Medical Policy

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Title: Cytochrome p450 Genotype-Guided Treatment Strategy

Related Policies	▪ *Genetic Testing for Diagnosis and Management of Mental Health Conditions*

Professional / Institutional
Original Effective Date: February 25, 2010 / November 29, 2010
Latest Review Date: August 11, 2026
Current Effective Date: September 8, 2022

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Populations	Interventions	Comparators	Outcomes
Individuals: • With need for antiplatelet therapy who are undergoing or being considered for clopidogrel therapy	Interventions of interest are: • CYP2C19-guided treatment strategy	Comparators of interest are: • Clinically guided management	Relevant outcomes include: • Overall survival • Medication use • Treatment-related morbidity
Individuals: • Who are undergoing or being considered for treatment with highly active antiretroviral agents	Interventions of interest are: • CYP450-guided treatment strategy	Comparators of interest are: • Clinically guided management	Relevant outcomes include: • Medication use • Treatment-related morbidity

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Populations	Interventions	Comparators	Outcomes
Individuals: • Who are undergoing or being considered for treatment with immunosuppressant therapy for organ transplantation	Interventions of interest are: • CYP450-guided treatment strategy	Comparators of interest are: • Clinically guided management	Relevant outcomes include: • Medication use • Treatment-related morbidity
Individuals: • Who are undergoing or being considered for treatment with beta-blockers	Interventions of interest are: • CYP450-guided treatment strategy	Comparators of interest are: • Clinically guided management	Relevant outcomes include: • Medication use • Treatment-related morbidity
Individuals: • Who are undergoing or being considered for treatment with antitubercular medications	Interventions of interest are: • CYP450-guided treatment strategy	Comparators of interest are: • Clinically guided management	Relevant outcomes include: • Medication use • Treatment-related morbidity

DESCRIPTION

The cytochrome P450 (CYP450) family is involved in the metabolism of many currently administered drugs, and genetic variants in CYP450 are associated with altered metabolism of many drugs. Testing for CYP450 variants may assist in selecting and dosing drugs affected by these genetic variants.

OBJECTIVE

The objective of this evidence review is to evaluate whether testing for cytochrome P450 variants improves the net health outcome by influencing the selection and dosing of drugs metabolized by cytochrome P450 enzymes.

BACKGROUND

Drug Efficacy and Toxicity

Drug efficacy and toxicity vary substantially across individuals. Because drugs and doses are typically adjusted, if needed, by trial-and-error, clinical consequences may include a prolonged time to optimal therapy. In some cases, serious adverse events may result.

Multiple factors may influence the variability of drug effects, including age, liver function, concomitant diseases, nutrition, smoking, and drug-drug interactions. Inherited (germline) DNA sequence variation in genes coding for drug-metabolizing enzymes, drug receptors, drug transporters, and molecules involved in signal transduction pathways also may have major effects on the activity of those molecules and thus on the efficacy or toxicity of a drug.

Pharmacogenomics studies how an individual's genetic inheritance affects the body's response to drugs. It may be possible to predict therapeutic failures or severe adverse drug reactions in individual patients by testing for important DNA variants (genotyping) in genes related to the

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metabolic pathway (pharmacokinetics) or signal transduction pathway (pharmacodynamics) of the drug. Potentially, test results could be used to optimize drug choice and/or dose for more effective therapy, avoid serious adverse events, and decrease medical costs.

Cytochrome P450 System

The cytochrome P450 (CYP450) family is a major subset of all drug-metabolizing enzymes; several CYP450 enzymes are involved in the metabolism of a significant proportion of currently administered drugs. CYP2D6 metabolizes approximately 25% of all clinically used medications (eg, dextromethorphan, β-blockers, antiarrhythmics, antidepressants, morphine derivatives), including most prescribed drugs. CYP2C19 metabolizes several important types of drugs, including proton pump inhibitors, diazepam, propranolol, imipramine, and amitriptyline.

Some CYP450 enzymes are highly polymorphic, resulting in some enzyme variants that have variable metabolic capacities among individuals, and some with little to no impact on activity. Thus, CYP450 enzymes constitute an important group of drug-gene interactions influencing the variability of the effect of some CYP450-metabolized drugs.

Individuals with 2 copies (alleles) of the most common (wild-type) DNA sequence of a particular CYP450 enzyme gene resulting in an active molecule are termed extensive metabolizers (EMs; normal). Poor metabolizers (PMs) lack active enzyme gene alleles, and intermediate metabolizers, who have 1 active and 1 inactive enzyme gene allele, may experience to a lesser degree some of the consequences of PMs. Ultrarapid metabolizers (UMs) are individuals with more than 2 alleles of an active enzyme gene. There is pronounced ethnic variability in the population distribution of metabolizer types for a given CYP enzyme.

UMs administered an active drug may not reach therapeutic concentrations at usual recommended doses of active drugs, while PMs may suffer more adverse events at usual doses due to reduced metabolism and increased concentrations. Conversely, for administered prodrugs that must be converted by CYP450 enzymes into active metabolites, UMs may suffer adverse events, and PMs may not respond.

Many drugs are metabolized to varying degrees by more than one enzyme, either within or outside of the CYP450 superfamily. Also, the interaction between different metabolizing genes, the interaction between genes and environment, and interactions among different nongenetic factors also influence CYP450-specific metabolizing functions. Thus, identification of a variant in a single gene in the metabolic pathway may be insufficient in all but a small proportion of drugs to explain interindividual differences in metabolism and consequent efficacy or toxicity.

Determining Genetic Variability in Drug Response

Genetically determined variability in drug response has been traditionally addressed using a trial-and-error approach to prescribing and dosing, along with therapeutic drug monitoring for drugs with a very narrow therapeutic range and/or potentially serious adverse events outside that range. However, therapeutic drug monitoring is not available for all drugs of interest, and a cautious trial-and-error approach can lengthen the time to achieving an effective dose.

CYP450 enzyme phenotyping (identifying metabolizer status) can be accomplished by administering a test enzyme substrate to a patient and monitoring parent substrate and

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metabolite concentrations over time (eg, in urine). However, testing and interpretation are time-consuming and inconvenient; as a result, phenotyping is seldom performed.

The clinical utility of *CYP450* genotyping (ie, the likelihood that genotyping will significantly improve drug choice, dosing, and patient outcomes) may be favored when the drug under consideration has a narrow therapeutic dose range, when the consequences of treatment failure are severe, and/or when serious adverse reactions are more likely in patients with gene sequence variants. Under these circumstances, genotyping may direct early selection of the most effective drug or dose, and/or avoid drugs or doses likely to cause toxicity. For example, warfarin, some neuroleptics, and tricyclic antidepressants have narrow therapeutic windows and can cause serious adverse events when concentrations exceed certain limits, resulting in cautious dosing protocols. The potential severity of the disease condition may call for immediate and sufficient therapy; genotyping might speed up the process of achieving a therapeutic dose and avoiding significant adverse events.

REGULATORY STATUS

Clinical laboratories may develop and validate tests in-house and market them as a laboratory service; laboratory-developed tests must meet the general regulatory standards of the Clinical Laboratory Improvement Amendments (CLIA). Diagnostic genotyping tests for certain CYP450 enzymes are available under the auspices of the CLIA. Laboratories that offer laboratory-developed tests must be licensed by the CLIA for high-complexity testing. To date, the U.S. Food and Drug Administration (FDA) has chosen not to require any regulatory review of this test.

Several testing kits for *CYP450* genotyping cleared for marketing by the FDA (FDA product code: NTI) are summarized in Table 1.

Table 1. Selected Testing Kits for *CYP450* Genotyping Cleared for Marketing by the Food and Drug Administration

Device Name	Manufacturer	Approval Date
Genomadix Cube CYP2C19 System	Genomadix Inc.	2023
xTAG Cyp2c19 Kit V3	Luminex Molecular Diagnostics (now Diasorin)	2013
Spartan Rx Cyp2c19 Test System	Spartan Bioscience	2013
Verigene Cyp2c19 Nucleic Acid Test (2c19)	Nanosphere	2012
Infiniti Cyp2c19 Assay	AutoG enomics	2010
xTAG Cyp2d6 Kit V3, Model I030c0300 (96)	Luminex Molecular Diagnostics	2010
Invader Ugt1a1 Molecular Assay	Third Wave Technologies (now Hologic)	2005
Roche AmpliChip Cyp450 Test	Roche Molecular Systems	2005

CYP450: cytochrome P450.

Several manufacturers market diagnostic genotyping panel tests for *CYP450* genes, such as the YouScript Panel (Aranscia), which includes *CYP2D6*, *CYP2C19*, *CYP2C9*, *VKORC1*, *CYP3A4*, and *CYP3A5*. Other panel tests include both *CYP450* and other non-*CYP450* genes involved in drug

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metabolism, such as the GeneSight Psychotropic panel (Myriad Genetics). These tests are beyond the scope of this evidence review.

