Clinical Pharmacogenetics Implementation Consortium (CPIC) Guideline for CYP2D6 and Tamoxifen Therapy

Matthew P. Goetz1, Katrin Sangkuhl2, Henk-Jan Guchelaar3, Matthias Schwab4,5,6, Michael Province7, Michelle Whirl-Carrillo2, W. Fraser Symmans8, Howard L. McLeod9, Mark J. Ratain10, Hitoshi Zembutsu11, Andrea Gaedigk12, Ron H. van Schaik13,14, James N. Ingle1, Kelly E. Caudle15 and Teri E. Klein2

Tamoxifen is biotransformed by CYP2D6 to 4-hydroxytamoxifen and 4-hydroxy N-desmethyl tamoxifen (endoxifen), both with greater antiestrogenic potency than the parent drug. Patients with certain CYP2D6 genetic polymorphisms and patients who receive strong CYP2D6 inhibitors exhibit lower endoxifen concentrations and a higher risk of disease recurrence in some studies of tamoxifen adjuvant therapy of early breast cancer. We summarize evidence from the literature and provide therapeutic recommendations for tamoxifen based on CYP2D6 genotype.

The purpose of this guideline is to provide clinicians information that will allow the interpretation of clinical CYP2D6 genotype tests so that the results can be used to guide prescribing of tamoxifen. Detailed guidelines for the use of tamoxifen as well as analyses of cost effectiveness are beyond the scope of this article. The Clinical Pharmacogenetics Implementation Consortium (CPIC) guidelines are periodically updated at www.cpicpgx.org/guidelines/.

FOCUSED LITERATURE REVIEW

A systematic literature review focused on CYP2D6 genotype and tamoxifen use (details in Supplement) was conducted.

GENE: CYP2D6

CYP2D6 is highly polymorphic, with over 100 known allelic variants and subvariants identified (https://www.pharmvar.org/gene/CYP2D6; CYP2D6 Allele Definition Table in Ref. 1). CYP2D6 alleles have been extensively studied in multiple geographically, racially, and ethnically diverse groups and significant differences in allele frequencies have been observed (CYP2D6 Frequency Table1). The most commonly reported alleles are categorized into functional groups as follows: normal function (e.g., CYP2D6*1 and *2), decreased function (e.g., CYP2D6*9, *10, *17, and *41), and no function (e.g., CYP2D6*3, *4, *5, *6).2,3 Because CYP2D6 is subject to gene deletions, duplications, or multiplications, many clinical laboratories also report copy number variations. CYP2D6*5 represents a gene deletion (no function allele), whereas gene duplications and multiplications are denoted by “xN” (e.g., CYP2D6*1xN with xN representing the number of CYP2D6 gene copies). Alleles carrying two or more normal function gene copies are categorized as alleles with increased function.

The combination of alleles is used to determine a patient's diplotype (Table 1). Each functional status is assigned an activity value ranging from 0 to 1 (e.g., 0 for no function, 0.5 for decreased, and 1.0 for normal function).3 Supplemental Table S1 describes the activity score (AS) values assigned to selected alleles. If an allele contains multiple copies of a
A group of CYP2D6 diplotype into phenotypes. Patients with an activity score of 1.0 may be classified as intermediate metabolizers by some reference laboratories. A group of CYP2D6 (contrast to the classification used in previous guidelines. A metabolizer or intermediate metabolizer (this guideline, an AS of 1.0 is classified as a CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains) a.

Thus, for those with an AS of 1.5 or 2.0 represent normal metabolizers (NMs). Patients with a score > 1.0 have less activity towards tamoxifen compared with patients with an AS of 1.5 or 2.

Table 1 Assignment of likely CYP2D6 phenotypes based on genotypes

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Activity score</th>
<th>Genotype</th>
<th>Examples of CYP2D6 diplotypes b</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYP2D6 ultrarapid metabolizer</td>
<td>&gt; 2.0</td>
<td>An individual carrying duplications of functional alleles</td>
<td>*1/*1xN, *1/*2xN, *2/*2xN.</td>
</tr>
<tr>
<td>CYP2D6 normal metabolizer</td>
<td>1.5 and 2.0</td>
<td>An individual carrying two normal function alleles or one normal function and one decreased function allele</td>
<td>*1/*1, *1/*2, *1/*9, *1/*41, *2/*2,</td>
</tr>
<tr>
<td>CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains)</td>
<td>1.0</td>
<td>An individual carrying two decreased function alleles or one normal function and one no function allele. An activity score (AS) of 1.0 is associated with decreased tamoxifen metabolism to endoxifen compared to those with an AS of 1.5 or 2.</td>
<td>*1/*4, *1/*5, *41/*41</td>
</tr>
<tr>
<td>CYP2D6 intermediate metabolizer</td>
<td>0.5</td>
<td>An individual carrying one decreased function and one no function allele</td>
<td>*4/*10, *4/*41, *5/*9</td>
</tr>
<tr>
<td>CYP2D6 poor metabolizer</td>
<td>0</td>
<td>An individual carrying only no functional alleles</td>
<td>*3/*4, *4/*4, *5/*5, *5/*6</td>
</tr>
</tbody>
</table>

