		CYP2C9
carbamazepine (Tegretol, Equetro, Tegretol)	CYP1A2, CYP2B6, CYP2C9, CYP2C19, CYP3A (strong)	
celecoxib (Celebrex)		CYP2D6
ceritinib (Zykadia)		CYP2C9, CYP3A (strong)
char-grilled meats	CYP1A2	
chloramphenicol		CYP2C19, CYP3A4/5
chlorpromazine		CYP2D6
cimetidine (Tagamet)		CYP1A2, CYP2C19, CYP2D6, CYP3A4/5
cinacalcet (Sensipar)		CYP2D6 (strong)
ciprofloxacin (Cetraxal, Cipro, Otiprio)		CYP1A2 (strong)
citalopram (Celexa)		CYP1A2, CYP2D6, CYP2C19
clarithromycin		CYP3A4 (strong)
clemastine (Dayhist)		CYP2D6
clobazam (Onfi)		CYP3A4, CYP2D6
clomipramine (Anafranil)		CYP2D6
clopidogrel (Plavix)		CYP2C8
cocaine		CYP2D6
dabrafenib (Tafinlar)	CYP3A4, CYP2B6, CYP2C9	
dasatinib (Sprycel)		CYP3A4
delavirdine (Rescriptor)		CYP3A (strong), CYP2C9, CYP2C19, CYP2D6

Table 2: Inducers and Inhibitors of Cytochrome P450 (CYP) Enzymes (continued)

Drug	Induces	Inhibits
diltiazem (Cartia, Tiazac, Cardizem, Matzim, Cardizem, Taztia)		CYP3A4
diphenhydramine (Benadryl, Nytol, Banophen)		CYP2D6
doxepin (Silenor, Zonalon, Prudoxin)		CYP2D6
dronedarone (Multaq)		CYP2D6, CYP3A4/5
duloxetine (Irenka, Cymbalta)		CYP1A2, CYP2D6
efavirenz (Sustiva)	CYP3A4, CYP2B6	CYP1A2, CYP2C9
elagolix (Orilissa)	CYP3A	CYP2C19
entrectinib (Rozlytrek)		CYP3A4/5
enzalutamide (Xtandi)	CYP2C9, CYP2C19, CYP3A4/5 (strong)	
erythromycin		CYP3A4
escitalopram (Lexapro)		CYP3A
eslicarbazepine (Aptiom, Zebinix)	CYP3A4	CYP2C19
esomeprazole (Nexium)		CYP2C19, CYP3A4/5
felbamate (Felbatol)		CYP2C19
fenofibrate (Triglide, Fibricor, Lipofen)		CYP2A6, CYP2C8, CYP2C9, CYP2C19
fluconazole (Diflucan)		CYP2C9 (strong), CYP3A4
fluoxetine (Prozac, Sarafem)		CYP2D6 (strong)
fluvastatin (Lescol)		CYP2C9
fluvoxamine (Luvox)		CYP1A2 (strong), CYP2C9, CYP2C19, CYP2D6, CYP3A4
fosamprenavir (Lexiva)	CYP3A4	CYP3A4
furafylline		CYP1A2
grapefruit juice		CYP3A4/5
haloperidol (Haldol)		CYP2D6
hydroxyzine (Vistaril, Atarax)		CYP2D6
idelalisib (Zydelig)	CYP2B6	CYP2C8, CYP2C19, UGT1A1
imatinib (Gleevec)		CYP2C9 (strong), CYP2D6 (strong), CYP3A4/5 (strong)
indinavir (Crixivan)		CYP3A4 (strong)
insulin	CYP1A2	
isoniazid		CYP2C9, CYP2C19
itraconazole (Sporanox, Onmel, Sporanox, Pulsepak)		CYP3A4 (strong)
ivacaftor (Kalydeco)		CYP3A, CYP2C9
ketoconazole (Nizoral, Xolegel, Extina)		CYP3A4 (strong)
lapatinib (Tykerb)		CYP2C8, CYP3A4
letermovir (Prevymis)	CYP3A, CYP2B6	CYP2C8, CYP3A4