Food and Drug Administration Labeling on *CYP450* Genotyping
The FDA maintains online compendia of pharmacogenetic associations under 3 categories: 1) pharmacogenetic associations for which the data support therapeutic management recommendations; 2) pharmacogenetic associations for which the data indicate a potential impact on safety or response; and 3) pharmacogenetic associations for which the data demonstrate a potential impact on pharmacokinetic properties only.[1,]

The FDA has included pharmacogenomics information in the physician prescribing information (drug labels) of multiple drugs. In most cases, this information is general and lacks specific directives for clinical decision making. In the following examples, the FDA has given clear and specific directives on either use of a specific dose (eg, eliglustat, tetrabenazine) or when a drug may not be used at all (eg, codeine) and therefore evidence in such cases is not reviewed in the Rationale section.

Eliglustat
The FDA has approved eliglustat for treatment of adults with Gaucher disease type 1 who are CYP2D6 EMs, intermediate metabolizers, or PMs as detected by an FDA-cleared test. Further, the label acknowledges the limitation of use among UMs because they may not achieve adequate concentrations and a specific dosage was not recommended for patients with indeterminate CYP2D6 metabolizer status. Further, the label states that the dosing strategy should be 84 mg orally, twice daily for CYP2D6 EMs or intermediate metabolizers and 84 mg orally, once daily for CYP2D6 PMs. [2,]

Tetrabenazine
The FDA has approved tetrabenazine for the treatment of chorea associated with Huntington disease. According to the label, patients requiring doses above 50 mg per day should be genotyped for the drug-metabolizing enzyme CYP2D6 to determine if the patient is a PM or EM. For patients categorized as PMs using an FDA-approved test, the maximum daily dose should not exceed 50 mg, with a maximum single dose of 25 mg. For patients categorized as intermediate metabolizers or EMs, the maximum daily dose should not exceed 100 mg, with a maximum single dose of 37.5 mg.[3,]

Codeine
The FDA does not recommend genotyping before prescribing codeine. The FDA has contraindicated codeine for treating pain or cough in children under 12 years of age and codeine is not recommended for use in adolescents ages 12 to 18 years who are obese or have conditions such as obstructive sleep apnea or severe lung disease. There is an additional warning to mothers not to breastfeed when taking codeine.[4,]

Siponimod
The FDA has approved siponimod for the treatment of relapsing forms of multiple sclerosis, to include clinically isolated syndrome, relapsing-remitting disease, and active secondary progressive disease in adults. The recommended maintenance dosage is 2 mg. The recommended maintenance dosage in patients with a *CYP2C9* 1/*3* or **2/*3* genotype is 1 mg. Siponimod is contraindicated in patients with a *CYP2C9*3/*3* genotype.[5,]

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POLICY

A. CYP2D6 genotyping to determine drug metabolizer status may be considered **medically necessary** for individuals with one of the following:

1. With Gaucher disease being considered for treatment with eliglustat, **OR**
2. With Huntington disease being considered for treatment with tetrabenazine in a dosage greater than 50 mg per day

B. CYP2C9 genotyping to determine drug metabolizer status may be considered **medically necessary** for individuals:

1. With relapsing forms of multiple sclerosis, to include clinically isolated syndrome, relapsing-remitting disease, and active secondary progressive disease, being considered for treatment with siponimod.

C. CYP450 genotyping for the purpose of aiding in the choice of drug or dose to increase efficacy and/or avoid toxicity for the following drugs is considered **experimental / investigational**, aside from determinations in the separate policies noted above:

1. dosing of efavirenz and other antiretroviral therapies for HIV infection
2. dosing of immunosuppressants for organ transplantation
3. selection or dosing of β-blockers (e.g., metoprolol)
4. dosing and management of antitubercular medications
5. selection or dosage of codeine

D. CYP450 genotyping for the purpose of aiding in the choice of clopidogrel versus alternative antiplatelet agents, or in decisions on the optimal dosing for clopidogrel, is considered **experimental / investigational**.

E. The use of genetic testing panels that include multiple CYP450 variants is considered **experimental / investigational**.

POLICY GUIDELINES

A. This policy does not address the use of genetic panel tests for genes other than cytochrome P450 (CYP45) related genes (e.g., the Genecept Assay).

B. The Food and Drug Administration maintains a database of pharmacogenomic biomarkers in drug labeling. See section "Regulatory Status" for details.

Please refer to the member's contract benefits in effect at the time of service to determine coverage or non-coverage of these services as it applies to an individual member.

RATIONALE

This evidence review was created using searches of the PubMed database. The most recent literature update was performed through April 24, 2026.

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The primary goal of pharmacogenomics testing and personalized medicine is to achieve better clinical outcomes in compared with the standard of care. Drug response varies greatly between individuals, and genetic factors are known to play a role. However, in most cases, the genetic variation only explains a modest portion of the variance in the individual response because clinical outcomes are also affected by a wide variety of factors including alternate pathways of metabolism and patient- and disease-related factors that may affect absorption, distribution, and elimination of the drug. Therefore, assessment of clinical utility cannot be made by a chain of evidence from clinical validity data alone. In such cases, evidence evaluation requires studies that directly demonstrate that the pharmacogenomic test alters clinical outcomes; it is not sufficient to demonstrate that the test predicts a disorder or a phenotype.

Evidence reviews assess the clinical evidence to determine whether the use of technology improves the net health outcome. Broadly defined, health outcomes are the length of life, quality of life, and ability to function-including benefits and harms. Every clinical condition has specific outcomes that are important to patients and managing the course of that condition. Validated outcome measures are necessary to ascertain whether a condition improves or worsens; and whether the magnitude of that change is clinically significant. The net health outcome is a balance of benefits and harms.

To assess whether the evidence is sufficient to draw conclusions about the net health outcome of a technology, 2 domains are examined: the relevance, and quality and credibility. To be relevant, studies must represent one or more intended clinical use of the technology in the intended population and compare an effective and appropriate alternative at a comparable intensity. For some conditions, the alternative will be supportive care or surveillance. The quality and credibility of the evidence depend on study design and conduct, minimizing bias and confounding that can generate incorrect findings. The randomized controlled trial (RCT) is preferred to assess efficacy; however, in some circumstances, nonrandomized studies may be adequate. RCTs are rarely large enough or long enough to capture less common adverse events and long-term effects. Other types of studies can be used for these purposes and to assess generalizability to broader clinical populations and settings of clinical practice.

CYTOCHROME P450 GENOTYPE-GUIDED TREATMENT STRATEGY

Clinical Context and Therapy Purpose

The purpose of a cytochrome P450 (*CYP450*) genotype-guided strategy is to tailor selection and dosing of drugs based on gene composition for drug metabolism. In theory, this should lead to early selection and optimal dosing of the most effective drugs, while minimizing treatment failures or toxicities.

The following PICO was used to select literature to inform this review.

Populations

The relevant populations of interest is individuals being considered for treatment with clopidogrel, efavirenz and other antiretroviral therapies for HIV infection, immunosuppressants for organ transplantation, β-blockers (eg, metoprolol), and antitubercular medications.

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Interventions
Commercial tests for individual genes or gene panels are available and are listed in the Regulatory Status section. Only those panels that include *CYP450* genes are listed in that section.

Comparators
The following practice is currently being used: standard clinical management without genetic testing.

Outcomes
Specific outcomes of interest are listed in Table 2.

Table 2. Outcomes of Interest for Individuals With Altered Drug Metabolism

Drug	Outcomes
Clopidogrel	• Initial and maintenance dose selection • Decrease in platelet reactivity • Myocardial infarction, cardiovascular or all-cause death, revascularization, fatal/nonfatal cerebrovascular accident, aortic event
Highly active antiretroviral agents	• Dose selection • Avoidance of treatment failure • Avoidance or reduction of adverse events
Immunosuppressant therapy for organ transplantation	• Dose selection • Avoidance of organ failure • Avoidance or reduction of adverse events
β-blocker(s)	• Dose selection • Superior control of blood pressure • Avoidance or reduction of adverse events due to overtreatment
Antitubercular medications	• Dose selection • Avoidance or reduction of hepatotoxicity due to overtreatment

REVIEW OF EVIDENCE

Clopidogrel
Dual antiplatelet therapy with aspirin and a P2Y12 inhibitor (clopidogrel, prasugrel, ticagrelor) is the standard of care for the prevention of subsequent atherothrombotic events such as stent thrombosis or recurrent acute coronary syndrome in patients who undergo a percutaneous coronary intervention (PCI) or who have an acute coronary syndrome.

