



Kansas City

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Assays of Genetic Expression in Tumor Tissue as a Technique to Determine Prognosis in Patients with Breast Cancer

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Policy

Blue Cross and Blue Shield of Kansas City (Blue KC) will provide coverage for assays of genetic expression in tumor tissue as a technique to determine prognosis in patients with breast cancer when it is determined to be medically necessary because the criteria shown below are met.

When Policy Topic is covered

The use of the 21-gene RT-PCR assay (i.e., Oncotype DX) to determine recurrence risk for deciding whether or not to undergo adjuvant chemotherapy may be considered **medically necessary** in women with primary breast cancer meeting the following characteristics:

- unilateral, non-fixed tumor;
- hormone receptor positive (that is, estrogen-receptor [ER]-positive or progesterone-receptor [PR]-positive);
- human epidermal growth factor receptor 2 (HER2) negative;
- tumor size 0.6–1 cm with moderate/poor differentiation or unfavorable features OR tumor size >1cm;
- node negative (lymph nodes with micrometastases (less than 2 mm in size) are considered node negative for this policy statement);
- who will be treated with adjuvant endocrine therapy, e.g., tamoxifen or aromatase inhibitors; AND
- when the test result will aid the patient in making the decision regarding chemotherapy (i.e., when chemotherapy is a therapeutic option); AND
- when ordered within 6 months following diagnosis, since the value of the test for making decisions regarding delayed chemotherapy is unknown.

The 21-gene RT-PCR assay Oncotype DX should only be ordered on a tissue specimen obtained during surgical removal of the tumor and after subsequent pathology examination of the tumor has been completed and determined to meet the above criteria (i.e., the test should not be ordered on a preliminary core biopsy). The test should be ordered in the context of a physician-patient discussion regarding risk preferences when the test result will aid in making decisions regarding chemotherapy.

For patients who otherwise meet the above characteristics but who have multiple ipsilateral primaries, a specimen from the tumor with the most aggressive histological characteristics should be submitted for testing, as this is how prognosis is clinically determined. It is not necessary to conduct Oncotype DX testing on each tumor.

When Policy Topic is not covered

All other indications for the 21-gene RT-pcr assay (i.e., Oncotype DX™), including determination of recurrence risk in breast cancer patients who are lymph node positive or patients with bilateral disease, are considered **investigational**.

The use of other gene expression assays (e.g., MammaPrint 70-gene signature, Mammostrat Breast Cancer Test, the Breast Cancer Index, the BreastOncPx, NexCourse® Breast IHC4, Prosigna™, BreastPRS and EndoPredict) for any indication is considered **investigational**.

The use of gene expression assays in men with breast cancer is considered **investigational**.

The use of gene expression assays to molecularly subclassify breast cancer (e.g., BluePrint) is considered **investigational**.

The use of gene expression assays for quantitative assessment of ER, PR and HER2 overexpression (e.g., TargetPrint) is considered **investigational**.

Considerations

Unfavorable features that may prompt testing in tumors from 0.6 to 1 cm in size include the following: angiolymphatic invasion, high histologic grade, or high nuclear grade.

The 21-gene reverse transcriptase-polymerase chain reaction (RT-PCR) assay Oncotype DX®, should not be ordered as a substitute for standard estrogen receptor, progesterone receptor, or human epidermal growth factor receptor 2 (HER2) testing.

The current American Society of Clinical Oncology-College of American Pathologists guideline, “Recommendations for Human Epidermal Growth Factor Receptor 2 Testing in Breast Cancer,”(1) defines positive, negative, and equivocal HER2 test results as shown in Table 2. ASCO/CAP Definitions of HER2 Test Results(1)

Result	Immunohistochemistry	Fluorescence in situ hybridization
Negative	0 or 1+: No staining or weak, incomplete membrane staining in any proportion of tumor cells	Ratio of <i>HER2</i> /CEP17a is <1.8 Or An average of <4 copies of <i>HER2</i> gene per nucleus
Positive	3+: At least 30% of tumor cells exhibit intense membrane staining	Ratio of <i>HER2</i> /CEP17 is >2.2 Or An average of >6 copies of <i>HER2</i> gene per nucleus
Equivocal	2+: Complete membrane staining that is either nonuniform or weak in intensity but with obvious circumferential distribution in at least 10% of cells	Ratio of <i>HER2</i> /CEP 17 is between 1.8 and 2.2 or An average of 4 to 6 copies of <i>HER2</i> gene per nucleus

CEP, chromosome enumeration probe; HER2, human epidermal growth factor receptor 2

a CEP 17 is a centromeric probe for chromosome 17 (internal control probe).

bSignals per nucleus for test systems without an internal central probe

Description of Procedure or Service

Laboratory tests have been developed that detect the expression, via messenger RNA (mRNA) or protein, of many different genes in breast tumor tissue and combine the results into a prediction of distant recurrence risk for women with early stage breast cancer. Test results may help providers and patients decide whether to include adjuvant chemotherapy in post-surgical management.

Background

For women with early-stage breast cancer, adjuvant chemotherapy provides the same proportional benefit regardless of prognosis. However, the absolute benefit of chemotherapy depends on the baseline risk of recurrence. For example, women with the best prognosis have small tumors, are

estrogen-receptor-positive, and lymph node negative. These women have an approximately 15% baseline risk of recurrence; approximately 85% of these patients would be disease free at 10 years with tamoxifen treatment alone and could avoid the toxicity of chemotherapy, if they could be accurately identified. Conventional risk classifiers estimate recurrence risk by considering criteria such as tumor size, type, grade, and histologic characteristics; hormone receptor status; and lymph node status. However, no single classifier is considered a gold standard, and several common criteria have qualitative or subjective components that add variability to risk estimates. As a result, more patients are treated with chemotherapy than can benefit. Better predictors of baseline risk could help women, who prefer to avoid chemotherapy if assured that their risk is low, make better treatment decisions in consultation with their physicians.

Recently, several groups have identified panels of gene expression markers (“signatures”) that appear to predict the baseline risk of invasive breast cancer recurrence after surgery, radiotherapy, and endocrine therapy (for hormone receptor-positive tumors). Several gene expression tests commercially available in the U.S. are listed in Table 1. If these panels are more accurate risk predictors than current conventional classifiers, they could be used to aid chemotherapy decision making when current guidelines do not strongly advocate chemotherapy, without negatively affecting disease-free and overall survival (OS).

Table 1. Gene Expression Tests for Breast Cancer Commercially Available in the U.S.

Test	Manufacturer	Description
Oncotype DX®	Genomic Health	21-gene RT-PCR
MammaPrint®	Agendia	70-gene DNA microarray
<ul style="list-style-type: none"> ▪ Blueprint® ▪ TargetPrint® 	Agendia	Both tests are intended for use with MammaPrint®: <ul style="list-style-type: none"> ▪ Blueprint®: 80-gene subtype classifier ▪ TargetPrint®: quantitative ER, PR and HER2 microarray
Breast Cancer Index SM	bioTheranostics	Combines MGI and the HOXB13:IL17BR (H/I) Index
Mammostrat® Breast Cancer Test	Clariant Diagnostic Services	IHC assay of 5 biomarkers independent of tumor proliferation and grade
BreastOncP _x TM (Breast Cancer Prognosis Gene Expression Assay)	LabCorp	14-gene RT-PCR
NexCourse® Breast IHC4	Geneoptix	IHC assay of ER, PR, HER2, and Ki-67
Prosigna TM	NanoString Technologies	DNA microarray based on the PAM50 breast cancer intrinsic subtype classifier
BreastPRS TM	Signal Genetics	200-gene assay
EndoPredict TM	Sividon Diagnostics	12-gene RT-PCR

ER, estrogen receptor; HER2, human epidermal growth factor receptor 2; IHC, immunohistochemistry; Ki-67, a marker of tumor proliferation; MGI, Molecular Grade Index; PAM50, prediction analysis of microarray 50 gene set; PR, progesterone receptor; RT-PCR, real-time reverse transcriptase-polymerase chain reaction

Blueprint® and TargetPrint®

Gene expression patterns have led to the identification of molecular subtypes of breast cancer, which have different prognoses and responses to treatment regimens. These molecular subtypes are largely distinguished by the differential expression of estrogen receptors (ER), progesterone receptors (PR) and human epidermal growth factor receptor 2 (HER2) in the tumor, and are classified as luminal, basal

or HER2 type. Luminal-like breast cancers are ER positive, basal-like breast cancers correlate best with ER, PR and HER2 negative (“triple negative”), and HER2 type with high expression of HER2.

