

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

Matthew P. Goetz<sup>1</sup>, Katrin Sangkuhl<sup>2</sup>, Henk-Jan Guchelaar<sup>3</sup>, Matthias Schwab<sup>4,5,6</sup>, Michael Province<sup>7</sup>, Michelle Whirl-Carrillo<sup>2</sup>, W. Fraser Symmans<sup>8</sup>, Howard L. McLeod<sup>9</sup>, Mark J. Ratain<sup>10</sup>, Hitoshi Zembutsu<sup>11</sup>, Andrea Gaedigk<sup>12</sup>, Ron H. van Schaik<sup>13,14</sup>, James N. Ingle<sup>1</sup>, Kelly E. Caudle<sup>15</sup> and Teri E. Klein<sup>2</sup>

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/](http://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 Table<sup>1</sup>). 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*).<sup>2,3</sup> 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).<sup>3</sup> **Supplemental Table S1** describes the activity score (AS) values assigned to selected alleles. If an allele contains multiple copies of a

<sup>1</sup>Department of Oncology, Department of Molecular Pharmacology and Experimental Therapeutics, Mayo Clinic, Rochester, Minnesota, USA; <sup>2</sup>Department of Biomedical Data Science, Stanford University, Stanford, California, USA; <sup>3</sup>Department of Clinical Pharmacy and Toxicology, Leiden University Medical Center, Leiden, The Netherlands; <sup>4</sup>Dr Margarete Fischer-Bosch-Institute of Clinical Pharmacology, Stuttgart, Germany; <sup>5</sup>Department of Clinical Pharmacology, University Hospital, Tuebingen, Germany; <sup>6</sup>Department of Pharmacy and Biochemistry, University of Tuebingen, Tuebingen, Germany; <sup>7</sup>Division of Statistical Genomics, Washington University School of Medicine, St. Louis, Missouri, USA; <sup>8</sup>Department of Pathology, University of Texas MD Anderson Cancer Center, Houston, Texas, USA; <sup>9</sup>Moffitt Cancer Center, Tampa, Florida, USA; <sup>10</sup>Center for Personalized Therapeutics, University of Chicago, Chicago, Illinois, USA; <sup>11</sup>Division of Human Genetics, National Cancer Center, Research Institute, Tokyo, Japan; <sup>12</sup>Division of Clinical Pharmacology, Toxicology & Therapeutic Innovation, Children's Mercy Kansas City and Department of Pediatrics, University of Missouri-Kansas City, Kansas City, Missouri, USA; <sup>13</sup>International Expertcenter Pharmacogenetics, Dept Clinical Chemistry, Erasmus MC, Rotterdam, The Netherlands; <sup>14</sup>LKCH UMC Utrecht, The Netherlands; <sup>15</sup>Department of Pharmaceutical Sciences, St. Jude Children's Research Hospital, Memphis, Tennessee, USA. Correspondence: Matthew P. Goetz ([goetz.matthew@mayo.edu](mailto:goetz.matthew@mayo.edu); [cpic@pharmgkb.org](mailto:cpic@pharmgkb.org))

**Table 1 Assignment of likely CYP2D6 phenotypes based on genotypes**

Phenotype <sup>a</sup>	Activity score	Genotype	Examples of CYP2D6 diplotypes <sup>b</sup>
Metabolizer			
CYP2D6 ultrarapid metabolizer	> 2.0	An individual carrying duplications of functional alleles	*1/*1xN, *1/*2xN, *2/*2xN <sup>c</sup>
CYP2D6 normal metabolizer	1.5 and 2.0	An individual carrying two normal function alleles or one normal function and one decreased function allele	*1/*1, *1/*2, *1/*9, *1/*41, *2/*2,
CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains) <sup>d</sup>	1.0	An individual carrying two decreased function alleles or one normal function and one no function allele. <i>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.</i>	*1/*4, *1/*5, *41/*41
CYP2D6 intermediate metabolizer	0.5	An individual carrying one decreased function and one no function allele	*4/*10, *4/*41, *5/*9
CYP2D6 poor metabolizer	0	An individual carrying only no functional alleles	*3/*4, *4/*4, *5/*5, *5/*6

<sup>a</sup>See the CYP2D6 frequency table<sup>1</sup> for race-specific allele and phenotype frequencies. <sup>b</sup>For a complete list of CYP2D6 diplotypes and resulting phenotypes, see the CYP2D6 genotype to phenotype table.<sup>1,6</sup> Note that genotypes with an activity score of 1 are classified as NMs in the online CYP2D6 genotype to phenotype table. <sup>c</sup>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 diplotypes into phenotypes. <sup>d</sup>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<sup>1,6</sup>).

functional gene, the value is multiplied by the number of copies present. Thus, 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.<sup>3</sup> (See the CYP2D6 DiploTYPE-Phenotype Table<sup>1</sup> for a complete list of possible diplotypes and phenotype assignment.)