Clopidogrel is a prodrug that is converted to its active form by several CYP450 enzymes (particularly CYP2C19). Individuals with genetic variants that inactivate the CYP2C19 enzyme are associated with lack of response to clopidogrel. There are several variants of *CYP2C19* but the 2 most frequent variants associated with loss of function (LOF) alleles are *CYP2C19*2* and *CYP2C19*3*. It is hypothesized that such individuals may benefit from other drugs such as prasugrel or ticagrelor or a higher dose of clopidogrel. Approximately 30% of White and Black

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individuals and 65% of Asians carry a nonfunctional *CYP2C19* gene variant.[6,] While CYP2C19 is the major enzyme involved in the generation of clopidogrel active metabolite, the variability in clinical response seen with clopidogrel may also result from other factors such as variable absorption, accelerated platelet turnover, reduced CYP3A metabolic activity, increased adenosine diphosphate exposure, or upregulation of P2Y12 pathways, drug-drug interactions, comorbidities (eg, diabetes, obesity), and medication adherence.

Multiple observational studies in patients undergoing PCI have reported associations between the presence of LOF alleles and lower levels of active clopidogrel metabolites, high platelet reactivity, and increased risk of adverse cardiovascular events. However, evidence of publication bias has been reported in these studies where smaller studies have reported larger benefits than larger studies which have reported no effect or smaller effect.[7,] Wang et al (2016) reported a post hoc analysis of the Clopidogrel in High-Risk Patients with Acute Nondisabling Cerebrovascular Events trial conducted in China; it randomized patients with a transient ischemic attack (TIA) or minor stroke to clopidogrel plus aspirin or aspirin alone. In a subgroup analysis of patients who did not have the LOF alleles, clopidogrel plus aspirin versus aspirin alone was associated with statistical significant reduction in the risk of stroke (6.7% vs. 12.4%; hazard ratio [HR], 0.51; 95% confidence interval [CI], 0.35 to 0.75) but not among those who carried LOF alleles (9.4% vs. 10.8%; HR, 0.93; 95% CI, 0.69 to 1.26).[8,] Results of this analysis have contributed to the formulation of the hypothesis of a differential effect of clopidogrel in patients with and without LOF alleles.

Trials are important to validate such hypotheses. However, only a few trials of genotype-directed dosing or drug choice have been conducted; they are summarized in Tables 3 and 4 and discussed next. It is important to note that these trials use "high on-treatment platelet reactivity" as the outcome measure. Patients who exhibit "high on-treatment platelet reactivity" are referred to as being nonresponsive, hyporesponsive, or resistant to clopidogrel in the published literature.

Systematic Reviews

Biwas et al (2025) conducted a meta-analysis to evaluate the effect of CYP2C19 genotype status on the efficacy and safety of genotype-guided ticagrelor or prasugrel compared with clopidogrel in patients with transient ischemic attack (TIA) or ischemic stroke (IS) carrying CYP2C19 LOF alleles.[9,] Five RCTs and 1 retrospective cohort comprising 14,124 adults with TIA or non-cardioembolic IS were included, with follow-up ranging from 90 days to approximately 104 weeks. All studies were conducted in either China or Japan. Eligible participants were required to carry CYP2C19 LoF alleles and to receive ticagrelor (90 mg twice daily) or prasugrel (3.75 mg daily), with or without aspirin, compared with clopidogrel (50 to 75 mg daily), with or without aspirin. The primary efficacy outcomes were recurrent stroke and composite vascular events (including ischemic or hemorrhagic stroke, myocardial infarction, or vascular death), while the primary safety outcome was clinically significant bleeding based on standardized criteria. Genotype-guided ticagrelor or prasugrel therapy significantly reduced the risk of composite vascular events compared with clopidogrel (risk ratio [RR], 0.76; 95% CI, 0.66 to 0.89; p = 0.0004) and similarly reduced recurrent stroke (RR, 0.76; 95% CI, 0.64 to 0.90, p = 0.002). There was no statistically significant difference in bleeding risk between treatment strategies (RR , 0.91; 95% CI, 0.65 to 1.27; p = 0.58).

Maas et al (2024) conducted a meta-analysis to evaluate the effect of CYP2C19 genotype status on atherothrombotic events in atherosclerotic diseases such as coronary artery disease (CAD),

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stroke, and peripheral arterial disease (PAD).[10,] The analysis included RCTs published through July 2023 comparing genotype-guided versus standard antithrombotic treatment, cohort studies, and post hoc analyses of RCTs on the association between CYP2C19 genotype and outcomes in clopidogrel-treated patients. Primary endpoints were major adverse cardiovascular events (MACE) and major bleeding, while secondary endpoints included myocardial infarction, stent thrombosis, and ischemic stroke. Forty-four studies were identified: 11 on CAD, 29 on stroke, and 4 on PAD. In CAD, genotype-guided therapy lowered the risk of MACE (RR, 0.60; 95% CI 0.43 to 0.83), myocardial infarction (RR, 0.53; 95% CI, 0.42 to 0.68), and stent thrombosis (RR, 0.64; 95% CI, 0.43 to 0.94) compared to standard treatment. Major bleeding rates showed no significant difference (RR, 0.93; 95% CI, 0.70 to 1.23). Stroke patients with LOF alleles had higher MACE (RR, 1.61; 95% CI, 1.25 to 2.08) and recurrent ischemic stroke risks (RR, 1.89; 95% CI, 1.48 to 2.40), with no difference in major bleeding (RR, 0.90; 95% CI, 0.43 to 1.89). In the 6955 patients with symptomatic PAD treated with clopidogrel in the EUCLID trial,[11,] no differences were observed in MACE or major bleeding between LOF carriers and non-carriers. There were several limitations in this meta-analysis included heterogeneity in studies on CAD and cerebrovascular disease for MACE and cardiovascular death, varied definitions of MACE and major bleeding, different CYP2C19 genotype classifications, drug dosage differences, varied follow-up durations, unspecified stroke types in many studies, and RCTs only in CAD, none in PAD and few in cerebrovascular disease. Cohort studies and post hoc RCT analyses were used for these latter two populations.

The American Heart Association (2024) conducted a review of clinical trials and meta-analyses in support of their scientific statement on *CYP2C19* genetic testing for P2Y12 inhibitor therapy.[12,]A review was undertaken of recent RCTs (reviewed below) that specifically evaluated the clinical impact of genetic-guided versus standard or conventional oral P2Y12 inhibitor therapy (clopidogrel, prasugrel, ticagrelor). The essential points from the AHA scientific statement on *CYP2C19* genetic testing for P2Y12 inhibitor therapy are summarized in the Supplemental Information section.

Randomized Controlled Trials

Roberts et al (2012) reported on the results of an RCT that allocated patients undergoing PCI for acute coronary syndrome or stable angina to genotype-guided management to select for treatment with prasugrel (carriers) or clopidogrel (noncarriers) or to standard treatment with clopidogrel.[13,] Among those who received prasugrel and clopidogrel based on genotyping test, 0% and 10%, respectively, exhibited high on-treatment platelet reactivity while 17% of patients who received standard treatment with clopidogrel without any genotypes testing exhibited high on-treatment platelet reactivity. This difference was not statistically significant.

So et al (2016) reported on the results of an RCT that randomized patients with ST-elevation myocardial infarction who were carriers of *CYP2C19*2*, *ABCB1* TT, and *CYP2C19*17* alleles to prasugrel 10 mg daily or an augmented dosing strategy of clopidogrel (150 mg per day for 6 days and subsequently 75 mg per day).[14,] Results showed that (1) carriers did not respond to augmented clopidogrel as well as they did to prasugrel (24% patients with high platelet reactivity vs. 0%) and (2) among noncarriers, physician-directed clopidogrel was effective for most patients (95% did not have high platelet reactivity).

Claassens et al (2019) reported on the results of the CYP2C19 Genotype Guided Treatment With Antiplatelet Drugs in Patients With ST-segment-elevation Myocardial Infarction Undergoing

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Immediate PCI With Stent Implantation: Optimization of Treatment (POPular Genetics) trial.[15,] In this non-inferiority trial, patients with acute coronary syndrome were randomly assigned to receive standard treatment (prasugrel or ticagrelor) or genotype-guided treatment (clopidogrel in those without *CYP2C19* LOF variants; standard treatment otherwise). Results of the primary combined endpoint met the P value for non-inferiority. Thus, one can conclude that a genotype guided strategy led to outcomes that were at least as good as, if not better than, outcomes with the standard approach of prescribing prasugrel or ticagrelor to all patients. However, the trial results do not inform whether using genotype based strategy for prescribing clopidogrel results in any incremental net health benefit versus standard treatment with clopidogrel. Furthermore, there was no difference in the incidence of PLATelet inhibition and patient Outcomes (PLATO) major bleeding between the genotype-guided group and the standard-treatment group (2.3% in both groups; HR, 0.97; 95% CI, 0.58 to 1.63). The statistically significant difference observed in the primary bleeding outcome was primarily driven by PLATO minor bleeding events in the genotype-guided group versus standard-treatment group (7.6% vs. 10.5%; HR, 0.72; 95% CI, 0.55 to 0.94).