CYP2D6 genotype to phenotype translation system. Note that genotypes with an activity score of 1 are classified as NMs in the online CYP2D6 genotype to phenotype table. Where xN represents the number of CYP2D6 gene copies. For individuals with CYP2D6 duplications or multiplications, see supplemental data for additional information on how to translate duplotype into phenotypes. Patients with an activity score of 1.0 may be classified as intermediate metabolizers by some reference laboratories. A group of CYP2D6 experts are currently working to standardize the CYP2D6 genotype to phenotype translation system. CPIC will update the CPIC website accordingly (CYP2D6 genotype to phenotype table).

To interpret the CYP2D6 AS that is used to define CYP2D6 phenotype is the sum of the values assigned to each allele, which typically ranges from 0 to 3.0 but may exceed 3.0 in rare cases. The CYP2D6 AS has been translated into the phenotype classification system for other CPIC guidelines as follows (CYP2D6 Allele Definition Table): patients with an AS of 0 are poor metabolizers (PMs), those with a score of 0.5 are considered intermediate metabolizers (IMs), and those with a score of 1.5 or 2.0 represent normal metabolizers (NMs). Patients with a score > 2.0 are classified as ultrarapid metabolizers (UMs). However, the AS of 1.0 has less activity towards tamoxifen compared with those with an AS of 1.5 or 2.0 and patients with an AS of 1.0 may be classified as IMs by some reference laboratories. Thus, for this guideline, an AS of 1.0 is classified as a CYP2D6 normal metabolizer or intermediate metabolizer (Table 1). This is in contrast to the classification used in previous guidelines. A group of CYP2D6 experts are currently working to standardize the CYP2D6 genotype to phenotype translation system. Note that genotypes with an AS of 1 are classified as NMs in the CYP2D6 genotype to Phenotype Table and the CPIC will update the CPIC website and this table accordingly when the CYP2D6 genotype to phenotype standardization is complete.

Because reference laboratories providing clinical CYP2D6 genotyping may use varying methods to assign phenotypes, it is advisable to note a patient’s CYP2D6 diplotype and to calculate an AS before making therapeutic decisions about tamoxifen therapy.

### Genetic test interpretation

Clinical laboratories rarely sequence the entire CYP2D6 gene or interrogate every known variant position. Instead, they typically test for variants that are used to determine high-frequency allele haplotypes using the star-allele (*) nomenclature system, found at the Pharmacogene Variation Consortium website (http://www.PhrmVar.org). Table S1 and tables found on the CPIC and PharmGKB website contain a list of CYP2D6 alleles, the specific combination of variants that can be used to determine the allele, functional status, and frequency across major ethnic populations as reported in the literature.

The limitations of genetic testing as described here include: 1) rare variants may not be detected; 2) known star (*) alleles not tested for will not be reported, and, instead, the allele will be reported as a ‘?’ and 3) tests are not designed to detect unknown or de novo variants. The Supplemental Material (Genetic Test Interpretation Section) contains additional information regarding CYP2D6 genetic test interpretation and phenotype assignment.

### Available genetic test options


### Incidental findings

Currently, there are no diseases or conditions that have been consistently linked to variation in the CYP2D6 gene independently of drug metabolism and response.

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*aSee the CYP2D6 frequency table for race-specific allele and phenotype frequencies. bFor a complete list of CYP2D6 diplotypes and resulting phenotypes, see the CYP2D6 genotype to phenotype table. cWhere xN represents the number of CYP2D6 gene copies. For individuals with CYP2D6 duplications or multiplications, see supplemental data for additional information on how to translate duplotype into phenotypes. dPatients with an activity score of 1.0 may be classified as intermediate metabolizers by some reference laboratories. A group of CYP2D6 experts are currently working to standardize the CYP2D6 genotype to phenotype translation system. CPIC will update the CPIC website accordingly (CYP2D6 genotype to phenotype table).
Other considerations
Chromosomal instability, i.e., loss of heterozygosity, is frequently observed in breast tumor tissue. Genotype information derived from such tissue may therefore not accurately reflect the germline genotype that determines CYP2D6 activity in the liver, where tamoxifen is metabolized. We therefore strongly recommend genotype testing be performed on nontumor DNA isolated from a peripheral blood, or a saliva/buccal swab sample.