At present, the methodology for molecular subtyping is not standardized, and breast cancer subtyping is routinely assessed by immunohistochemistry (IHC) and fluorescence in situ hybridization (FISH).

BluePrint® is an 80-gene expression assay which classifies breast cancer into basal type, luminal type or ERBB2-type. The test is marketed as an additional stratification into a molecular subtype following risk assessment with MammaPrint.

TargetPrint® is a microarray-based gene expression test which offers a quantitative assessment of ER, PR and HER2 overexpression in breast cancer. The test is marketed to be used in conjunction with MammaPrint and BluePrint.

Regulatory Status

MammaPrint® was U.S. Food and Drug Association (FDA)-approved on February 6, 2007.

MammaPrint® is performed in Agendia laboratories in the Netherlands and in California.

Prosigna™ received 510(k) clearance from FDA based on substantial equivalence to MammaPrint® on September 6, 2013.

Other tests mentioned in this policy are offered as laboratory-developed tests under Clinical Laboratory Improvement Amendments (CLIA)-licensed laboratories. Clinical laboratories may develop and validate tests in-house and market them as a laboratory service; laboratories offering such tests as a clinical service must meet general regulatory standards of CLIA and must be licensed by CLIA for high-complexity testing.

Rationale

This policy was created in 2004, and has been updated periodically with literature searches using MEDLINE. The most recent search covered the period through June 14, 2014.

In 2014, a TEC Assessment addressed gene expression profiling in women with lymph node-negative breast cancer to select adjuvant chemotherapy, specifically use of Oncotype DX®, MammaPrint®, the Breast Cancer IndexSM, and Prosigna™/PAM50 gene expression assay.(2) The Assessment concluded that use of Oncotype DX® to determine recurrence risk for deciding whether to undergo adjuvant chemotherapy in women with unilateral, hormone receptor-positive, lymph node-negative breast cancer who will receive hormonal therapy meets the Blue Cross and Blue Shield Association Technology Evaluation Center (TEC) criteria; and that use of MammaPrint®, the Breast Cancer IndexSM, and Prosigna™ to determine recurrence risk in women with unilateral, hormone receptor-positive, lymph node-negative breast cancer who will receive hormonal therapy does not meet TEC criteria.

This policy evidence review is based on the above TEC Assessment and on published evidence related to the assays listed in the Background.

Oncotype DX®

Description

The initial indication for the 21-gene expression profile (Oncotype DX®) was for patients newly diagnosed with stage 1 or 2, lymph node-negative, estrogen-receptor (ER)-positive invasive breast cancer who would be treated with tamoxifen. Primary validation studies enrolled node-negative patients; this indication is reviewed first. More recently, Genomic Health has expanded indications for Oncotype DX® to include all stage 2 disease (tumor ≤2 cm with spread to axillary lymph nodes or 2-5

cm without lymph node involvement) and ductal carcinoma in situ (DCIS); these indications are reviewed separately.

Results from the Oncotype DX® 21-gene expression profile are combined into a recurrence score (RS). Based on a study of analytic validity, tissue sampling rather than technical performance of the assay is likely to be the greatest source of variability in results.(3) The 21-gene expression profile was validated in studies using archived tumor samples from subsets of patients enrolled in already completed randomized controlled trials (RCTs) of early breast cancer treatment. Patients enrolled in the trial arms from which specimens were obtained had primary, unilateral breast cancer with no history of prior cancer and were treated with tamoxifen; tumors were ER-positive, most were human epidermal growth factor receptor 2 (HER2)-negative, and in the case of at least 1 trial, (4) multifocal tumors were excluded.

Lymph Node-Negative Patients

Studies delineating the association between the 21-gene RS and recurrence risk are shown in Table 3.(5-8) Results indicated strong, independent associations between the RS and distant disease recurrence or death from breast cancer.(5, 8) In secondary reclassification analyses of the Paik et al data,(6) Bryant et al(7) (published in Tang et al(9)) classified individual patient risk levels by conventional risk classifiers, then reclassified patients by Oncotype DX®. Oncotype DX® added additional risk information to the conventional clinical classification of individual high-risk patients and identified a subset of patients who would otherwise be recommended for chemotherapy but who were actually at lower risk of recurrence (average 7% to 9% risk at 10 years; upper 95% confidence interval [CI] limits, 11% to 15%). The analysis did not indicate significant erroneous reclassification given known outcomes. Thus, a woman who prefers to avoid the toxicity and inconvenience of chemotherapy and whose Oncotype DX® RS value shows that she is at very low risk of recurrence might reasonably decline chemotherapy. The lower the RS value, the greater the confidence the woman can have that chemotherapy will not provide net benefit; outcomes are improved by avoiding chemotherapy toxicity.

An additional study, in which samples from a RCT of ER-positive, node-negative breast cancer patients treated with tamoxifen versus tamoxifen plus chemotherapy were tested by Oncotype DX, provides supportive evidence. RS high-risk patients derived clear benefit from chemotherapy, whereas the average benefit for other patients was statistically not significant, although the confidence intervals were wide and included the possibility of a small benefit.(4)

TEC Assessment. The 2014 Assessment concluded that the 21-gene RT-PCR assay Oncotype DX® meets criteria for women similar to those in the validation studies, ie, women younger than 70 years of age (or with a life expectancy >10 years), with unilateral, ER-positive, node-negative (by full axillary dissection) invasive carcinomas, who are treated with surgery (mastectomy or lumpectomy), radiotherapy, and tamoxifen. In 1 trial, patients in the experimental arm also were treated with cyclophosphamide, methotrexate, and 5-fluorouracil (CMF) chemotherapy. Most (92%) patients were negative for HER2.(2)

Because clinical care for breast cancer patients has evolved since the original trials from which archived samples were acquired for assay validation, differences in evaluation and treatment regimens were considered. It was concluded that the 21-gene Oncotype DX® meets TEC criteria for the following women with node-negative invasive breast cancer:

- Those receiving aromatase inhibitor (AI)-based endocrine therapy instead of tamoxifen therapy: AI-based therapy would likely reduce recurrence rates for all RS risk groups. Thus, if a patient declined chemotherapy today on the basis of a low-risk RS (risk categories defined by outcomes with tamoxifen treatment), the even lower risk associated with AI treatment would not change that decision. This has been confirmed in the prospectively planned and blinded analysis of samples from the completed Arimidex, Tamoxifen, Alone or in Combination (ATAC) Trial, which evaluated 5 years of anastrozole, tamoxifen, or both in postmenopausal women with localized breast cancer.(10) Relative risk reduction for anastrozole compared with tamoxifen was similar across

different RS values, and risk for distant recurrence in RS low-risk patients was as low or lower than reported in the original validation studies.

- Those receiving anthracycline-based chemotherapy instead of CMF: The type of chemotherapy does not change interpretation of the Oncotype DX® risk estimate. Additionally, a recent meta-analysis indicated that anthracyclines do not improve disease-free survival (DFS) or overall survival (OS) in women with early, HER2-negative breast cancer, (11) and therefore may not be prescribed in this population.
- Lymph nodes with micrometastases are not considered positive for purposes of treatment recommendations.(12) Current practice largely involves a detailed histologic examination of sentinel lymph nodes, allowing for the detection of micrometastases (<2 mm in size).
- Those whose tumors are ER-positive or progesterone-receptor (PR)-positive: Only ER-positive women were enrolled in Oncotype DX® validation studies, whereas current clinical guidelines include either ER or PR positivity in the treatment pathway for hormone receptor-positive women with early breast cancer.(12) Some studies have shown that ER-negative/PR-positive patients also tend to benefit from endocrine therapy.(13, 14) Studies documenting the low incidence (1% to 4%) and instability (lack of reproducibility) of the ER-negative/PR-positive subtype(15) and the reduction in reports of this subtype with improved assay techniques(16) suggest that this subtype may represent a false negative result.

Papers related to the use of Oncotype DX® that have been published since the 2014 Assessment will be briefly mentioned.

Tzeng et al (2010) examined how women receive and incorporate results of Oncotype DX® using mailed survey and chart review.(17) Approximately two thirds of women believed they understood most or all of what they were told about their recurrence risk based on their test results; most who experienced test-related distress had intermediate or high estimated recurrence risks by RS result. The objective, recalled, and perceived recurrence risks by women in the study were surprisingly similar, and 95% agreed that the test gave them a better understanding of their treatment options and chances of success. However, approximately one third of women believed they understood only a moderate amount or less during these discussions. The study was limited in generalizability in that participants were mostly white, well-educated women who had health insurance and came from urban areas.