The CYP2D6 AS has been translated into the phenotype classification system for other CPIC guidelines<sup>4,5</sup> as follows (CYP2D6 Allele Definition Table<sup>1</sup>): 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.<sup>4,5</sup> 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<sup>1</sup> and the CPIC will update the CPIC website and this table accordingly when the CYP2D6 genotype to phenotype standardization is complete.<sup>6</sup> 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.PharmVar.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.<sup>1,6</sup>

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 \*1 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**

See Supplemental Material and [www.ncbi.nlm.nih.gov/gtr/](http://www.ncbi.nlm.nih.gov/gtr/) for more information on commercially available clinical testing 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.

### Other considerations

Chromosomal instability, i.e., loss of heterozygosity, is frequently observed in breast tumor tissue.<sup>7,8</sup> 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).<sup>9</sup> 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 halves the annual recurrence rate and reduces the breast cancer mortality rate by one-third in both pre- and postmenopausal women.<sup>10</sup> 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 of 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.<sup>11,12</sup> Furthermore, tamoxifen can exhibit either antiestrogenic or proestrogenic properties, depending on the target tissue and the presence or absence of coactivators or corepressors.<sup>13,14</sup>

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,<sup>15</sup> followed by CYP2D6-mediated oxidation to 4-hydroxy-N-desmethyltamoxifen (endoxifen).<sup>16</sup> 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.<sup>17,18</sup> 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.<sup>11,19–24</sup> Maximum inhibition of estrogen-induced stimulation and ER transcription is achieved with endoxifen concentrations ranging between 100–1,000 nM.<sup>11</sup> 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.<sup>25,26</sup>

Both inter- and intraindividual variation in the concentration of tamoxifen and its metabolites have been described.<sup>16,22,27–29</sup> As it relates to the active metabolites, 4HT concentrations are low, typically <5 nM,<sup>17,22</sup> 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.<sup>17,22,30</sup> 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.<sup>22,31</sup>

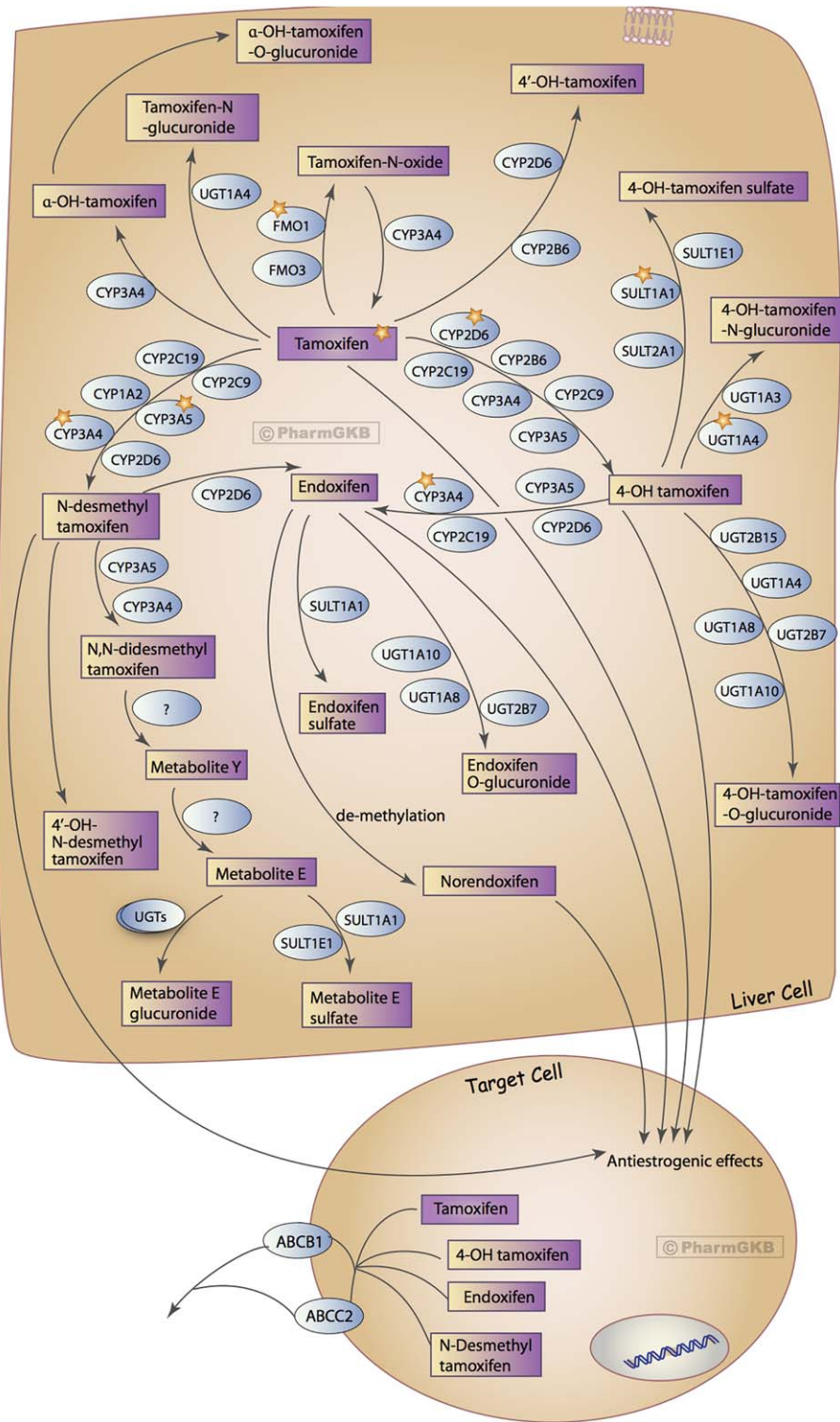
Clinical studies to evaluate the association between endoxifen concentrations and CYP2D6 polymorphisms with tamoxifen outcome have yielded conflicting results. Initial<sup>32</sup> and follow-up data<sup>33,34</sup> demonstrated that CYP2D6 PMs had an ~2–3-fold higher risk of breast cancer recurrence (compared to CYP2D6 NMs) 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.<sup>35</sup> However, this label change was not implemented because of conflicting data from secondary analyses of 5-year tamoxifen prospective trials including ATAC,<sup>36</sup> BIG1–98,<sup>37</sup> and ABCSG 8.<sup>38</sup> 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.<sup>39</sup>