Pereira et al (2021) reported the results of the open-label randomized TAILOR-PCI trial of 5302 patients undergoing PCI for acute coronary syndromes or stable coronary artery disease.[16,] The genotype-guided group underwent point-of-care genotyping for detection of *CYP2C19* carriers and were prescribed ticagrelor (prasugrel was recommended as an alternative for patients who did not tolerate ticagrelor) and noncarriers were prescribed clopidogrel. Patients randomized to the conventional group were prescribed clopidogrel and underwent genotyping after 12 months. Among 5302 patients randomized (median age, 62 years; 25% women), 94% completed the trial. Of 1849 *CYP2C19* carriers, 764 of 903 (85%) assigned to genotype-guided therapy received ticagrelor, and 932 of 946 (99%) assigned to conventional therapy received clopidogrel. The primary end point (a composite of cardiovascular death, myocardial infarction, stroke, stent thrombosis, and severe recurrent ischemia at 12 months) occurred in 35 of 903 *CYP2C19* carriers (4.0%) in the genotype-guided therapy group and 54 of 946 (5.9%) in the conventional therapy group at 12 months (HR, 0.66; 95% CI, 0.43 to 1.02; p=.06). None of the 11 prespecified secondary end points showed significant differences, including major or minor bleeding in *CYP2C19* carriers in the genotype-guided group (1.9%) versus the conventional therapy group (1.6%) at 12 months (HR, 1.22; 95% CI, 0.60 to 2.51; p=.58). Among all randomized patients, the primary end point occurred in 113 of 2641 (4.4%) in the genotype-guided group and 135 of 2635 (5.3%) in the conventional group (HR, 0.84; 95% CI, 0.65 to 1.07; p=.16). The trial failed to meet the pre-specified end point and the authors contend that the trial was underpowered to detect an effect size less than the 50% relative risk after a revised sample calculation. Despite the occurrence of 89 ischemic events observed in this trial, which exceeded the 76 events anticipated to provide adequate power, the observed relative risk reduction was 34% instead of the estimated 50%, hence a borderline p value of.056 was observed. Further, the authors also comment that the potential benefit of genotype-guided oral P2Y12 inhibitor therapy may be important early after PCI rather than 12 months after PCI. A post-hoc analysis of the data from the trial showed that a nearly 80% reduction in the rate of adverse events occurred in the first three months of treatment among patients who received genetically guided therapy compared with those who did not.

Wang et al (2021) published results of the Ticagrelor versus Clopidogrel in CYP2C19 Loss-of-Function Carriers with Stroke or TIA (CHANCE-2) trial.[17,] This double-blind, multicenter RCT in China compared ticagrelor and clopidogrel for the secondary prevention of stroke in individuals

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with minor ischemic stroke or TIA who were CYP2C19 LOF carriers. Overall, 6412 individuals (98% Chinese) with ischemic stroke or TIA were determined to be LOF carriers and were included and randomized 1:1 to receive either ticagrelor or clopidogrel for 90 days duration. All patients received aspirin for the first 21 days. The median time from symptom onset to randomization was 14 hours and the average turnaround time of point-of-care testing was 80.3 minutes. Of those included, 5001 (78%) were intermediate metabolizers and 1411 (22%) were poor metabolizers. A primary-outcome event of new ischemic or hemorrhagic stroke within 90 days occurred in 191 (6.0%) patients in the ticagrelor group and 243 (7.6%) patients in the clopidogrel group (HR, 0.77; 95% CI, 0.64 to 0.94). Severe or moderate bleeding occurred in 9 (0.3%) patients on ticagrelor and 11 (0.3%) on clopidogrel. Any bleeding event occurred in 170 (5.3%) patients and 80 (2.5%) patients in the ticagrelor and clopidogrel groups, respectively. In subgroup analysis, the primary outcome benefit with ticagrelor was consistent in individuals who were intermediate metabolizers (150 vs. 191 events; HR, 0.78; 95% CI, 0.63 to 0.97), but not in poor metabolizers (41 vs. 52 events; HR, 0.77; 95% CI, 0.50 to 1.18). The risk of recurrent stroke within 90 days among Chinese LOF carriers was modestly lower with ticagrelor than with clopidogrel, without an increased risk of severe or moderate bleeding. Ticagrelor was associated with more total bleeding events compared to clopidogrel. This study is limited by its homogenous study population, making generalizability to populations other than Han Chinese patients difficult. Additionally, no patients with delayed presentation after stroke, receipt of thrombolysis, or cardioembolic stroke were included. One-year follow-up data were published by Meng et al (2024).[18,] At 1 year, 7.91% of patients in the ticagrelor and 9.73% of patients in the clopidogrel group had a new stroke (HR, 0.80; 95% CI, 0.68 to 0.95; p=.007); however, new stroke occurring between 3 months and 1 year was not difference between groups (2.07% vs. 2.32%; p=.48).

Table 3. Summary of Key Randomized Controlled Trial Characteristics

Study	Countries	Sites	Dates	Participants	Interventions	
					Active	**Comparator**
So et al (2016)[14,]; RAPID STEMI	Canada	1	2011 - 2012	18 to 75 y who had PCI for STEMI who received POC testing for *CYP2C19*2*, *ABCB1* TT, and *CYP2C19*17* alleles (N=102)	Carriers randomized to prasugrel 10 mg/d (n=30) or augmented clopidogrel (150 mg/d for 6 d and then 75 mg/d) (n=29)	Noncarriers given clopidogrel with dosing as per treating physician (n=43)
Roberts et al (2012)[13,]; RAPID GENE	Canada	1	2010 - 2011	18 to 75 y undergoing PCI for acute coronary syndrome or stable angina (N=200)	POC testing for *CYP2C19*2* allele (n=102). Of these, 23 carriers were given prasugrel 10 mg/d, and 74 noncarriers were given clopidogrel 75 mg/d.	No genetic testing and clopidogrel 75 mg/d
Claassens et al (2019);[15,];	Europe	10	2011 - 2018	21 y or older with signs and symptoms of STEMI	Genotype-guided group: Individuals received clopidogrel (non-carriers)	Prasugrel/ticagrelor for one year

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Study	Countries	Sites	Dates	Participants	Interventions	
POPular Genetics				undergoing PCI (N=2488)	or prasugrel/ticagrelor (carriers) for one year	
Pereira et al (2021)[16]; TAILOR PCI	US, Canada, South Korea, and Mexico	40	2013 - 2018	Adult undergoing PCI for ACS or stable CAD (N=5302).	Genotype-guided therapy group using POC genotyping. *CYP2C19* carriers were prescribed ticagrelor for maintenance therapy, and noncarriers or those with inconclusive results were prescribed clopidogrel. Prasugrel was recommended as an alternative for patients who did not tolerate ticagrelor (n=2653 randomized; n=2641eligible for analysis; n=903 *CYP2C19* carriers identified and included in primary analysis).	Conventional therapy group without prospective genotyping. All were prescribed clopidogrel according to drug label (n=2650 randomized; n=2635 eligible for analysis; n=946 *CYP2C19* carriers identified and included in primary analysis).
Wang et al (2021)[17]; CHANCE-2	China	202	2019 - 2021	Individuals (median age, 64.8 years; 33.8% female; 98% Chinese) with minor ischemic stroke or TIA who carried *CYP2C19* LOF alleles (N=6412)	Ticagrelor (180 mg loading dose on day 1, followed by 90 mg twice daily on days 2 through 90) and aspirin for the first 21 days (n=3205)	Clopidogrel (300 mg loading dose on day 1, followed by 75 mg daily on days 2 through 90) and aspirin for the first 21 days (n=3207)

ACS: acute coronary syndrome; CAD: coronary artery disease; CHANCE-2: Ticagrelor or Clopidogrel with Aspirin in High-Risk Patients with Acute Nondisabling Cerebrovascular Events II trial; CYP: cytochrome P450; LOF: loss-of-function; PCI: Percutaneous coronary intervention; POC; point of care; POPular Genetics: Cost-effectiveness of CYP2C19 Genotype Guided Treatment With Antiplatelet Drugs in Patients With ST-segment-elevation Myocardial Infarction Undergoing Immediate PCI With Stent Implantation: Optimization of Treatment; RAPID GENE: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy Based on GENetic Evaluation; RAPID STEMI: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy in Patients With ST-segment Elevation Myocardial Infarction; STEMI: ST-elevation myocardial infarction; TIA: transient ischemic attack.