Several studies have been published regarding the impact of RS results on chemotherapy recommendations by medical oncologists.(18-28) These studies generally reported that decisions changed for 25% to 40% of patients with physician knowledge of RS, most often from endocrine therapy plus chemotherapy to endocrine therapy alone. For example:

- In a retrospective reclassification analysis, Joh et al (2011) found that addition of Oncotype DX® RS resulted in a 25% change in (after-the-fact) treatment recommendations, resulting in fewer patients projected to receive chemotherapy.(25)
- Hassett et al (2012) evaluated registry data from the National Comprehensive Cancer Network (NCCN) Breast Cancer Outcomes Database Project focusing on women diagnosed with hormone-receptor (HR)-positive stage 2 to 3 unilateral breast cancer during 2006 to 2008. (24) Compared with women who had Oncotype-determined intermediate-risk cancer, women who had Oncotype-determined high-risk cancers were more likely to receive chemotherapy (odds ratio [OR]=12.0 [95% CI, 6.7 to 21.3]), and women with low-risk cancers were less likely to receive chemotherapy (OR=0.1 [95% CI, 0.1 to 0.2]).
- Carlson et al (2013) conducted a systematic review of studies of Oncotype DX® used to inform actual adjuvant chemotherapy decisions in ER-positive, lymph node-negative patients with early stage breast cancer.(26) In 8 identified studies (total N=1437), Oncotype DX® RS changed the chemotherapy recommendation based on clinical-pathologic factors in 33% of patients. Compared with Oncotype DX® high risk patients, low risk patients were statistically more likely to follow Oncotype DX®-directed treatment (relative risk [RR]=1.07 [95% CI, 1.01 to 1.14]).

Some view these studies as evidence of clinical utility because more patients avoid the toxicity of chemotherapy (29); however, actual patient outcomes were not reported in these studies. Additionally, none of the studies formalized and described how information was delivered to patients, nor did they

evaluate how patient preferences were incorporated into final treatment decisions. Lo et al (2010) conducted a prospective multicenter study that examined both physician and patient treatment selection, as well as impact of RS results on patients' anxiety, quality of life, and satisfaction with choice of treatment.(18) However, the study did not ensure that results were presented in a consistent format for all patients.

Ongoing Trials

Limitations of the current evidence, such as confirmation of optimal RS cutoff values for tamoxifen-treated and separately for AI-treated patients and recommendations for patients with intermediate RS values, are likely to be answered by results of the ongoing Trial Assigning Individualized Options for Treatment (Rx), also known as TAILORx (NCT00310180).(30)

Table 3. Summary of Oncotype DX® Recurrence Score and Recurrence Risk Studies

Study Study Type	Total N	Study Objective	Results
Paik 2004(5) TAM arm of NSABP B- 14 RCT	668	Predict recurrence	RS risk % of patients K-M distant recurrence at 10 yr % (95% CI) Low (<18) 51 6.8 (4.0–9.6) Intermed (18–30) 22 14.3 (8.3–20.3) High (>31) 27 30.5 (23.6–37.4) All 100 15 (12.5–17.9)
Paik 2004(6) Additional analysis of Paik 2004(5) data	668	Reclassification study; determine incremental risk compared with conventional classifier	Risk Risk N % DRF at 10 yr classification reclassification (95% CIb) by NCCNa by Oncotype DX® Low (8%) Low 38 100 (NR) Intermed 12 80 (59–100) High 3 56 (13–100) High (92%) Low 301 93 (89–96) Intermed 137 86 (80–92) High 178 70 (62–77)
Bryant 2005(7); Tang 2011(9) Additional analysis of Paik et al 2004(5) data	668	Reclassification study; determine incremental risk compared with conventional classifier	Risk Risk N % recurrence at classification reclassification 10 years by Adjuvant! by Oncotype DX® (95%CIb) Onlinea Low (53%) Low 214 5.6 (2.5-9) Int-High 140 12.9 (7-19) Int-High (47%) Low 120 8.9 (4-14) Int-High 194 30.7 (24-38)
Habel 2006(8) Case control	255 ER+ TAM+; 361 ER+ TAM-	Predict mortality	RS risk 10-yr absolute risk of death, % (95% CI) ER+, TAM-treated ER+, No TAM Low (<18) 2.8 (1.7–3.9) 6.2 (4.5–7.9) Int (18–30) 10.7 (6.3–14.9) 17.8 (11.8–23.3) High (>31) 15.5 (7.6–22.8) 19.9 (14.2–25.2)

DRF, distant recurrence-free; ER, estrogen receptor; N, total number of patients; NR, not reported; RS, Oncotype DX® recurrence score; K-M, Kaplan Meier; NSABP, National Surgical Adjuvant Breast and Bowel Project; RCT, randomized controlled trial; TAM, tamoxifen; NCCN, National Comprehensive Cancer Network (2004); Int/Intermed, Intermediate.

a Percentages are percent of total N.

b Estimated from graphs. Note that different outcomes were reported between Paik et al 2004(6) and Bryant 2005(7, 9) and could not be converted to similar outcomes with confidence intervals.

Lymph Node-Positive Patients

Albain et al (2010) evaluated samples from the Southwest Oncology Group Trial 8814, in which randomized node-positive, ER-positive patients treated with tamoxifen for 5 years were compared with those treated with cyclophosphamide, doxorubicin, fluorouracil (CAF) chemotherapy followed by tamoxifen (CAF-T) for 5 years.(31) Samples were available for determination of RS for 41% (n=148) and 39% (n=219) of the trial arms, respectively.

In this study, 10-year DFS and OS outcomes in the tamoxifen study arm differed by RS risk category (stratified log-rank tests, $p=0.017$ and 0.003 , respectively), suggesting that the RS is prognostic. When the 2 treatment arms were compared within RS risk categories, only patients in the high RS category significantly benefited from the addition of CAF to tamoxifen (10-year DFS, 42% [tamoxifen] vs 55% [CAF-T], $p=0.033$; 10-year OS, 51% [tamoxifen] vs 68% [CAF-T], $p=0.027$), suggesting that RS is also predictive of response to chemotherapy.

A multivariate analysis of RS interaction with disease-free survival (DFS), adjusted for number of positive nodes, was significant for the first 5 years of follow-up at $p=0.029$ and remained significant after adjusting for age, race, tumor size, PR status, grade, p53, and HER2. However, the interaction was not significant ($p=0.15$) after adjusting for ER level (ER gene expression is a component of the 21-gene profile). Interaction results were similar for OS.

Dowsett et al (2010) included a separate evaluation of node-positive patients in their examination of the ATAC trial samples.(10) Of 306 node-positive patients, 243 had 1-to 3 involved nodes, and 63 had 4 or more; these were not evaluated separately. Rates of distant recurrence at 9 years were 17% (95% CI, 12% to 24%), 28% (95% CI, 20% to 39%), and 49% (95% CI, 35% to 64%), in low, intermediate, and high RS risk groups, respectively. It is unclear that the risk of distant recurrence in low-risk RS patients would be sufficiently low to forgo the choice of chemotherapy. The authors note that their study “did not directly evaluate the value of RS in predicting the benefit of chemotherapy.”

Goldstein et al (2008) evaluated samples from the Eastern Cooperative Oncology Group E2197 trial, which included patients with 0 to 3 positive lymph nodes and operable tumor greater than 1 cm.(32) Patients were randomly assigned to doxorubicin plus cyclophosphamide or docetaxel plus 5 years of endocrine therapy; outcomes were not significantly different for the study arms. A case-control study of samples from this trial found that low-risk RS patients with 0 to 1 positive nodes had a recurrence risk of 3.3% (95% CI, 2.2 to 5), and low-risk patients with 2 to 3 positive nodes had a recurrence risk of 7.9% (95% CI, 4.3 to 14.1). RS also was a significant predictor of risk regardless of nodal status.

Chang et al (2008) reported that in women with locally advanced breast cancer treated with neoadjuvant docetaxel (N=97), a complete response was more likely in those with a high RS ($p=0.008$).(33) Gianni et al (2005) studied 93 patients with locally advanced breast cancer who received neoadjuvant taxane chemotherapy, then postsurgery CMF treatment and tamoxifen (if ER-positive).(34) Pathologic complete response was more likely in patients with high RS than with low RS ($p<0.01$).