Table 2: Inducers and Inhibitors of Cytochrome P450 (CYP) Enzymes (continued)

Drug	Induces	Inhibits
lorcaserin (Belviq)		CYP2D6
lorlatinib (Lorbrena)	CYP3A, CYP2B6	
luliconazole (Luzu)		CYP2C19
methadone (Diskets, Methadose)		CYP2D6
methoxsalen (Oxsoralen-Ultra)		CYP1A2
metronidazole (Metrogel, Nuvessa, MetroCream)		CYP2C9
mifepristone (Korlym, Mifeprex)		CYP3A4
moclobemide (Amira, Aurorix, Clobemix, Depnil, Manerix)		CYP2D6
modafinil (Provigil)	CYP1A2, CYP2B6, CYP3A	CYP2C19
nafcilllin	CYP1A2	
nefazodone		CYP3A4 (strong)
nelfinavir (Viracept)		CYP3A4 (strong)
netupitant		CYP3A4/5
nevirapine (Viramune)	CYP2B6, CYP3A	
nilotinib (Tasigna)	CYP2B6, CYP2C8	CYP2C8, CYP2D6, UGT1A1
norethindrone	CYP2C19	
norfloxacin (Noroxin)		CYP3A4/5
norfluoxetine (Seproxetine)		CYP3A4/5
omeprazole (Prilosec, Zegerid, OmePPi)		CYP2C19
oritavancin (Orbactiv)	CYP2D6, CYP3A4	CYP1A2, CYP2B6, CYP2C9, CYP2C19, CYP2D6, CYP3A4
oxcarbazepine (Trileptal, Oxtellar)	CYP3A4/5	CYP2C19
panobinostat (Farydak)		CYP2C19, CYP2D6, CYP3A4
pantoprazole (Protonix)		CYP2C19
paroxetine (Paxil, Pexeva)		CYP2D6 (strong)
pazopanib (Votrient)	CYP3A4	CYP1A2, CYP2B6, CYP2C8, CYP2C9, CYP2C19, CYP2D6, CYP2E1, CYP3A4
perampanel (Fycompa)	CYP2B6, CYP3A4/5, UGT1A1, UGT1A4	CYP2C8, CYP3A4, UGT1A9, and UGT2B7
perphenazine		CYP2D6
phenobarbital (Luminal)	CYP2B6, CYP2C9, CYP3A4/5	
phenytoin (Phenytek, Dilantin)	CYP2B6, CYP3A4/5	
pioglitazone (Actos)	CYP3A4/5	
prednisone	CYP2C19	
quercetin		CYP1A2, CYP2C9, CYP2C19, CYP3A4/5
quinidine		CYP2D6 (strong)
quinine sulfate		CYP3A4, CYP2D6

Table 2: Inducers and Inhibitors of Cytochrome P450 (CYP) Enzymes (continued)