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Table 4. Summary of Key Randomized Controlled Trial Results

Study	Outcome			
	High Platelet Reactivity[a]	**New stroke within 90 days, n (%)**	**Severe or moderate bleeding within 90 days, n (%)**	**Any bleeding, n (%)**
So et al (2016)[14,]; RAPID STEMI	N=102	NA	NA	NA
Carriers				
Prasugrel	0%[d]			
Augmented clopidogrel	24%[d]			
Noncarriers				
Clopidogrel as per treating physician	5%[d]			
p	.0046[b];.507[c]			
Roberts et al (2012)[13,]; RAPID GENE	N=187	NA	NA	NA
Genotype-guided management				
Prasugrel 10 mg/d	0%			
Clopidogrel 75 mg/d	10%			
Entire cohort	10%			
Standard clinical management				
Clopidogrel 75 mg/d	17%[e]			
p	NS			
Claassens et al (2019);[15,]; POPular Genetics	Primary Combined Outcome[f]	NA	NA	NA
Genotype-guided management (n=1242)	63 (5.1%)			
Standard-treatment group (n=1246)	73 (5.9%)			
Absolute difference (95% CI); p	0.7 (−2.0 to 0.7); <.001 for noninferiority			
	Primary Bleeding Outcome[g]			
Genotype-guided management (n=1242)	122 (9.8%)			
Standard-treatment group (n=1246)	156 (12.5%)			
HR (95% CI); p	0.78 (0.61 to 0.98);.04			

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Study	Outcome			
Pereira et al (2021)[16]; TAILOR PC	Primary Combined Outcome[h]	NA	NA	NA
Genotype-guided management (n=903)	35 (4%)			
Conventional therapy (n=946)	54 (5.9%)			
Difference in 12-month event rates, % (95% CI)	−1.8 (−3.9 to 0.1)			
HR (95% CI); p	0.66 (0.43 to 1.02);.06			
	Secondary Combined Outcome[i]			
Genotype-guided management (n=903)	16 (1.9%)			
Conventional therapy (n=946)	14 (1.6%)			
Difference in 12-month event rates, % (95% CI)	0.3 (−0.9 to 1.6)			
HR (95% CI); p	1.22 (0.60 to 2.51);.58			
Wang et al (2021)[17]; CHANCE-2	NA			
Ticagrelor (n=3205)		191 (6.0)	9 (0.3)	170 (5.3)
Clopidogrel (n=3207)		243 (7.6)	11 (0.3)	80 (2.5)
HR (95% CI); p		0.77 (0.64 to 0.94);.008		

CHANCE-2: Ticagrelor or Clopidogrel with Aspirin in High-Risk Patients with Acute Nondisabling Cerebrovascular Events II trial; CI: confidence interval; HR: hazard ratio; NA; not applicable; NS: not significant; POPular Genetics: Cost-effectiveness of CYP2C19 Genotype Guided Treatment With Antiplatelet Drugs in Patients With ST-segment-elevation Myocardial Infarction Undergoing Immediate PCI With Stent Implantation: Optimization of Treatment; RAPID GENE: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy Based on GENetic Evaluation; RAPID STEMI: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy in Patients With ST-segment Elevation Myocardial Infarction.

[a] P2Y12 reaction unit >234 (a measure of high on-treatment platelet reactivity).

[b] Prasugrel vs. augmented clopidogrel.

[c] Prasugrel vs. physician-directed clopidogrel.

[d] At 30 days.

[e] At 1 week.

[f] Death from any cause, myocardial infarction, definite stent thrombosis, stroke, or major bleeding as defined by Platelet Inhibition and Patient Outcomes (PLATO) criteria at 12 months.

[g] PLATO major bleeding (coronary artery bypass graft [CABG]-related and non–CABG-related) or minor bleeding at 12 months (primary bleeding outcome).

[h] Cardiovascular death, myocardial infarction, stroke, severe recurrent ischemia, stent thrombosis.

[i] Major or minor bleeding as defined by the Thrombolysis in Myocardial Infarction (TIMI) criteria.

The purpose of the limitation tables (see Tables 5 and 6) is to display notable limitations identified in each study. This information is synthesized as a summary of the body of evidence following each table and provides the conclusions on the sufficiency of the evidence supporting the position statement. The studies were, in general, well-designed and conducted, the major

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limitation being the use of platelet activity, which is an intermediate outcome measure, and lack of reporting on health endpoints over a longer follow-up. Platelet reactivity during treatment is an intermediate endpoint that has been shown to have a limited value in guiding therapeutic decisions based on results of the large Assessment by a Double Randomization of a Conventional Antiplatelet Strategy Versus a Monitoring-Guided Strategy for Drug-Eluting Stent Implantation and of Treatment Interruption Versus Continuation One Year After Stenting (ARCTIC) RCT.[19,20,] Briefly, the ARCTIC trial randomized 2440 patients scheduled for coronary stenting to platelet-function monitoring or no monitoring. Platelet-function testing was performed in the monitored group both before and 14 to 30 days after PCI. Multiple therapeutic changes, including an additional loading dose of clopidogrel (at a dose ≥600 mg) or a loading dose of prasugrel (at a dose of 60 mg) before the procedure, followed by a daily maintenance dose of clopidogrel 150 mg or prasugrel 10 mg, were made according to a predefined protocol. There was no difference in the rate of the primary composite endpoint (death, myocardial infarction, stent thrombosis, stroke, or urgent revascularization) at 1 year between the monitoring (34.6%) and no monitoring groups (31.1%). Further, an adequately powered TAILOR-PCI RCT reported no statistically significant difference in a composite end point of cardiovascular death, myocardial infarction, stroke, stent thrombosis, and severe recurrent ischemia among patients with *CYP2C19* LOF alleles who underwent PCI, genotype-guided selection of an oral P2Y12 inhibitor compared with conventional clopidogrel therapy. Limitations of this trial included the possibility of being underpowered when sample size calculations were revised, some patients not receiving designated antiplatelet therapy and the open-label nature of the trial. However, the adjudication of all events was blinded.

Table 5. Study Relevance Limitations

Study	Population[a]	Intervention[b]	Comparator[c]	Outcomes[d]	Follow-Up[e]
So et al (2016)[14,]; RAPID STEMI				2. Platelet activity is an intermediate outcome measure 3. CONSORT harms not reported	1,2. Outcomes assessed at 1 mo
Roberts et al (2012)[13,]; RAPID GENE				2. Platelet activity is an intermediate outcome measure 3. CONSORT harms no reported	1,2. Outcomes assessed at 1wk
Claassens et al (2019); [15,];	2. Clinical context is unclear	2. Not standard or optimal			

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Study	Population[a]	Intervention[b]	Comparator[c]	Outcomes[d]	Follow-Up[e]
POPular Genetics					
Pereira et al (2021)[16]; TAILOR PC		2. Version used unclear (some patients not receiving designated antiplatelet therapy)			
Wang et al (2021)[17]; CHANCE-2	4. 98% of patients included were Chinese 5. Exclusion criteria included cardioembolic stroke, moderate or severe stroke, delayed presentation after stroke, and those who received thrombolysis				

CHANCE-2: Ticagrelor or Clopidogrel with Aspirin in High-Risk Patients with Acute Nondisabling Cerebrovascular Events II trial; POPular Genetics: Cost-effectiveness of CYP2C19 Genotype Guided Treatment With Antiplatelet Drugs in Patients With ST-segment-elevation Myocardial Infarction Undergoing Immediate PCI With Stent Implantation: Optimization of Treatment; RAPID GENE: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy Based on GENetic Evaluation; RAPID STEMI: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy in Patients With ST-segment Elevation Myocardial Infarction.
The evidence limitations stated in this table are those notable in the current review; this is not a comprehensive gaps assessment.
[a] Population key: 1. Intended use population unclear; 2. Study population is unclear; 3. Study population not representative of intended use; 4, Enrolled populations do not reflect relevant diversity; 5. Other.
[b] Intervention key: 1. Not clearly defined; 2. Version used unclear; 3. Delivery not similar intensity as comparator; 4.Not the intervention of interest.
[c] Comparator key: 1. Not clearly defined; 2. Not standard or optimal; 3. Delivery not similar intensity as intervention; 4. Not delivered effectively.
[d] Outcomes key: 1. Key health outcomes not addressed; 2. Physiologic measures, not validated surrogates; 3. No CONSORT reporting of harms; 4. Not establish and validated measurements; 5. Clinical significant difference not prespecified; 6. Clinical significant difference not supported.
[e] Follow-Up key: 1. Not sufficient duration for benefit; 2. Not sufficient duration for harms.