One study surveyed oncologists ordering the 21-gene profile for lymph node-positive patients to determine the effect of assay results on treatment recommendations.(35) Approximately half of oncologists who replied (16% response rate) changed their recommendations after receiving RS results, with 33% recommending endocrine therapy alone instead of endocrine plus chemotherapy. However, only medical oncologists who were already using the assay were surveyed, thus biasing the results. Finally, no outcomes were reported, providing no firm evidence of clinical utility.

Ongoing Trials

Additional studies are necessary before it is possible to confidently withhold currently-recommended chemotherapy (12) from lymph node-positive invasive breast cancer patients with low/intermediate RS results. The RxPONDER (Rx for Positive Node, Endocrine Responsive Breast Cancer) trial (NCT01272037), led by the Southwest Oncology Group, will enroll 4000 women with RS of 25 or less who have early-stage, HR-positive, HER2-negative breast cancer involving 1 to 3 lymph nodes. Patients will be randomized to receive either chemotherapy with endocrine therapy or endocrine therapy alone. Primary completion is expected December 2016.

Patients with DCIS

DCIS is breast cancer located in the lining of the mammary ducts that has not yet invaded nearby tissues. It may progress to invasive cancer if untreated. The incidence of DCIS diagnosis in the U.S. has increased in tandem with the widespread use of screening mammography, accounting for about 20% of all newly diagnosed invasive plus noninvasive breast tumors. Recommended treatment is lumpectomy (mastectomy is also an option) with or without radiation treatment; postsurgical tamoxifen treatment is recommended for ER-positive DCIS, especially if excision alone is used. Because the overall rate of ipsilateral tumor recurrence (DCIS or invasive carcinoma) is about 25% at 10 years, it is believed many women are overtreated with radiotherapy. Thus, accurate prediction of recurrence risk may identify those women who may safely avoid radiation.

The Oncotype DX® DCIS test uses information from 12 of the 21 genes assayed in the standard Oncotype DX® test for early breast cancer to predict 10-year risk of local recurrence (DCIS or invasive carcinoma). The stated purpose is to help guide treatment decision-making in women with DCIS treated by local excision, with or without adjuvant tamoxifen therapy.

According to the Oncotype website, analyses from the National Surgical Adjuvant Breast and Bowel Project (NSABP) B-14 study (5, 36) and a case-control study by Habel et al (2006)(8) were used to select genes that predict the risk of recurrence independent of tamoxifen treatment and ER status. In a retrospective analysis of data and samples from patients in the prospective Eastern Cooperative Oncology Group E5194 study, the Oncotype DX® Score for DCIS was compared with 10-year recurrence risk in a subset of DCIS patients treated only with surgery and some with tamoxifen (n=327).(37) Oncotype DX® DCIS Score was significantly associated with recurrence outcomes (HR=2.31 [95% CI, 1.15 to 4.49]; p=0.02) whether or not patients were treated with tamoxifen. The standard Oncotype DX® Score for early breast cancer was not associated with DCIS recurrence outcomes. These studies addressed the development of the Oncotype DX® DCIS Score and clinical validity (association of the test result with recurrence outcomes). Whether women are better categorized as to their recurrence risk by Oncotype DX® DCIS Score compared with standard clinical indicators of risk has not been addressed.

MammaPrint®

MammaPrint, also called the 70-gene signature, is a prognostic test for women with ER-positive or ER-negative, lymph node-negative invasive breast cancer. The 2014 TEC Assessment(2) reviewed available studies (38-49) and found insufficient evidence to determine whether MammaPrint® is better than conventional risk assessment tools in predicting recurrence. Limited technical performance evaluation of the commercial version of the assay, using fresh frozen tumor samples, suggested good reproducibility. In 2014, Sapino et al published a validation study of MammaPrint® using FFPE tissue.(50) In a validation set of 221 tumor samples, concordance of FFPE and frozen tissue low- and high-risk classification was 91.5%(95% CI, 86.9 to 94.5). Concordance of repeat analyses of the same tumor was 96%, and interlaboratory reproducibility (ie, between labs in the Netherlands and in California) was 96%.

Studies of Primarily Node-Negative Disease

In studies reviewed in the TEC Assessment, recurrence rates of patients classified by MammaPrint® as low risk were 15% to 25%, likely too high for most patients and physicians to consider forgoing chemotherapy. Similarly, in 1 study, after Adjuvant! Online risk classification, patients reclassified as low risk by the 70-gene signature in either Adjuvant! Online risk group had 10-year DFS rates of 88% to 89%, with lower confidence limits of 74% to 77%. Patients reclassified as high risk had 10-year DFS rates of 69%, with lower confidence limits of 45% to 61% and upper confidence limits of 76% to 84%. Receiver operating characteristic (ROC) analyses suggested both small(42) and large(44) improvements in risk prediction with MammaPrint® added to a conventional risk classifier (Adjuvant! Online).

Because initial studies had been conducted on samples from younger patients (age younger than 61 years), Wittner et al (2008) studied a cohort of 100 lymph node-negative patients with a median age of 62.5 years and a median follow-up of 11.3 years.(51) Twenty-seven low-risk patients by MammaPrint® had distant metastasis-free survival at 10 years of 100%. However, the study was underpowered, and patients were heterogeneous in terms of ER-positivity (73%), endocrine therapy (25%), and chemotherapy (23%) making conclusions difficult. An additional small study of samples from women with lymph node-negative disease suggested that the 70-gene signature was an independent and significant predictor of distant metastases, but the small number of events limited conclusions.(52)

Original validation studies included patients with both node-negative and node-positive disease. Mook et al (2010) retrospectively evaluated 148 consecutive, node-negative, postmenopausal patients, with primarily ER-positive tumors; only 18% received 2 years of adjuvant tamoxifen and none received chemotherapy.(46) For the 61% with good prognosis, 5-year distant metastasis-free survival (DMFS) probability was 93% (95% CI, 87 to 99), whereas for those with poor prognosis, DMFS was 72% (95% CI, 60 to 84). The authors reported on concordance with Adjuvant! Online, but did not conduct a net reclassification analysis to determine additional impact of the MammaPrint® signature on outcomes.

The Microarray Prognostics in Breast Cancer (RASTER) study was designed to assess feasibility of implementation and impact on treatment decisions of the MammaPrint® 70-gene signature, as well as assess recurrence outcomes.(53) Five-year follow-up results of 427 node-negative, early stage breast cancer patients who participated in the RASTER Study and had a 70-gene signature (MammaPrint®) were published in 2013. (54) Use of MammaPrint® to help direct postsurgery treatment decisions was compared with Adjuvant! Online (AOL). Patients were aged 18- to 61 years and had a histologically-confirmed, unilateral, unifocal, primary operable, invasive adenocarcinoma of the breast. Median follow-up was 61.6 months. Eighty percent of patients were ER-positive. Discordant risk classifications occurred in 161 (38%) of 427 cases: 124 (29%) of 427 cases were discordant MammaPrint® low risk and AOL high risk, and 37 (9%) of 427 cases were discordant MammaPrint® high risk and AOL low risk. Use of MammaPrint® reduced the proportion of AOL high-risk patients by 20% (87/427). Five-year distant recurrence-free interval (DRFI) probabilities were excellent for patients who were clinically high risk but had a low-risk score with MammaPrint®, even in the absence of adjuvant systemic therapy. Results of patients receiving adjuvant therapy are presented in Table 4. Results suggested that MammaPrint® is a better prognostic classifier than standard clinical and pathologic classifiers. However, the study had several limitations. Patient numbers are low, and event numbers very low, making firm conclusions difficult. Actual treatment decisions were based on restrictive Dutch guidelines from 2004 and patients' and doctors' preferences. Additionally, AOL risk estimates were calibrated for 10-year outcomes, whereas RASTER outcomes were at 5 years. Because most clinical relapses in lymph node-negative, ER-positive breast cancers do not occur until 5 or even 10 years after diagnosis, with or without the use of adjuvant therapy, study data should be considered not yet mature.