Drug	Induces	Inhibits
rabeprazole (AcipHex)		CYP2C19
regorafenib (Stivarga)		CYP2B6,CYP2C8, CYP2C9, CYP2C19, CYP3A4
ribociclib (Kisqali)		CYP1A2, CYP2E1, CYP3A4/5
rifabutin (Mycobutin)	CYP3A	
rifampin (Rifadin)	CYP1A2, CYP2B6, CYP2C8, CYP2C9, CYP2C19, CYP3A4, UGT	
rifapentine (Priftin)	CYP3A, CYP2C8, CYP2C9	
ritonavir (Norvir)	CYP1A2, CYP2B6, CYP2C9, CYP2C19, CYP3A	
roflumilast (Daliresp)	CYP2B6	
rolapitant (Varubi)		CYP2D6
rucaparib (Rubraca)	CYP1A2	CYP2C8, CYP2D6
saquinavir (Invirase)		CYP3A4 (strong)
secobarbital (Seconal)	CYP2C9	
sertraline (Zoloft)		CYP2D6
simeprevir (Olysio)		CYP1A2, CYP3A4/5
St. John's Wort	CYP2C9, CYP2C19, CYP3A4/5	
starfruit		CYP3A4/5
stiripentol (Diacomit)	CYP1A2, CYP2B6, CYP3A4	CYP1A2, CYP2B6, CYP2C8, CYP2C19, CYP3A4
sulfamethoxazole (Bactrim, Sulfatrim)		CYP2C9
sulfaphenazole		CYP2C9 (strong)
telithromycin (Ketek)		CYP3A4/5 (strong)
telotristat (Xermelo)	CYP3A4/5	
terbinafine		CYP2D6
teriflunomide (Aubagio)	CYP1A2	CYP2C8
thiotepa (Tepadina)		CYP2B6
ticagrelor (Brilinta)	CYP3A5	CYP3A4
ticlopidine (Ticlid)		CYP2C19
tobacco	CYP1A2	
topiramate (Trokendi, Qudexy, Topamax)		CYP2C9
tucatinib (Tukysa)		CYP2C8, CYP3A (strong)
vemurafenib (Zelboraf)		CYP1A2, CYP2A6, CYP2B6, CYP2C8, CYP2C9, CYP2C19, CYP2D6, CYP3A4/5
verapamil (Calan, Verelan)		CYP3A4
voriconazole (Vfend)		CYP2C9, CYP2C19, CYP3A4 (strong)
zafirlukast (Accolate)		CYP2C9, CYP3A4

Appendix 1: Links to publicly available information about drugs and pharmacogenomically relevant genes

FDA Table of Pharmacogenetic Associations: www.fda.gov/medical-devices/precision-medicine/table-pharmacogenetic-associations

At the time that this document was written, this link contained three tables that stratify pharmacogenetic associations according to those supported by data for therapeutic management recommendations, those with a potential impact on safety or response, and associations where the data only suggests a potential impact on pharmacokinetic properties. While the FDA tables are regularly updated and provide basic information on specific phenotypes and/or variants, review of the FDA label is recommended. Dailymed is an online resource to review FDA label information.

Dailymed: dailymed.nlm.nih.gov/dailymed/

Dailymed provides access to the latest drug labels. By typing in the proprietary or generic drug name and clicking on Search, a list of labels is generated from which to choose. The PDF of the label can be opened. Generally, most pharmacogenomically relevant information will be found in the Dosage and Administration section, Section 8: "Use in Specific Populations," and Section 12: "Clinical Pharmacology." In addition, searching the document for key words such as "pharmacogenomics," "pharmacogenetics," or specific enzyme names (eg, CYP2D6) is helpful.

Clinical Pharmacogenetics Implementation Consortium (CPIC): cpicpgx.org

CPIC is an international consortium interested in the facilitating the use of pharmacogenomic tests for patient care. The consortium reviews gene-drug pairs and stratifies them based upon the level of evidence. Those with the strongest associations are published in peer-reviewed journals with guidance on how to use the pharmacogenomic information. By clicking on the "Genes-Drugs" link, the articles can be viewed and downloaded. This information may help guide treatment decisions, and is useful in discussions with patients and insurers.

Pharmacogenomics Knowledge Base (PharmGKB): www.pharmgkb.org

PharmGKB is a comprehensive resource that curates knowledge about the impact of genetic variation on drug response for clinicians and researchers. By clicking on the "Clinical Guideline Annotations," the clinician can see a side-by-side listing of guidelines published by CPIC and the Royal Dutch Association for the Advancement of Pharmacy-Pharmacogenetics Working Group (DPWG), as well as other organizations, such as the European Medicines Agency (EMA), Swiss Agency of Therapeutic Products (Swissmedic), Pharmaceuticals and Medical Devices Agency – Japan (PMDA), and Health Canada (Sante Canada) (HCSC), all of which publish best practices in pharmacogenomics. PharmGKB also publishes many pharmacokinetic and pharmacodynamic pathways that aid in understanding the ways the body metabolizes medications and drug targets.