Table 6. Study Design and Conduct Limitations

Study	Allocation[a]	Blinding[b]	Selective Reporting[d]	Data Completeness[e]	Power[d]	Statistical[f]
So et al (2016)[14]; RAPID STEMI						
Roberts et al (2012)[13]; RAPID GENE	3. Allocation concealment unclear					
Claassens et al (2019)[15]; POPular Genetics		1. Not blinded to treatment assignment;				

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Study	Allocation[a]	Blinding[b]	Selective Reporting[d]	Data Completeness[e]	Power[d]	Statistical[f]
Pereira et al (2021)[16,]; TAILOR PC		1. Not blinded to treatment assignment				
Wang et al (2021)[17,]; CHANCE-2						

CHANCE-2: Ticagrelor or Clopidogrel with Aspirin in High-Risk Patients with Acute Nondisabling Cerebrovascular Events II trial; POPular Genetics: Cost-effectiveness of CYP2C19 Genotype Guided Treatment With Antiplatelet Drugs in Patients With ST-segment-elevation Myocardial Infarction Undergoing Immediate PCI With Stent Implantation: Optimization of Treatment; RAPID GENE: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy Based on GENetic Evaluation; RAPID STEMI: ReAssessment of Anti-Platelet Therapy Using an InDividualized Strategy in Patients With ST-segment Elevation Myocardial Infarction.
The evidence limitations stated in this table are those notable in the current review; this is not a comprehensive gaps assessment.
[a] Allocation key: 1. Participants not randomly allocated; 2. Allocation not concealed; 3. Allocation concealment unclear; 4. Inadequate control for selection bias.
[b] Blinding key: 1. Not blinded to treatment assignment; 2. Not blinded outcome assessment; 3. Outcome assessed by treating physician.
[c] Selective Reporting key: 1. Not registered; 2. Evidence of selective reporting; 3. Evidence of selective publication.
[d] Data Completeness key: 1. High loss to follow-up or missing data; 2. Inadequate handling of missing data; 3. High number of crossovers; 4. Inadequate handling of crossovers; 5. Inappropriate exclusions; 6. Not intent to treat analysis (per protocol for noninferiority trials).
[e] Power key: 1. Power calculations not reported; 2. Power not calculated for primary outcome; 3. Power not based on clinically important difference.
[f] Statistical key: 1. Intervention is not appropriate for outcome type: (a) continuous; (b) binary; (c) time to event; 2. Intervention is not appropriate for multiple observations per patient; 3. Confidence intervals and/or p values not reported; 4.Comparative treatment effects not calculated.

Observational Studies

Jung et al (2025) conducted a prospective nonrandomized clinical trial (PLATELET, NCT04072705) to examine the relationship between CYP2C19 genotypes and the clinical prognosis of acute ischemic stroke patients treated with clopidogrel.[21,] From September 2019 to January 2023, 2925 patients were enrolled across 37 clinical sites in South Korea. Patients who received clopidogrel within 72 hours of an acute ischemic stroke were included and genotyped for CYP2C19 to categorize them into carriers or noncarriers of the CYP2C19 LOF allele. The mean (standard deviation) age of the participants was 65.3 (12.4) years, and 1928 (66%) were men. Among these patients, 15 (0.5%) were excluded. Of the remaining 2910 patients, 61% were classified as poor or intermediate metabolizers and 39% as extensive metabolizers. The primary outcome assessed cardiovascular events within 6 months post-stroke, revealing higher occurrence in LOF allele carriers compared to noncarriers under intention-to-treat analysis (2.7% vs 1.6%, p=.048). Safety outcomes showed no significant differences in major bleeding (0.6% vs 0.8%, p=.56) or all-cause mortality (0.3% vs 0.1%, p=.27). There were several limitations to this study include lack of randomization, a short follow-up duration of 6 months, and being conducted solely in South Korea, suggesting the need for further research across other populations.

Section Summary: Clopidogrel

A meta-analysis, including 44 studies to evaluate the effect of CYP2C19 genotype on atherothrombotic events, found that genotype-guided therapy reduced major adverse

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cardiovascular events (MACE), myocardial infarction, and stent thrombosis in CAD, but had no significant impact on bleeding rates. Stroke patients with LOF alleles had higher risks of MACE and recurrent ischemic stroke, while no differences in MACE or major bleeding were observed in PAD patients. This meta-analysis, however, faced several limitations, including heterogeneity in studies on CAD and cerebrovascular disease, varied follow-up durations, unspecified stroke types in many studies, and the use of cohort studies and post hoc RCT analyses for PAD and cerebrovascular disease, with RCTs only in CAD. Another meta-analysis of 6 studies found that genotype-guided ticagrelor or prasugrel therapy significantly reduced the risk of composite vascular events and recurrent strokes compared with clopidogrel, but there was no statistically significant difference in bleeding risk between treatment strategies. Five RCTs have evaluated the role of CYP2C19 genetic testing in selecting appropriate antiplatelet treatment and/or increasing clopidogrel dosing, using an intermediate outcome measure of platelet reactivity to predict CYP2C19 metabolic state. One RCT has shown there was no statistical difference in patients with "on-treatment high platelet reactivity" who received genotype-guided management or standard treatment with clopidogrel. The second RCT showed that carriers of LOF alleles did not respond to augmented clopidogrel as well as they did to prasugrel, while physician-directed clopidogrel was effective for most noncarriers. However, routine testing using platelet reactivity as an outcome measure to predict CYP2C19 metabolic state has not been shown to improve health outcomes. The third non-inferiority RCT showed that genotype guided strategy led to outcomes that were at least as good as, if not better than, outcomes with the standard approach of prescribing prasugrel or ticagrelor to all patients. Results of this trial do not inform whether using genotype based strategy for prescribing clopidogrel results in any incremental net health benefit versus standard treatment with clopidogrel. Furthermore, the statistical significant difference observed in favor of genotype guided strategy for bleeding outcome was primarily driven by minor bleeding events. There was no difference in the incidence of major bleeding between the 2 groups. Results of TAILOR-PCI reported no statistically significant difference in a composite end point of cardiovascular death, myocardial infarction, stroke, stent thrombosis, and severe recurrent ischemia among patients with *CYP2C19*LOF alleles who underwent percutaneous coronary intervention (PCI), genotype-guided selection of an oral P2Y12 inhibitor compared with conventional clopidogrel therapy. In a trial comparing ticagrelor and clopidogrel use in individuals with stroke, results of the CHANCE-2 RCT reported a statistically significant decrease in risk of recurrent stroke in *CYP2C19* LOF carriers taking ticagrelor compared to clopidogrel in the first 90 days after presentation, without an increased risk of significant bleeding. Ticagrelor was associated with a higher number of total bleeding events compared to clopidogrel. These results are limited, however, by the homogenous Han Chinese population, lack of inclusion of those with delayed presentation, receipt of thrombolysis, or cardioembolic stroke, and majority of patients genotyped as intermediate metabolizers, limiting generalizability. A prospective, nonrandomized clinical trial conducted across multiple clinical sites in South Korea to examine the impact of CYP2C19 genotypes on the prognosis of acute ischemic stroke patients treated with clopidogrel, found higher cardiovascular events in LOF allele carriers compared to noncarriers. The study observed no significant differences in major bleeding or all-cause mortality but highlighted limitations such as lack of randomization and short follow-up duration.

SELECTION AND DOSING OF OTHER DRUGS

Antiretroviral Agents

Efavirenz is a widely used non-nucleoside reverse transcriptase inhibitor component of highly active antiretroviral therapy for patients with HIV infection. However, unpredictable

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interindividual variability in efficacy and toxicity remain important limitations associated with its use. Forty percent to 70% of patients have reported adverse central nervous system events. While most resolve in the first few weeks of treatment, about 6% of patients discontinue efavirenz due to adverse events.[22,] Efavirenz is primarily metabolized by the CYP2B6 enzyme, and inactivating variants such as *CYP2B6*6* are associated with higher efavirenz exposure, although plasma levels appear not to correlate with adverse events. On the other hand, *CYP2B6* poor metabolizers have markedly reduced adverse events while maintaining viral immunosuppression at substantially lower doses, based on a case report of 1 patient (Torno et al [2008]) and a case series of 12 patients (Gatanaga et al [2007]).[23,24,] An increased early discontinuation rate with efavirenz has been reported in retrospective cohort studies evaluating multiple *CYP450* variants including *CYP2B6.*[25,26,] *CYP2B6 G516T* and *T983C* single nucleotide variants were reported by Ciccacci et al (2013) to be associated with susceptibility to Stevens-Johnson syndrome in a case-control study of 27 patients who received nevirapine-containing antiretroviral treatment.[27,] However, no RCTs or large observational studies have been identified indicating that genetic testing prior to treatment initiation results in an avoidance of treatment failure, reduction of adverse events, or guides dose selection. The current evidence documenting the usefulness of *CYP450* variant genotyping to prospectively guide antiretroviral medications and assess its impact on clinical outcomes is lacking.

Immunosuppressants for Therapy for Organ Transplantation

Tacrolimus is the mainstay immunosuppressant drug and multiple studies have shown that individuals who express *CYP3A5* (extensive and intermediate metabolizers) generally have decreased dose-adjusted trough concentrations of tacrolimus, possibly delaying achievement of target blood concentrations compared with those who are *CYP3A5* nonexpressers (poor metabolizers) in whom drug levels may be elevated and possibly result in nephrotoxicity. The current evidence demonstrating the impact of *CYP3A5* genotyping to guide tacrolimus dosing and its impact on clinical outcomes includes RCTs by Thervet et al (2010)[28,] and Min et al (2018).[29,] Both RCTs compared the impact of *CYP3A5* genotype-informed dosing with standard dosing strategies on tacrolimus drug levels. The trials were not powered to assess any clinical outcomes such as graft function or survival, which otherwise were similar between groups in Thervet et al (2010).[28,]

b-Blockers

Several reports have indicated that lipophilic b-blockers (eg, metoprolol), used in treating hypertension, may exhibit impaired elimination in patients with *CYP2D6* variants.[30,31,] The current evidence documenting the usefulness of *CYP2D6* genotyping to prospectively guide antitubercular medications and assess its impact on clinical outcomes is lacking.