Table 4. Five-Year Results of the RASTER Study: DRFI in MammaPrint®- and Adjuvant! Online-Classified Patients who Received Adjuvant Systemic Treatment

70-Gene Signature Category	Adjuvant! Online Category	AST	5-year DRFI, % (95% CI)
Low	Low	7/95 (7%)	95.3 (90.9 to 100)
High	Low	32/37 (86%)	100.0 (100 to 100)

Low	High	54/124 (44%)	98.4 (96.1 to 100)
High	High	166/171 (97%)	89.8 (85.1 to 94.8)

AST, adjuvant systemic therapy; DRFI, distant recurrence-free interval

Drukker et al (2014) reported additional comparisons between MammaPrint® and clinical risk classifiers in RASTER patients.(55) As measured by ROC analyses, MammaPrint® improved prognostic performance of all 6 clinical classifiers studied (Adjuvant! Online, Nottingham Prognostic Index, St. Gallen [2003], Dutch National guidelines [2004 and 2012], and PREDICT Plus, a clinicopathologic algorithm for estimating 5- and 10-year survival probabilities). However, area under the ROC curve for the best performing combination, MammaPrint® and PREDICT Plus, was only 0.662. Five-year distant recurrence-free survival estimates in 158 untreated patients who were classified by MammaPrint® as low risk are shown in Table 5. Among MammaPrint® low-risk patients, 5-year survival estimates for patients classified as low or high risk by clinical risk classifiers were similar; only PREDICT Plus included the possibility of a less than 10% survival estimate for high-risk patients. Survival estimates for untreated patients classified as high risk by MammaPrint® were not reported, limiting full comparison of these risk stratifiers.

Table 5. Five-Year Distant Recurrence-Free Survival Estimates of 158 Untreated RASTER Patients Classified as Low Risk by MammaPrint®

	Low Risk			High Risk		
	%n	Estimate	95% CI	%n	Estimate	95% CI
Adjuvant! Online	56	95.0	90.3 to 99.9	44	100.0	100.0 to 100.0
NPI	97	97.1	94.3 to 100.0	3	100.0	100.0 to 100.0
St. Gallen 2003	37	98.2	94.8 to 100.0	63	96.6	92.8 to 100.0
Dutch National guidelines 2004	96	97.1	94.3 to 100.0	4	100.0	100.0 to 100.0
Dutch National guidelines 2012	53	98.8	96.3 to 100.0	47	95.4	90.4 to 100.0
PREDICT Plus	89	97.6	94.9 to 100.0	11	94.1	83.6 to 100.0

%n, proportion of patients classified; NPI, Nottingham Prognostic Index

Studies of Mixed or Node-Positive Disease

In a study of node-positive disease, Mook et al (2009) evaluated 241 patients with 1 to 3 positive nodes and primarily ER-positive, HER2-negative tumors treated variably.(56) The 70-gene signature was a significant predictor of outcome. Reclassification analysis using Adjuvant! Online versus MammaPrint® showed significant additional discrimination of outcomes by the gene signature, but all were confounded by heterogeneous patient treatment. This study also updated the results of 106 patients with 1 to 3 positive nodes from the validation study,(38) reporting 10-year breast cancer-specific survival of 98% (95% CI, 94 to 100) for good prognosis signatures and 64% (95% CI, 52 to 76) for poor prognosis signatures (adjusted HR=3.63 [95% CI, 0.88 to 15.0], log-rank test, p=0.07. Based on these results, the ongoing MINDACT trial of MammaPrint® was enlarged to include patients with 1 to 3 positive lymph nodes. Pilot phase results of the MINDACT trial were published in 2011 and showed successful implementation of the biomarker-stratified trial design and compliance with chemotherapy treatment according to MammaPrint® risk of recurrence classification.(57)

The 2012 I-SPY trial evaluated 237 patients with locally advanced, lymph node-positive disease by correlating imaging and MammaPrint® signatures with outcomes of pathologic complete response (pCR) and recurrence-free survival (RFS).(58) Despite having locally advanced disease, patients with 70-gene low-risk profiles tended not to respond to chemotherapy and to have good short-term RFS. Results are shown in Table 6.

Table 6. Results of I-SPY 1: MammaPrint® 70-Gene Signature Results and Trial Outcomes

MammaPrint Risk Category N (%)	Pathologic Complete Response (pCR)		Recurrence-Free Survival (RFS)	
	Proportion of patients with pCR, % (n/N)	P value of odds ratio	3-yr RFS, % (n/N)	Hazard ratio, pCR vs no
Low 11 (9)	0% (0/11)	0.00	100% (11/11)	0.00 (-)
High 109 (91)	24% (25/105)	0.02	75% (80/105)	0.29a (0.07 to 0.82)

a Denotes significant proportional hazard ratio (likelihood ratio $p < 0.05$). A value of 0.00 indicates that there were no recurrences in this category among patients who had a pCR.

Other studies comprised primarily small case series and pooled reanalyses of subgroups from previously published retrospective studies. A pooled analysis of 964 patients from previously reported studies with pT1 tumors (≤ 2 cm) included 84% with ER-positive tumors, 68% with HER2-negative tumors (no HER2 information on 23%), 27% with node-positive disease, 68% given no adjuvant treatment, and the rest treated variably.(45) In these patients, overall DMFS at 10 years was 87% (95% CI, 84 to 91) for good prognosis patients and 72% (95% CI, 66 to 78) for poor prognosis patients. (HR=2.7 ;95% CI, 1.88 to 3.88; $p < 0.001$). Results are confounded by nodal status, HER2 status, and adjuvant therapy.

Kunz et al (2011) conducted a pooled reanalysis of a subgroup of patients age 35 to 55 years from previously published studies.(59) Patients were 75% ER-positive and 45% node-positive; 60% were untreated, and 40% were treated variably. The 70-gene signature categorized 39% of patients as good prognosis; for these patients, 10-year DMFS was 88% (95% CI, 84 to 92). Bighin et al (2010) commented that nearly 25% of samples from 21 prospectively studied patients were not assessable by the 70-gene signature and that results led to a change in clinical decision in fewer than 20% of cases.(60)

Retel et al (2010) reported a cost-effectiveness analysis that simulated the course of events in a hypothetical cohort of 1000 patients age 50 years who had early operable, node-negative, ER-positive breast cancer, and were treated with 2.5 years of tamoxifen and 2.5 years of an aromatase inhibitor.(61) The authors compared the 70-gene signature with Adjuvant! Online and St. Gallen clinicopathologic classifiers. Although all 3 strategies were equally clinically effective, St. Gallen was more costly, and the 70-gene signature was most cost-effective when quality-adjusted life-years were taken into account.

Saghatchian et al (2013) evaluated MammaPrint® signatures of frozen tumor samples from patients who had 4 to 9 positive lymph nodes.(62) Approximately half of patients were ER-positive, half were HER2- positive, and half had received adjuvant radiotherapy or chemotherapy. Seventy (40%) of 173 samples were classified as low risk by MammaPrint®, and 103 (60%) were classified as high risk. With median follow-up of 8 years, 5-year breast cancer-specific survival in the low- and high-risk groups were 97% and 76%, respectively (log-rank test, $p < 0.01$); 5-year distant metastasis-free survival was 87% and 63%, respectively (log-rank test, $p = 0.004$). Survival estimates were reported without 95% CIs; it is therefore not possible to assess the degree of overlap between risk groups.

Ahn et al (2013) investigated the use of MammaPrint® to further risk-stratify 82 ER-negative patients (56% lymph node-negative) who had Oncotype DX® intermediate risk scores.(63) Although MammaPrint® risk classification was significantly associated with 10-year OS in multivariate analysis (log-rank test, $p=0.013$), this result was confounded by receipt of adjuvant chemotherapy, which also was significantly associated with OS (log-rank test, $p=0.024$).

To assess the impact of MammaPrint® on treatment decision making, Cusumano et al (2014) distributed clinical information about 194 patients in European countries to multidisciplinary teams in 2 other countries (eg, data from the Netherlands was sent to Belgium and Italy) first without and then with MammaPrint® gene signatures.(64) Eighty-six percent of patients were ER-positive, 88% were HER2-negative, and 66% were lymph node-negative. With the addition of MammaPrint® signatures, treatment recommendations changed in 27% of patients, 22% from chemotherapy to no chemotherapy, and 35% from no chemotherapy to chemotherapy. In the subset of 453 ER-positive, HER2-negative patients, treatment advice changed in 32% of patients, with similar proportions changing from chemotherapy to no chemotherapy and vice versa.

Ongoing Trials

MINDACT trial (Microarray In Node-Negative and 1-3 Node-Positive Disease May Avoid ChemoTherapy; NCT00433589) is a prospective randomized trial comparing MammaPrint® with Adjuvant! Online for decision making about adjuvant chemotherapy.