DRUG: TAMOXIFEN
Background
About 65–75% of breast cancer express estrogen receptors (ERs) or progesterone receptors (PRs). In this group of patients, endocrine therapy represents the most important treatment modality. Tamoxifen, a selective estrogen receptor modulator (SERM), has been studied and utilized in breast cancer for more than 40 years. When administered to women with ER-positive breast cancer for 5 years after surgery, tamoxifen almost halved the annual recurrence rate and reduces the breast cancer mortality rate by one-third in both pre- and postmenopausal women. While tamoxifen has multiple US Food and Drug Administration (FDA) approvals for both the prevention and treatment of premenopausal and postmenopausal breast cancer, tamoxifen’s continued importance is reflected by its status as the only hormonal agent approved by the FDA for the prevention for premenopausal breast cancer, the treatment of ductal carcinoma in situ, and the adjuvant and metastatic treatment of premenopausal invasive breast cancer.

The pharmacology of tamoxifen is complex. Tamoxifen is a weak antiestrogen that is extensively metabolized, and its metabolites exhibit similar, less, or more potent antiestrogenic activity. Furthermore, tamoxifen can exhibit either antiestrogenic or proestrogenic properties, depending on the target tissue and the presence or absence of coactivators or corepressors.

Tamoxifen undergoes extensive primary and secondary liver metabolism by cytochrome P450 enzymes via two major pathways: N-demethylation and 4-hydroxylation (Figure 1). The predominant metabolic pathway (considered to contribute to over 90% of tamoxifen metabolism) is the demethylation of tamoxifen to N-desmethyltamoxifen primarily mediated by CYP3A4, followed by CYP2D6-mediated oxidation to 4-hydroxy-N-desmethyltamoxifen (endoxifen). A minor metabolic pathway is hydroxylation of tamoxifen (mediated mainly by CYP2D6 but also catalyzed by CYP3A4 and CYP2C19) to 4-hydroxytamoxifen (4HT), which can then be further metabolized to endoxifen. While tamoxifen and its metabolites undergo glucuronidation and sulfation, no consistent effect of pharmacogenetic variation in any of the UGT or SULT isoforms on either tamoxifen pharmacokinetics or clinical outcomes has been observed to date.

The hydroxylation of either tamoxifen or N-desmethyltamoxifen is considered to bioactivate tamoxifen. Both 4HT and endoxifen exhibit nearly 100-fold greater antiestrogenic potency than the parent drug. Maximum inhibition of estrogen-induced stimulation and ER transcription is achieved with endoxifen concentrations ranging between 100–1,000 nM. However, even low Z-endoxifen levels were necessary to block estrogen-mediated cell growth in models mimicking estrogen concentrations of pre- or postmenopausal women who were treated with tamoxifen and its metabolites.

Both inter- and intraindividual variation in the concentration of tamoxifen and its metabolites have been described. As it relates to the active metabolites, 4HT concentrations are low, typically <5 nM, and the role of interpatient variability in 4HT as it relates to breast cancer outcomes is not well understood. In contrast, endoxifen plasma concentrations are up to 10-fold higher than 4HT, exhibiting substantial variability.

Patients with low CYP2D6 enzyme activity, as a result of CYP2D6 genetic polymorphisms or the coadministration of strong CYP2D6 inhibitors, exhibit significantly lower endoxifen concentrations when treated with tamoxifen.

Clinical studies to evaluate the association between endoxifen concentrations and CYP2D6 polymorphisms with tamoxifen outcome have yielded conflicting results. Initial and follow-up data demonstrated that CYP2D6 PMs had an ~2–3-fold higher risk of breast cancer recurrence (compared to CYP2D6 NM) and led an FDA special emphasis panel to recommend a tamoxifen label change to incorporate data that CYP2D6 genotype was an important biomarker associated with tamoxifen efficacy. However, this label change was not implemented because of conflicting data from secondary analyses of 5-year tamoxifen prospective trials including ATAC, BIG1–98, and ABCSG 8. Multiple other studies were summarized in a meta-analysis that demonstrated an association between CYP2D6 genotype and disease-free survival, but only in patients who received tamoxifen as adjuvant therapy at a dose of 20 mg/day for 5 years.