Antitubercular Medications

A number of studies, summarized in an umbrella review of meta-analyses by Cheng et al (2025) and a systematic review by Wang et al (2016), have reported an association between *CYP2E1* status and the risk of liver toxicity from antitubercular medications.[32,33,] The current evidence documenting the usefulness of *CYP2E1* genotyping to prospectively guide antitubercular medications and assess its impact on clinical outcomes is lacking. Furthermore, in the umbrella review, no significant association was found between the *CYP2E1* polymorphism and the risk of anti-tuberculosis drug-induced liver injury (odds ratio, 0.79; 95% CI, 0.61 to 1.02; p=.08).

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Section Summary: Selection and Dosing of Other Drugs
In general, most published *CYP450* pharmacogenomic studies for highly active antiretroviral agents, immunosuppressants, b-blockers, and antitubercular medications are retrospective evaluations of *CYP450* genotype associations or underpowered RCTs, reporting intermediate outcomes (eg, circulating drug concentrations) or less often, final outcomes (eg, adverse events or efficacy). Many of these studies are small, underpowered, and hypothesis generating. Prospective intervention studies, including RCTs documenting clinical usefulness of *CYP450* genotyping to improve existing clinical decision-making to guide dose or drug selection, which will then translate into improvement in patient outcomes, were not identified.

SUPPLEMENTAL INFORMATION
The purpose of the following information is to provide reference material. Inclusion does not imply endorsement or alignment with the evidence review conclusions.

Clinical Input From Physician Specialty Societies and Academic Medical Centers
While the various physician specialty societies and academic medical centers may collaborate with and make recommendations during this process, through the provision of appropriate reviewers, input received does not represent an endorsement or position statement by the physician specialty societies or academic medical centers, unless otherwise noted.

2012 Input
In response to requests, input was received from 4 physician specialty societies and 4 academic medical centers while this policy was under review in 2012. Opinions on use of genotype testing of patients being considered for clopidogrel treatment were mixed, with 5 suggesting the test be considered investigational and 3 suggesting it be considered medically necessary.

Practice Guidelines and Position Statements
Guidelines or position statements will be considered for inclusion in 'Supplemental Information' if they were issued by, or jointly by, a US professional society, an international society with US representation, or National Institute for Health and Care Excellence (NICE). Priority will be given to guidelines that are informed by a systematic review, include strength of evidence ratings, and include a description of management of conflict of interest.

American College of Cardiology Foundation
A consensus statement by the American College of Cardiology Foundation (ACCF) and the American Heart Association (AHA) on genetic testing for the selection and dosing of clopidogrel was published in 2010.[34,] The recommendations for practice included the following statements:

1. "Adherence to existing ACCF/AHA guidelines for the use of antiplatelet therapy should remain the foundation for therapy. Careful clinical judgment is required to assess the importance of the variability in response to clopidogrel for an individual patient and its associated risk to the patient…
2. Clinicians must be aware that genetic variability in CYP [cytochrome P450] enzymes alter clopidogrel metabolism, which in turn can affect its inhibition of platelet function. Diminished responsiveness to clopidogrel has been associated with adverse patient outcomes in registry experiences and clinical trials.
3. The specific impact of the individual genetic polymorphisms on clinical outcome remains to be determined....

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4. Information regarding the predictive value of pharmacogenomic testing is very limited at this time; resolution of this issue is the focus of multiple ongoing studies. The selection of the specific test, as well as the issue of reimbursement, is both important additional considerations.
5. The evidence base is insufficient to recommend either routine genetic or platelet function testing at the present time….
6. There are several possible therapeutic options for patients who experience an adverse event while taking clopidogrel in the absence of any concern about medication compliance."

American College of Cardiology, American Heart Association Task Force et al

In 2016, the American College of Cardiology and the American Heart Association (AHA) Task Force, in collaboration with other specialty societies, issued a guideline on dual antiplatelet therapy (DAPT) in coronary artery disease.[35,]The following recommendation was made on use of genetic testing:

- "To date, no RCT has demonstrated that routine platelet function testing or genetic testing to guide P2Y12 inhibitor therapy improves outcome; thus, the routine use of platelet function and genetic testing is not recommended (Class III: No Benefit)."

American Heart Association

In 2024, the AHA, following a review of key clinical trials and meta-analyses, released a scientific statement concerning CYP2C19 genetic testing in relation to P2Y12 inhibitor therapy (clopidogrel, prasugrel, ticagrelor).[12,] Below are the essential points from this AHA scientific statement:

1. There is significant variability in the efficacy and safety of oral P2Y12 inhibitors, which are used to prevent ischemic outcomes in common diseases such as coronary and peripheral arterial disease and stroke.
2. Clopidogrel, a prodrug, is the most used oral P2Y12 inhibitor and is activated primarily after being metabolized by a highly polymorphic hepatic cytochrome CYP2C219 enzyme.
3. Loss-of-function genetic variants in *CYP2C219* are common, can result in decreased active metabolite levels and increased on-treatment platelet aggregation, and are associated with increased ischemic events on clopidogrel therapy. Such patients can be identified by *CYP2C19* genetic testing and can be treated with alternative therapy.
4. Conversely, universal use of potent oral P2Y12 inhibitors such as ticagrelor or prasugrel, which are not dependent on CYP2C19 for activation, has been recommended but can result in increased bleeding.
5. Recent clinical trials and meta-analyses have suggested that a precision medicine approach in which loss-of-function carriers are prescribed ticagrelor or prasugrel and noncarriers are prescribed clopidogrel may reduce ischemic events without increasing bleeding risk.
6. The evidence appears to support *CYP2C19* genetic testing before oral P2Y12 inhibitors are prescribed in patients with acute coronary syndromes (ACS) or percutaneous coronary intervention (PCI).
7. Clinical implementation of such genetic testing will depend on multiple factors: rapid availability of results or adoption of the concept of performing preemptive genetic testing, provision of easy-to-understand results with therapeutic recommendations, and seamless integration in the electronic health record.
8. The 2016 American College of Cardiology/American Heart Association/Society for Cardiovascular Angiography and Interventions guideline on dual antiplatelet therapy

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(DAPT) in coronary artery disease (CAD) does not recommend the routine use of genetic testing (see above).

9. The 2017 European Society of Cardiology focused update on DAPT in CAD similarly does not recommend routine genetic testing except in specific situations such as for patients with recurrent adverse events if the results of testing may change therapy.
10. Given the pharmacokinetic, pharmacodynamic, clinical trial data (with mixed results) and recent meta-analyses findings, *CYP2C19* genetic testing before prescription of clopidogrel or ticagrelor/prasugrel in patients with ACS or PCI may be beneficial but needs more real-world high-quality validation data.

U.S. Preventive Services Task Force Recommendations

No U.S. Preventive Services Task Force recommendations for cytochrome P450 testing have been identified.

Ongoing and Unpublished Clinical Trials

Some currently ongoing or unpublished trials that might influence this review are listed in Table 7.

Table 7. Summary of Key Trials

NCT No.	Trial Name	Planned Enrollment	Completion Date
Ongoing			
Unpublished			
NCT06319391	Analysis of the Effect of Donor CYP3A5 Gene Polymorphism on Early Tacrolimus Concentration and Postoperative Acute Renal Injury After Liver Transplantation	60	Oct 2025 (last update posted: Mar 2024)

NCT: national clinical trial.
[a] Denotes industry-sponsored or cosponsored trial.

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CODING

The following codes for treatment and procedures applicable to this policy are included below for informational purposes. This may not be a comprehensive list of procedure codes applicable to this policy.

Inclusion or exclusion of a procedure, diagnosis or device code(s) does not constitute or imply member coverage or provider reimbursement. Please refer to the member's contract benefits in effect at the time of service to determine coverage or non-coverage of these services as it applies to an individual member.

The code(s) listed below are medically necessary ONLY if the procedure is performed according to the "Policy" section of this document.