Section Summary

Most MammaPrint® studies, including early validation studies, suffered from confounding by heterogeneous patient samples. Subsequent pooled reanalyses of subpopulations controlled for 1 variable (eg, nodal status), but confounding remained from other variables (eg, treatment heterogeneity). Results for 70-gene signature good prognosis patients have confidence intervals that likely confer too much risk for U.S. patients and providers. Because the test result is not a continuous numerical result, patients cannot view their result within the spectrum of good prognosis results and adjust their preferences accordingly. The recently published RASTER (Microarray Prognostics in Breast Cancer) study represents an improved study design, and results suggested that MammaPrint® may accurately re-classify early, node-negative breast cancer patients classified as high risk for recurrence by clinical and pathologic variables to low risk, such that chemotherapy may be avoided. However, patient numbers and events are too low for firm conclusions, and follow-up is not yet sufficiently mature.

Blueprint® and TargetPrint®

The BluePrint® molecular subtyping profile was developed using 200 breast cancer specimens that had concordant ER, PR, and HER2 protein levels by IHC and TargetPrint® mRNA readout.(65) Using a 3-fold cross validation procedure, 80 genes thought to best discriminate the 3 molecular subtypes were identified. BluePrint® was confirmed on 4 independent validation cohorts (total $N=784$), which included patients from a consecutive series of patients seen at the Netherlands Cancer Institute and treated with adjuvant tamoxifen monotherapy ($n=274$), a group of patients from the RASTER trial ($n=100$), and 2 publicly available data sets ($n=410$). Additionally, in 133 patients treated with neoadjuvant chemotherapy, the molecular subtyping profile was tested as a predictor of chemotherapy response. The authors concluded that use of BluePrint® classification showed improved distribution of pCR among molecular subgroups compared with local pathology: 56% of patients had a pCR in the basal-type subgroup, 3% in the MammaPrint® low-risk, luminal-type subgroup, 11% in the MammaPrint® high-risk, luminal-type subgroup, and 50% in the HER2-type subgroup.

Nguyen et al (2012) undertook a comparison of molecular subtyping with Blueprint®, MammaPrint®, and TargetPrint® to locally assess clinical subtyping using IHC and fluorescence FISH.(66) The 3 gene expression assays were performed on fresh tumor tissue at Agendia Laboratories, blinded for pathologic and clinical data. IHC and FISH testing were performed according to local practice at 11 institutions in the U.S. and Europe. ER, PR, and HER2 assays were performed on 132 samples.

Concordance between Blueprint® and IHC and FISH testing was 94% for both basal-type and luminal-type subgroups, and 95% for HER2-type. Concordance between Blueprint® and TargetPrint® was 98% for the basal-type, 96% for the luminal-type, and 97% for the HER2-type.

Viale et al (2014) reported concordance between TargetPrint® and IHC testing for ER, PR, and FISH for HER2 in the first 800 patients enrolled in the pilot phase of the MINDACT MammaPrint® trial.(67) For ER, positive and negative percent agreement between TargetPrint® and central testing were 98% and 96%, respectively; positive (PPV) and negative predictive value (NPV) were 99% and 87%, respectively. For PR, positive and negative percent agreement were 83% and 91%, respectively; PPV and NPV were 97% and 59%, respectively. For HER2, positive and negative percent agreement were 75% and 99%, respectively; PPV and NPV were 91% and 97%, respectively.

Breast Cancer IndexSM

Breast Cancer Index (BCI) is a simultaneous assessment of the HOXB13:IL17BR (H/I) ratio and the (Molecular Grade Index (MGI). The H/I ratio indicates estrogen-mediated signaling; MGI assesses tumor grade by measuring the expression of 5 cell-cycle genes and provides prognostic information in ER-positive patients regardless of nodal status. The 2014 TEC Assessment(2) reviewed available studies for the original component assays.(68-72) There was insufficient evidence to determine whether the H/I ratio is better than conventional risk assessment tools in predicting recurrence. Ten-year recurrence estimates of patients classified as low risk were 17% to 25%, likely too high for most patients and physicians to consider forgoing chemotherapy. Studies of the combination BCI are reviewed next.

Ma et al (2008) evaluated MGI along with H/I in 93 patients with lymph node-negative tumors who received adjuvant hormone therapy and found that each index modified the other's predictive performance.(73) High MGI was associated with significantly worse outcome only in patients with high H/I and vice versa. When the H/I ratio and MGI were categorically combined into a single predictor, estimates of 10-year distant metastasis-free survival were 98% (95% CI, 96 to 100), 87% (95% CI, 77 to 99), and 60% (95% CI, 47 to 78) for the low-, intermediate-, and high-risk groups, respectively.

Jerevall et al (2011) combined H/I ratio and MGI into a continuous risk model using 314 ER-positive, node-negative postmenopausal patients from the tamoxifen-only arm of an RCT.(74) The continuous model also was categorized, resulting in proportions of low-, intermediate-, and high-risk patients similar to those reported in the Ma et al 2008 study.(73) This continuous predictor was tested in patients from the no adjuvant treatment arm (n=274) of the same clinical trial, with estimates of rates of distant metastasis at 10 years in the low-, intermediate-, and high-risk groups of 8.3% (95% CI, 4.7 to 14.4), 22.9% (95% CI, 14.5 to 35.2), and 28.5% (95% CI, 17.9 to 43.6), respectively. Estimates of breast cancer-specific death were 5.1% (95% CI, 1.3 to 8.7), 19.8% (95% CI, 10.0 to 28.6), and 28.8% (95% CI, 15.3 to 40.2). An independent population of otherwise similar but tamoxifen-treated patients was not tested.

Jankowitz et al (2011) evaluated tumor samples from 265 ER-positive, lymph node -negative, tamoxifen-treated patients from a single academic institution's cancer research registry. (75) BCI categorized 55%, 21%, and 24% of patients as low, intermediate and high risk, respectively, for distant recurrence. Ten-year distant recurrence risk estimates were 6.6% (95% CI, 2.3 to 10.9), 12.1% (95% CI, 2.7 to 21.5), and 31.9% (95% CI, 19.9 to 43.9), and 10-year breast cancer-specific mortality risk estimates were 3.8%, 3.6% and 22.1% in low-, intermediate-, and high-risk groups, respectively. In multivariate analysis, BCI was a significant predictor of distant recurrence and breast cancer-specific mortality. In a time-dependent (10-year) ROC curve analysis of recurrence risk, the addition of BCI to Adjuvant! Online risk prediction increased maximum predictive accuracy in all patients from 66% to 76% and in tamoxifen only-treated patients from 65% to 81%.

SgROI et al (2013) examined 665 lymph node-negative, ER-positive, postmenopausal women receiving endocrine therapy but no chemotherapy in the ATAC trial.(76) For patients in the low- and intermediate-

risk groups, 10-year distant recurrence risks were 5% and approximately 19%, respectively, regardless of endocrine treatment (tamoxifen, anastrozole, or both). In the high-risk group, recurrence risk was lowest (22%) for patients taking anastrozole only – 22%, comparable to the intermediate-risk group, and highest for patients taking tamoxifen only (37%), although these groups were small (54 and 55 patients, respectively).

Mammostrat® Breast Cancer Test

Mammostrat® is an IHC test intended to evaluate risk of breast cancer recurrence in postmenopausal women with node-negative, ER-positive invasive breast cancer who will receive endocrine therapy and are considering adjuvant chemotherapy. The test employs 5 monoclonal antibodies to detect proteins biologically independent of each other and not involved in cell proliferation, hormone receptor status, or growth/differentiation, thus potentially allowing integration with clinically routine biomarkers. A proprietary diagnostic algorithm is used to calculate a risk score and to classify patients into high-, moderate-, or low-risk categories.

One study published in 2006 described the development of the assay but provided no information on technical performance (analytic validity).(77) In a validation study in an independent cohort, a multivariate model predicted 50%, 70%, and 87% 5-year DFS for patients classified as high, moderate, and low prognostic risk, respectively, by Mammostrat® ($p < 0.001$).(77) An additional study of the same trial samples used for Oncotype DX® validation (NSABP B-14 and B-20 trials) found that among patients with early, node-negative breast cancer treated only with tamoxifen, those stratified by Mammostrat® into low-, moderate-, and high-risk groups had RFS estimates of 85%, 85%, and 73%, respectively.(78) Both low- and high-risk groups benefited significantly from chemotherapy treatment, but high-risk patients benefited to a greater degree. The moderate-risk group was not well-separated from the low-risk group and thus, moderate-risk results do not appear to provide clinically useful information. A test for an interaction between chemotherapy and the risk group stratification was not significant ($p = 0.13$).