Regarding the role of measurement of endoxifen concentrations, Madlensky et al. identified an association between low endoxifen (lowest quintile) and recurrence. In a separate study of premenopausal patients, Saldores et al. demonstrated similar findings that patients with low endoxifen concentrations (<14 nM) exhibited a higher risk for distant relapse or death compared with those with high concentrations (>35 nM).

Given these conflicting data, a working group within CPIC was convened to review and summarize the strength of the data and to provide therapeutic recommendations for those patients in which the CYP2D6 genotype is known and for whom adjuvant tamoxifen is recommended.

Linking genetic variability to variability in drug-related phenotypes
Endoxifen concentrations. There is substantial evidence linking the CYP2D6 genotype with phenotypic variability in endoxifen concentrations. As outlined in Table S2, the evidence was considered uniformly strong that CYP2D6 PMs (AS = 0) have lower plasma endoxifen concentrations among patients taking adjuvant tamoxifen compared to CYP2D6 NM, and that reduced CYP2D6 activity (AS = 0 to 1) is associated with lower plasma endoxifen concentrations among patients taking adjuvant tamoxifen compared to normal CYP2D6 activity. CYP2D6 genotype explains 34–52% of the variability in absolute endoxifen concentrations.
Of particular note, for populations with a high frequency of the decreased function CYP2D6*10 allele, there was strong evidence that patients with CYP2D6 ASs of 0 to 1 had significantly lower plasma endoxifen concentrations compared to those with normal CYP2D6 activity (AS = 1.5 and 2).

Pharmacodynamic markers (Ki-67). One prospective clinical study examined the association between CYP2D6 genotype and change in tumor Ki-67, a phenotype linked to drug efficacy, in patients with early-stage breast cancer receiving neoadjuvant tamoxifen. In this study, patients with CYP2D6*10/*10
and CYP2D6*5/*10 genotypes had significantly lower Ki-67 response compared to patients genotyped as CYP2D6*1/*1.42

Breast cancer recurrence and survival. Because of the extensive biological variability across the various clinical settings where tamoxifen is administered (prevention, ductal carcinoma in situ, premenopausal and postmenopausal adjuvant setting, and metastatic), the current CPIC guidelines focuses only on the role of CYP2D6 genotype in the adjuvant treatment of ER+ breast cancer, using the endpoints of recurrence, recurrence-free survival, disease-free survival, distant relapse-free survival, breast cancer-specific survival, and overall survival. The body of evidence for each of these clinical endpoints is summarized in Table S2. For the clinical endpoints of recurrence and event-free survival, the evidence was graded as moderate for the statements that CYP2D6 PMs (AS = 0) have a higher risk of breast cancer recurrence or worse event-free survival. However, for the comparison of other metabolizer groups (IM, NM, and UM) and other clinical endpoints, the evidence was considered weak regarding an association between CYP2D6 metabolizer groups and clinical outcome (Table S2).

Therapeutic recommendations

Table 2 summarizes the therapeutic recommendations for tamoxifen prescribing based on the CYP2D6 phenotype. Based on current evidence (Table S2), CYP2D6 UMs and NMs are expected to achieve therapeutic endoxifen concentrations after administration of tamoxifen and should receive the recommended standard of care doses of tamoxifen. CYP2D6 PMs and IMs (including patients with an AS of 1.0, see Supplement) are expected to have lower endoxifen concentrations compared to NMs and have a higher risk of breast cancer recurrence, and worse event-free survival compared to NMs. For CYP2D6 PMs, a “strong” therapeutic recommendation was provided to recommend alternative hormonal therapy such as an aromatase inhibitor (AI) for postmenopausal women or AI along with ovarian function suppression in premenopausal women, given that these approaches are superior to tamoxifen regardless of CYP2D6 genotype43,44 and based on knowledge that CYP2D6 PMs patients who switch from tamoxifen to anastrozole do not exhibit an increased risk of recurrence.38 Given that escalation of tamoxifen dose from 20–40 mg/day in CYP2D6 PM significantly increases endoxifen concentrations (but not to concentrations achieved in CYP2D6 NMs45), the use of an AI (± ovarian function suppression) is recommended in this setting. Tamoxifen 40 mg/day can be considered for CYP2D6 PM if there are contraindications to AI use. There are no clinical data that toremifene, another selective estrogen receptor modulator that also undergoes bioactivation,46 should be substituted for tamoxifen based on CYP2D6 genotype.