Regarding the role of measurement of endoxifen concentrations, Madlensky *et al.* identified an association between low endoxifen (lowest quintile) and recurrence.<sup>40</sup> 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).<sup>41</sup>

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 NMs, 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.<sup>31</sup>



**Figure 1** Tamoxifen pathway, pharmacokinetics.<sup>57</sup> Permission has been given by PharmGKB and Stanford to use figure.

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*.<sup>42</sup>

**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* genotype<sup>43,44</sup> and based on knowledge that *CYP2D6* PMs patients who switch from tamoxifen to anastrozole do not exhibit an increased risk of recurrence.<sup>38</sup> 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* NMs<sup>45</sup>), the use of an AI ( $\pm$  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,<sup>46</sup> 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.<sup>45</sup> 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,<sup>47</sup> 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.<sup>48–51</sup> Possibly, there is also an increase in tamoxifen drug concentrations, as recently suggested.<sup>52</sup> While a meta-analysis demonstrated an association between *CYP2C19* genotype and increased survival in tamoxifen-treated breast cancer patients,<sup>53</sup> an analysis of the International Tamoxifen Consortium dataset failed to find this correlation,<sup>54</sup> 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 website<sup>6</sup>).

#### 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 tamoxifen,<sup>43,44</sup> and that *CYP2D6* PMs switched from tamoxifen to anastrozole do not exhibit an increased risk of recurrence,<sup>38</sup> 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 2 Dosing recommendations for tamoxifen based on CYP2D6 phenotype**

Phenotype	Activity score	Implications	Therapeutic recommendation <sup>b</sup>	Classification of recommendation <sup>a</sup>
Metabolizer status				
CYP2D6 ultrarapid metabolizer	>2.0	Therapeutic endoxifen concentrations	Avoid moderate and strong CYP2D6 inhibitors. Initiate therapy with recommended standard of care dosing (tamoxifen 20 mg/day).	Strong
CYP2D6 normal metabolizer	1.5 to 2.0	Therapeutic endoxifen concentrations	Avoid moderate and strong CYP2D6 inhibitors. Initiate therapy with recommended standard of care dosing (tamoxifen 20 mg/day).	Strong
CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains) <sup>b</sup>	1.0 (no *10 allele present) <sup>b</sup>	Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.	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. <sup>43</sup> If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). <sup>45</sup> Avoid CYP2D6 strong to weak inhibitors.	Optional <sup>b</sup>
CYP2D6 normal metabolizer or intermediate metabolizer (controversy remains) <sup>b</sup>	1.0 (*10 allele present) <sup>b</sup>	Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.	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. <sup>43</sup> If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). <sup>45</sup> Avoid CYP2D6 strong to weak inhibitors.	Moderate <sup>b</sup>
CYP2D6 intermediate metabolizer	0.5	Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.	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. <sup>43</sup> If aromatase inhibitor use is contraindicated, consideration should be given to use a higher but FDA approved tamoxifen dose (40 mg/day). <sup>45</sup> Avoid CYP2D6 strong to weak inhibitors.	Moderate
CYP2D6 poor metabolizer	0	Lower endoxifen concentrations compared to normal metabolizers; higher risk of breast cancer recurrence, event-free and recurrence-free survival compared to normal metabolizers.	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 <sup>43</sup> and based on knowledge that CYP2D6 poor metabolizers switched from tamoxifen to anastrozole do not have an increased risk of recurrence. <sup>38</sup> 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. <sup>45,56</sup>	Strong

<sup>a</sup>Rating scheme described in the Supplement. <sup>b</sup>CPIC 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 a \*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 information 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 making 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.<sup>55</sup> 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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Additional Supporting Information may be found in the online version of this article.

### CONFLICT OF INTEREST

A.G. is a paid consultant of Millennium Health.

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