Bartlett et al (2010) used Mammostrat® on 1540 of 1812 patient samples from a consecutive cohort for which minimum 9-year outcomes were available.(79) Tested samples were from tamoxifen-treated patients; 568 of these were from node-negative patients ER-positive tumors who were treated only with tamoxifen. In the latter group, 10-year distant recurrence at 10 years for low-, moderate-, and high-risk patients was 7.6% (95% CI, 4.6 to 10.5), 16.3% (95% CI, 10.0 to 22.6), and 20.9% (95% CI, 12.3 to 29.5) respectively. In multivariate analysis, Mammostrat® was not a significant predictor of RFS in node-negative, ER-positive patients treated only with tamoxifen. However, when all patients (24% node-positive, 20% tumors > 2.0 cm, 18% ER-negative, and 46% treated with chemotherapy) with complete Mammostrat® data ($n = 1300$) were included in multivariate analysis, Mammostrat® scores were independent predictors of RFS ($p < 0.001$). In exploratory analyses of various subgroups (eg, node-negative vs node-positive, ER-negative), Mammostrat® appeared to perform similarly in terms of identifying risk groups. However, patient numbers in these subgroups were small.

BreastOncPx™

BreastOncPx™ is a RT-PCR test performed on formalin-fixed, paraffin embedded tissue (FFPE) that measures the gene expression of 14 genes associated with key functions such as cell-cycle control, apoptosis, and DNA recombination and repair. Results are combined into a metastasis score, which is reported to be associated with the risk of distant metastases in patients who are node-negative and estrogen-receptor positive.

Tutt et al (2008) published information on the development and validation of the test (80); no information on analytic validity was provided. To develop a gene signature that was completely prognostic for distant recurrence and not confounded by treatment prediction, samples from untreated patients with early breast cancer were used. The training set ($n = 142$) was derived from a cohort diagnosed with lymph node-negative, stage T1 and T2 breast cancer from 1975 to 1986; ER-positive

samples from patients who had had no systemic treatment were selected for analysis. Fourteen genes were eventually selected as most prognostic of time-to-distant metastasis and were given equal weighting in a summary metastasis score (MS). Using a single cut point, patients are separated into high- and low-risk groups.

The 14-gene signature was validated on ER-positive samples (n=279) from a separate cohort of patients diagnosed with lymph node-negative primary breast cancer between 1975 and 2001.(80) Estimated 10- year distant metastasis-free survival was 72% (95% CI, 64% to 78%) for high-risk patients and 96% (95% CI, 90% to 99%) for low-risk patients. Overall 10-year survival for high- and low-risk patients was 68% (95 CI, 61 to 75) and 91% (95% CI, 84 to 95), respectively. After adjusting for age, tumor size, and tumor grade in a Cox multivariate analysis, HRs for distant MFS and OS for the high- versus low-risk group were 4.02 (95% CI, 1.91 to 8.44) and 1.97 (95% CI, 1.28 to 3.04), respectively. However, between-group differences in risk were not maintained when the analysis was restricted to patients with tumors larger than 2 cm (p value for interaction, 0.012).

ROC analysis of the continuous MS for distant metastasis and for death at 10 years, compared with Adjuvant! Online resulted in slightly higher area under the curves (AUCs) for the MS in each case: 0.715 versus 0.661 for distant metastases, and 0.693 versus 0.655 for death. MS was not added to Adjuvant! Online and compared with Adjuvant! alone.

NexCourse® Breast IHC4

NexCourse® Breast IHC4 evaluates the protein expression of ER/PR, HER2, and Ki-67 to provide a combined recurrence risk score. The assay technology uses quantitative image analysis to measure immunofluorescent signals, with results that can be combined in an algorithm to generate the recurrence risk score. The use of quantitative immunofluorescence is said to increase sensitivity, be more reproducible, and allow specific measurement of tumor cells.(81, 82)

Cuzick et al (2011) evaluated 1125 ER-positive patients from the Arimidex, Tamoxifen, Alone or in Combination (ATAC) trial who did not receive adjuvant chemotherapy, already had an Oncotype DX® Recurrence Score (RS) computed, and had adequate tissue for IHC4 measurements.(83) Of these, 793 (70%) were node-negative, and 59 (5%) were HER2-positive (but were not treated with trastuzumab). A prognostic model that combined the 4 IHC markers was created (IHC4). In models that combined either IHC4 or Oncotype DX® RS with classical prognostic variables, IHC4 score was found to be similar to Oncotype DX® RS, and little additional prognostic value was seen in the combined use of both scores. In direct comparison, IHC4 score was modestly correlated with Oncotype DX® RS ($r=0.72$); correlation was similar for the subgroup of node-negative patients ($r=0.68$). As an example, for a 1 to 2 cm, node-negative poorly differentiated tumor treated with anastrozole, 9-year distant recurrence at the 25th versus 75th percentiles for IHC4 and Oncotype DX® were 7.6% versus 13.9% and 9.2% versus 13.4%, respectively. IHC4 score was validated in a separate cohort of 786 ER-positive women, about half of whom received no endocrine therapy. IHC4 score was significant for recurrence outcomes (HR=4.1 [95% CI, 2.5 to 6.8]).

Barton et al (2012) assessed the clinical utility of IHC4 plus clinicopathologic factors (IHC4 + C) by comparison with Adjuvant! Online and the Nottingham Prognostic Index (NPI).(84) The study prospectively gathered clinicopathologic data for consecutively treated postmenopausal patients (n=101 evaluable) who had HR-positive, HER2-negative, LN-negative or LN-positive (1-2 nodes), resected early breast cancer. Of 59 patients classified as intermediate-risk by NPI, IHC4 reclassified 24 to low risk and 13 to high risk. IHC4 reclassified 13 of 32 Adjuvant! Online high-risk patients to intermediate risk, and 3 of 32 to low risk. Additionally, 15 of 26 Adjuvant! Online intermediate-risk patients were reclassified to low risk. No Adjuvant! Online low-risk patients were reclassified as high risk.

Prosigna™/PAM50 Breast Cancer Intrinsic Subtype Classifier

The 2014 TEC Assessment reviewed development and validation studies of the PAM50 intrinsic subtype classifier and Prosigna™ (2); these studies are reviewed next. Only 2 studies of the marketed Prosigna™ test were identified, 1 of which reported analytic validity. A third study performed the commercial assay on 46 of the PAM50 genes, excluding 1 HER2-associated gene (*GRB7*) and 3 proliferation-associated genes (*BIRC5* [also called *Survivin*], *MYBL2*, *CCNB1*) that are given special weighting to generate the Prosigna™ recurrence of recurrence (ROR) score. These and other studies published after the 2014 TEC Assessment are reviewed next.

Nielson et al (2014) assessed the analytical performance of Prosigna™ using the proprietary nCounter Analysis System (NanoString Technologies) at NanoString Technologies and 2 other laboratories.(85) Each tumor sample had been classified by a pathologist as invasive carcinoma (of any type), and all sample testing was blinded. Assay precision was assessed by testing 5 tumor RNA samples 36 times at the 3 labs. SD across labs was less than 1 ROR unit on the 0-100 ROR scale. Reproducibility was measured by testing 43 FFPE tumor samples in the 3 labs. Measured total standard deviation including all sources of variation (ie, tissue processing and RNA processing variability) was 2.9 ROR units, indicating that Prosigna™ measures a difference of 6.8 points between continuous 2 ROR scores with 95% confidence. Concordance across the 3 labs for risk categorization in node-negative patients ranged from 88% (95% CI, 73 to 96) to 93% (95% CI, 80 to 98), and in node-positive patients, from 90% (95% CI, 77 to 96) to 95% (95% CI, 84 to 99).