For CYP2D6 IMs and CYP2D6*10/*10 or CYP2D6*10/ decreased function allele, a “moderate” recommendation was made to consider use of an alternative hormonal therapy (i.e., aromatase inhibitor) for postmenopausal women or AI plus ovarian function suppression in premenopausal women is recommended. In CYP2D6 IMs, if AIs are contraindicated, consideration can be given to the use of a higher FDA-approved dose of tamoxifen (40 mg/day), which is known to result in significantly higher endoxifen concentrations without an increase in toxicity.45 Based on extrapolation from evidence in *10 individuals, a similar recommendation applies to individuals who carry other decreased function alleles resulting in an AS of 1.0 but with an “optional” recommendation, given the paucity of data for this group.

In general, prolonged overlap of tamoxifen with strong and moderate CYP2D6 inhibitors should be avoided in tamoxifen-treated patients,47 whereas weak inhibitors are also contraindicated in CYP2D6 IMs.

Recommendations for incidental findings

Not applicable.

Other considerations

Pharmacogenetic variation in other cytochrome P450 genes such as CYP2C9 and CYP3A4 or CYP3A5 is associated with a small effect on plasma concentrations of both 4HT and endoxifen, with unclear effects on clinical efficacy of tamoxifen. The CYP2C19 genotype has also been associated with therapy outcome, where IMs and PMs showed an increased survival (hazard ratio 0.70), and direct effects on endoxifen plasma concentrations were described.48–51 Possibly, there is also an increase in tamoxifen drug concentrations, as recently suggested.52 While a meta-analysis demonstrated an association between CYP2C19 genotype and increased survival in tamoxifen-treated breast cancer patients,53 an analysis of the International Tamoxifen Consortium dataset failed to find this correlation,54 leaving the clinical role of CYP2C19 genotyping for tamoxifen therapy unclear at the moment.

Implementation of this guideline. The guideline supplement contains resources that can be used within electronic health records (EHRs) to assist clinicians in applying genetic information to patient care for the purpose of drug therapy optimization (see Resources to incorporate pharmacogenetics into an electronic health record with clinical decision support sections of the Supplement and the CPIC website6).

POTENTIAL BENEFITS AND RISKS FOR THE PATIENT

The potential benefit of using CYP2D6 genotype to guide tamoxifen use is that patients with genotypes that are associated with a higher risk of breast cancer recurrence and worse event-free survival (e.g., CYP2D6 IMs and PMs) may be identified and alternative doses (e.g., 40 mg) and agents administered. Given that the alternative drug treatments (aromatase inhibitors either with or without ovarian function suppression) have been demonstrated to be superior to tamoxifen43,44 and that CYP2D6 PMs switched from tamoxifen to anastrozole do not exhibit an increased risk of recurrence,38 it is expected that the risks to use CYP2D6 genotyping to guide hormonal treatment would be low. Further research is necessary, however, to determine whether CYP2D6 genotypes associated with therapeutic endoxifen concentrations (e.g., NMs and UMs) should be preferentially maintained on tamoxifen. As
<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Metabolizer status</th>
<th>Activity score</th>
<th>Implications</th>
<th>Therapeutic recommendation</th>
<th>Classification of recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYP2D6 ultrarapid metabolizer</td>
<td>&gt;2.0</td>
<td>Therapeutic endoxifen concentrations</td>
<td>Avoid moderate and strong CYP2D6 inhibitors. Initiate therapy with recommended standard of care dosing (tamoxifen 20 mg/day).</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td>CYP2D6 normal metabolizer</td>
<td>1.5 to 2.0</td>
<td>Therapeutic endoxifen concentrations</td>
<td>Avoid moderate and strong CYP2D6 inhibitors. Initiate therapy with recommended standard of care dosing (tamoxifen 20 mg/day).</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td>CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains)</td>
<td>1.0 (no *10 allele present)</td>
<td>Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.</td>
<td>Consider hormonal therapy such as an aromatase inhibitor for postmenopausal women or aromatase inhibitor along with ovarian function suppression in premenopausal women, given that these approaches are superior to tamoxifen regardless of CYP2D6 genotype. If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). Avoid CYP2D6 strong to weak inhibitors.</td>
<td>Optional</td>
<td></td>
</tr>
<tr>
<td>CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains)</td>
<td>1.0 (*10 allele present)</td>
<td>Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.</td>
<td>Consider hormonal therapy such as an aromatase inhibitor for postmenopausal women or aromatase inhibitor along with ovarian function suppression in premenopausal women, given that these approaches are superior to tamoxifen regardless of CYP2D6 genotype. If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). Avoid CYP2D6 strong to weak inhibitors.</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>CYP2D6 intermediate metabolizer</td>
<td>0.5</td>
<td>Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.</td>
<td>Consider hormonal therapy such as an aromatase inhibitor for postmenopausal women or aromatase inhibitor along with ovarian function suppression in premenopausal women, given that these approaches are superior to tamoxifen regardless of CYP2D6 genotype. If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). Avoid CYP2D6 strong to weak inhibitors.</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>CYP2D6 poor metabolizer</td>
<td>0</td>
<td>Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.</td>
<td>Recommend alternative hormonal therapy such as an aromatase inhibitor for postmenopausal women or aromatase inhibitor along with ovarian function suppression in premenopausal women, given that these approaches are superior to tamoxifen regardless of CYP2D6 genotype and based on knowledge that CYP2D6 poor metabolizers switched from tamoxifen to anastrozole do not have an increased risk of recurrence. Note, higher dose tamoxifen (40 mg/day) increases but does not normalize endoxifen concentrations and can be considered if there are contraindications to aromatase inhibitor therapy.</td>
<td>Strong</td>
<td></td>
</tr>
</tbody>
</table>