CPT/HCPCS	
81225	CYP2C19 (cytochrome P450, family 2, subfamily C, polypeptide 19 (e.g., drug metabolism), gene analysis, common variants (e.g., *2, *3, *4, *8, *17)
81226	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism), gene analysis, common variants (e.g., *2, *3, *4, *5, *6, *9, *10, *17, *19, *29, *35, *41, *1XN, *2XN, *4XN)
81227	CYP2C9 (cytochrome P450, family 2, subfamily C, polypeptide 9) (e.g., drug metabolism), gene analysis, common variants (e.g., *2, *3, *5, *6)
81230	CYP3A4 (cytochrome P450 family 3 subfamily A member 4) (e.g., drug metabolism), gene analysis, common variant(s) (e.g., *2, *22)
81231	CYP3A5 (cytochrome P450 family 3 subfamily A member 5) (e.g., drug metabolism), gene analysis, common variants (e.g., *2, *3, *4, *5, *6, *7)
81402	Molecular Pathology Procedure Level 3 ▪ CYP21A2 (cytochrome P450, family 21, subfamily A, polypeptide 2) (e.g., congenital adrenal hyperplasia, 21-hydroxylase deficiency), common variants (e.g., IVS2-13G, P30L, I172N, exon 6 mutation cluster [I235N, V236E, M238K], V281L, L307FfsX6, Q318X, R356W, P453S, G110VfsX21, 30-kb deletion variant)
81404	Molecular Pathology Procedure Level 5 ▪ CYP1B1 (cytochrome P450, family 1, subfamily B, polypeptide 1) (e.g., primary congenital glaucoma), full gene sequence
81405	Molecular Pathology Procedure Level 7 ▪ CYP11B1 (cytochrome P450, family 11, subfamily B, polypeptide 1) (e.g., congenital adrenal hyperplasia), full gene sequence ▪ CYP17A1 (cytochrome P450, family 17, subfamily A, polypeptide 1) (e.g., congenital adrenal hyperplasia), full gene sequence ▪ CYP21A2 (cytochrome P450, family 21, subfamily A, polypeptide2) (e.g., steroid 21-hydroxylase isoform, congenital adrenal hyperplasia), full gene sequence
81418	Drug metabolism genomic sequence panel, must include testing of at least 6 genes, including CYP2C19, CYP2D6, and CYP2D6 duplications and deletions
0070U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, common and select rare variants (i.e., *2, *3, *4, *4N, *5, *6, *7, *8, *9, *10, *11, *12, *13, *14A, *14B, *15, *17, *29, *35, *36, *41, *57, *61, *63, *68, *83, *xN)

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CPT/HCPCS	
0071U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, full gene sequence (List separately in addition to code for primary procedure)
0072U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, targeted sequence analysis (i.e., CYP2D6-2D7 hybrid gene) (List separately in addition to code for primary procedure)
0073U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, targeted sequence analysis (i.e., CYP2D7-2D6 hybrid gene) (List separately in addition to code for primary procedure)
0074U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, targeted sequence analysis (i.e., non-duplicated gene when duplication/multiplication is trans) (list separately in addition to code for primary procedure)
0075U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, targeted sequence analysis (i.e., 5 gene duplication/multiplication) (list separately in addition to code for primary procedure)
0076U	CYP2D6 (cytochrome P450, family 2, subfamily D, polypeptide 6) (e.g., drug metabolism) gene analysis, targeted sequence analysis (i.e., 3 gene duplication/ multiplication) (list separately in addition to code for primary procedure)

REVISIONS	
10-26-2010	Policy added to the bcbsks.com web site.
08-12-2011	Rationale section updated.
	In Coding section: Updated nomenclature for CPT codes: 88385, 88386
	Reference section updated.
02-14-2012	In Coding section: ▪ Added CPT codes: 81225, 81226, 81227 (effective 01-01-2012) ▪ Added the following notations: ▪ "Use 81225, 81226, 81227 when indicated, otherwise use 88384, 88385, 88386. ▪ See the policies below for genetic testing related to these items: ○ Genetic Testing for Helicobacter pylori Treatment medical policy ○ Genetic Testing for Tamoxifen Treatment medical policy ○ Genetic Testing for Warfarin Dose medical policy"
01-01-2013	In Coding section: ▪ Removed CPT codes: 88384, 88385, 88386 (effective 12-31-2012)
03-31-2014	Description section updated
	In Policy section: ▪ In Item A revised wording from: "CYP450 phenotyping for CYP2C19 *2 and *3 alleles may be considered medically necessary in patients with cardiovascular disease undergoing treatment with clopidogrel (Plavix®) in order to identify those who are poor metabolizers of the drug (patients with CYP2C19*2/2,*3/3, and *2/3 genotypes) and who are, therefore, likely to exhibit poor response to the drug." To: "CYP450 genotyping for the purpose of aiding in the choice of clopidogrel versus alternative antiplatelet agents, or in decisions on the optimal dosing for clopidogrel, may be considered medically necessary."

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REVISIONS	
	▪ In Item B revised the wording from: "Aside from the use with clopidogrel treatment noted above, genotyping to determine specific cytochrome p450 (CYP450) genetic polymorphisms for the purpose of aiding in the choice of drug or dose increase efficacy and/or avoid toxicity is considered experimental / investigational. This includes, but is not limited to, CYP450 genotyping for the following applications:" To: "CYP450 genotyping for the purpose of aiding in the choice of drug or dose to increase efficacy and/or avoid toxicity for all other drugs is considered experimental / investigational. This includes, but is not limited to, CYP450 genotyping for the following applications:" ▪ In Item B removed E/I indication, "dose of atomoxetine HCl (approved for treatment of attention-deficit/hyperactivity disorder)" ▪ In Item B added E/I indications: "4. selection and dosing of selective norepinephrine reuptake inhibitors", "5. selection and dosing of tricyclic antidepressants", and "9. dosing and management of antituberculosis medications"
	Rationale section updated
	In Coding section: ▪ CPT Coding Instructions added ▪ Added ICD-10 Diagnoses Codes: P91.821, P91.822, P91.823 (Effective 10-01-2020)
	References updated
10-01-2016	In Coding section: ▪ ICD-10 Codes Added Effective 10-01-2016: I63.413, I63.423, I63.433, I63.443, I63513, I63.523, I63.533, I63.543
03-10-2021	Title revised to "Cytochrome p450 Genotype-Guided Treatment Strategy" from "Cytochrome p450 Genotyping"
	Description section updated
	In Policy section: ▪ Added "CYP2D6 genotyping to determine drug metabolizer status may be considered medically necessary for patients: 1. With Gaucher disease being considered for treatment with eliglustat 2. With Huntington disease being considered for treatment with tetrabenazine in a dosage greater than 50 mg per day" ▪ In Item B removed "This includes, but is not limited to, CYP450 genotyping for the following applications" and added "aside from the determinations in the separate policy statements above" to read "CYP450 genotyping for the purpose of aiding in the choice of drug or dose to increase efficacy and/or avoid toxicity for all other drugs is considered experimental / investigational. aside from determinations in the separate policy statements above:" ▪ In Item B 1 removed "deciding whether to prescribe" and "for nursing mother" and added "selection or dosage of" to read "selection or dosage of codeine" ▪ In Item B 2 removed "common component of highlight active" and added "and other" to read "dosing of efavirenz and other antiretroviral therapies for HIV infection" ▪ Removed the following as they are no longer pertinent to this policy: "6. selection or dose of selective serotonin reuptake inhibitor (SSRI) 7. selection or dose of antipsychotic drugs 8. selection and dosing of selective norepinephrine reuptake inhibitors 9. selection and dosing of tricyclic antidepressants" ▪ In Item C revised "may be considered medically necessary" to "is considered **experimental / investigational**" to read "CYP450 genotyping for the purpose of aiding in the choice of clopidogrel versus alternative antiplatelet agents, or in decisions on the optimal dosing for clopidogrel, is considered experimental / investigational."

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REVISIONS	
	▪ Added Item D "The use of genetic testing panels that include multiple CYP450 variants is considered experimental / investigational."
	Rationale section updated
	In Coding section: ▪ Added the following CPT and PLA codes: 81230, 81231, 0029U, 0031U, 0070U, 0071U, 0072U, 0073U ▪ Added the following ICD-10 codes: P91.821, P91.822, P91.823
	References updated
08-28-2021	Description section updated.
	In Policy section: ▪ Added Item B.5.
	Rationale section updated.
	Reference section updated.
09-08-2022	Updated Description Section
	Updated Policy Section ▪ Added Section B: CYP2C9 genotyping to determine drug metabolizer status may be considered medically necessary for individuals: 1. With relapsing forms of multiple sclerosis, to include clinically isolated syndrome, relapsing-remitting disease, and active secondary progressive disease, being considered for treatment with siponimod.
	Updated Policy Guideline Section ▪ Added Section B: "The Food and Drug Administration maintains a database of pharmacogenomic biomarkers in drug labeling. See section "Regulatory Status" for details."
	Updated Rationale Section
	Updated Coding Section ▪ Converted ICD-10 codes to ranges
	Updated References Section
01-03-2023	Updated Coding Section ▪ Added 81418 (eff 01-01-2023)
07-25-2023	Updated Description Section
	Updated Rationale Section
	Updated Coding Section ▪ Removed ICD-10 Codes
	Updated References Section
07-23-2024	Updated Description Section
	Updated Rationale Section
	Updated References Section
08-12-2025	Updated Description Section
	Updated Rationale Section
	Updated References Section
07-01-2026	Updated Coding Section ▪ Removed Deleted codes 0029U and 0031U (eff. 07-01-2026)
08-11 2026	Updated Description Section
	Updated Policy section ▪ Added to Statement A: with one of the following:
	Updated Rationale Section
	Updated References Section

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