*aRating scheme described in the Supplement.*bCPIC has generally classified patients with an activity score of 1 as a “normal metabolizer.” However, in the case of tamoxifen, prescribing recommendations for those with an AS of 1.0 are allele dependent, based on the presence of the *+10 allele. Those patients with an AS of 1.0 on the basis of *+10 allele are provided a “moderate” recommendation. In contrast, prescribing recommendations for those with an activity score of 1 based on the presence of CYP2D6 alleles other than *+10 are graded as “optional” because the recommendations are primarily extrapolated from evidence generated from *+10 individuals (i.e., limited data for clinical outcomes and pharmacokinetics for this group).
with any laboratory test, a possible risk to patients is an error in
genotyping or phenotype prediction, along with the presence of a
rare genomic variant not tested for, which could have long-term
adverse health implications for patients.

CAVEATS: APPROPRIATE USE AND/OR POTENTIAL
MISUSE OF GENETIC TESTS

Rare CYP2D6 variants may not be included in the genotype test
used and patients with rare variants may be assigned a "wildtype"
(CYP2D6*1) genotype by default. Thus, an assigned "wildtype"
allele could potentially harbor a no or decreased function variant.
Therefore, it is important that test reports do include informa-
tion on which variant alleles were tested. Furthermore, it is
important that the genetic testing platform includes testing for
gene copy number.

Like all diagnostic tests, CYP2D6 genotype is one of multiple
pieces of information that clinicians should consider when mak-
ing their therapeutic choice for each patient. For example, for the
treatment of ER+ breast cancer, there are well-accepted tumor
somatic factors that drive endocrine response, including the
tumor expression of ER, PR, and HER2 expression, and other
multigene assays that are associated with endocrine sensitivity.45
Although there are very few data, the implication of reduced
CYP2D6 metabolism in patients with low-risk breast cancer
e.g., early-stage breast cancer where the risk of distant recurrence
is low) may be substantially different than in patients with later-
stage disease with a much higher risk of distant recurrence.

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DISCLAIMER

Clinical Pharmacogenetics Implementation Consortium (CPIC) guidelines
reflect expert consensus based on clinical evidence and peer-reviewed
literature available at the time they are written and are intended only to
assist clinicians in decision-making, as well as to identify questions for
further research. New evidence may have emerged since the time a
guideline was submitted for publication. Guidelines are limited in scope
and are not applicable to interventions or diseases not specifically identi-
ﬁed. Guidelines do not account for all individual variation among patients
and cannot be considered inclusive of all proper methods of care or
exclusive of other treatments. It remains the responsibility of the health-
care provider to determine the best course of treatment for the patient.
Adherence to any guideline is voluntary, with the ultimate determination
regarding its application to be solely made by the clinician and the
patient. CPIC assumes no responsibility for any injury to persons or dam-
age to property related to any use of CPIC’s guidelines, or for any errors
or omissions.

Additional Supporting Information may be found in the online version of
this article.

CONFLICT OF INTEREST

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