In a study that supported FDA clearance of Prosigna™, Gnant et al (2014) evaluated tumor samples from 1047 lymph node-negative patients who participated in the Austrian Breast and Colorectal Cancer Study Group's trial 8 (ABCSCG-8); this represented 28% of the original trial sample.(86) ABCSCG-8 randomized HR-positive, postmenopausal women with early stage breast cancer to 5 years of endocrine adjuvant therapy, either tamoxifen for 5 years or tamoxifen for 2 years followed by anastrozole for 3 years. Adjuvant or neoadjuvant chemotherapy was not allowed. In the Gnant et al (2014) study, both PAM50 subtype and Prosigna™ ROR class were associated with 10-year distant RFS, with CIs that overlapped slightly or not at all. Lower confidence limits for women in the luminal A and low-risk groups were around 94%, and upper confidence limits for luminal B and high-risk groups were approximately 90%. That is, the risk distinction seemed clinically useful. Filipits et al (2014) subsequently studied 919 patients who survived the first 5 years after treatment without recurrence.(87) Fifteen-year late-distant DRS (ie, years 5-15) was 98%, 90%, and 86% in ROR low-, intermediate-, and high-risk groups, respectively.

Dowsett et al (2013) reported on groups from the ATAC trial stratified by subtype (luminal A or B) and by PAM50 ROR class, both with and without consideration of clinicopathologic factors.(88) Among 739 lymph node-negative patients, 10-year distant RFS was 94% in 529 luminal A patients and 75% in 176 luminal B patients and was comparable with low- and high-risk ROR groups with or without clinical factors: 95%, 85%, and 70% in low-, intermediate-, and high-risk groups, respectively. An ROC analysis in 649 lymph node-negative, HER2-negative patients showed that PAM50 plus clinical factors had greater discriminatory ability than either risk predictor alone. In this study, the commercial assay was performed on 46 of the PAM50 genes (ROR46). Because proliferation-associated genes are given special weighting to produce the Prosigna™ ROR score, it is unclear how closely ROR46 approximated the marketed test; the authors reported a correlation of 0.9989 between ROR50, which incorporated all PAM50 genes, and ROR46 risk classifications.

Initial development of the PAM50 breast cancer intrinsic classifier was reported in 2009 by Parker et al(89) The authors developed a qRT-PCR test based on a panel of 50 genes to identify the breast cancer "intrinsic" subtypes luminal A, luminal B, HER2-enriched, and basal-like, and to generate risk-of-relapse scores in node-negative patients who had not had systemic treatment for their cancer. In an independent test set, the test using 3 categories of risk (low, intermediate, high) was significantly prognostic (log-rank test, p<0.001).

Nielsen et al (2010) compared the PAM50 classifier with standard clinicopathologic factors as represented by Adjuvant! Online and with models based on IHC for biomarkers of intrinsic

subtypes.(90) The study used samples from patients diagnosed between 1986 and 1992 with ER-positive, node-negative or node-positive breast cancer at higher-risk (eg, with lymphovascular invasion), and treated with 5 years of tamoxifen but no adjuvant chemotherapy. In the node-negative population, Adjuvant! Online was inferior to all other biomarker models for predicting recurrence and disease-specific survival. A model including the PAM50 risk of recurrence score that also incorporated the influence of proliferation and tumor size identified patients with a greater than 95% chance of remaining alive and disease-free beyond 10 years. A slightly different gene expression model best fit the node-positive population but did not identify a population at sufficiently low-risk that adjuvant hormone therapy would likely be considered sufficient.

Because the cohort used to generate the models evaluated in this study was biased toward higher-risk early breast cancers, it is likely not generalizable. Nor did the authors clearly identify a final model for clinical use. Rather, the authors outlined potential additional studies.

Cheang et al (2012) determined PAM50 intrinsic subtypes for samples from a clinical trial that randomized premenopausal women with node-positive breast cancer to 2 different regimens of chemotherapy. (91) The PAM50 intrinsic subtype for 476 tumors was correlated to relapse-free survival (RFS; $p=0.0005$) and overall survival (OS: $p<0.001$). The HER2-enriched subgroup (22%) showed the greatest benefit from cyclophosphamide-epirubicin-fluorouracil (CEF) versus cyclophosphamide-methotrexate-fluorouracil (CMF), with absolute 5-year RFS and OS differences exceeding 20%. There was a less than 2% difference for non-HER2-enriched tumors (interaction test $p=0.03$ for RFS and 0.03 for OS). Within clinically defined HER2-positive tumors, 79% (72 of 91) were classified as the HER2-enriched subtype by gene expression, and this subset was associated with better response to CEF versus CMF (62% vs 22%, $p=0.0006$). There was no significant difference in benefit from CEF versus CMF in basal-like tumors.

Sestak et al (2013) reported on the prognostic ability of PAM50 ROR score in 940 (16%) of 5880 patients from the ATAC trial.(92) Thirty percent of patients were lymph node positive. Investigators modified the ROR scoring algorithm to exclude tumor size and defined cut points by the median for each outcome; patients were segregated into 2 rather than 3 risk classes. These modifications have not been validated and may increase considerably the risk of misclassification bias. Two outcomes were examined, distant recurrence during the first 5 years after completion of hormone therapy and after 5 years (up to 10 years). For the latter, the number of patients at risk at the start of the interval was not reported; in the first 5 years, 71 distant recurrences occurred. Finally, estimated uncertainty (eg, variance) was not reported for either outcome. Although distant RFS was longer in the low-risk than in the high-risk group, given the methodologic flaws of the study, the meaning of these results is uncertain.

BreastPRS™

BreastPRS™ is a gene expression assay that analyzes 200 genes and was validated in a meta-analysis of publically available genomic datasets.(93) BreastPRS™ is a binary assay which stratifies patients into low- and high-risk groups.(94)

D'Alfonso et al (2013) sought to translate a previously published validation study of BreastPRS, using fresh-frozen tissue, to FFPE tumor samples. (94) The authors compared BreastPRS™ to Oncotype DX® and correlated recurrence scores with clinicopathologic features. A linear relationship of BreastPRS™ prognostic scores between fresh-frozen and FFPE formats was observed. Using publically available whole genome profiles from a series of untreated ER-positive, node negative patients, investigators assessed the ability of BreastPRS™ to reclassify Oncotype DX® intermediate-risk patients into high- or low-risk categories with clinically significant differences in outcomes. BreastPRS™ prognosis scores were compared with Oncotype DX® recurrence scores in 246 patients with invasive breast carcinoma and known Oncotype DX® results. Using this series, a 120-gene Oncotype DX® approximation algorithm to predict Oncotype DX® risk groups was then applied to a series of untreated, ER-positive, node-negative patients from previously published studies with known

clinical outcomes. Of 30 high-risk Oncotype DX® cases, 27 (90%) were classified as high-risk by BreastPRS™, and 95 low-risk Oncotype DX® cases (76%) were classified as low-risk by BreastPRS™. The correlation of recurrence score and risk group between Oncotype DX® and BreastPRS™ was statistically significant ($p < 0.001$). Fifty-nine (23%) of 260 patients from 4 previously published studies were classified as intermediate-risk when the 120-gene Oncotype DX® approximation algorithm was applied. BreastPRS™ reclassified the 59 patients into binary risk groups (high vs low risk), with 23 (39%) patients classified as low risk and 36 (61%) as high risk (HR for a high-risk classification, 3.64 [95% CI, 1.40 to 9.50]; $p = 0.029$). Ten-year RFS was 90% in the low-risk group and 60% in the high-risk group. The authors concluded that BreastPRS™ prognosis score is comparable with Oncotype DX® recurrence score and can reclassify Oncotype DX® intermediate-risk patients into 2 groups with clinically significant differences in RFS.

EndoPredict™

Varga et al (2013) analyzed the EndoPredict™ (EP) test in 34 hormone positive, invasive breast cancer cases and compared the EndoPredict (EP) scores with the Oncotype DX® recurrence scores (RS) obtained from the same cancer samples. (95) EP classified 11 patients as low risk and 23 patients as high risk, whereas RS classified 15 patients as low risk, 10 patients as intermediate risk, and 9 patients as high risk. There were major discrepancies in 6 of 34 cases (18%), with low-risk RS classified as high risk by EP in 6 cases. When the RS intermediate- and high-risk groups were combined, the concordance between both tests was 76%. The clinical relevance of these discrepant test results with respect to outcome is unknown.

Martin et al (2013) assessed tumor samples from 566 ER-positive, HER2-negative patients who participated in the GEICAM 9906 RCT. (96) GEICAM 9906 compared 2 adjuvant chemotherapy regimens in 1246 women who had lymph node-positive disease: six 21-day cycles of 5-fluorouracil, epirubicin, and cyclophosphamide (FEC) or four 21-day cycles of FEC followed by 8 weekly courses of paclitaxel (FEC-P). EPclin score was calculated by combining EP score (RT-PCR assay of 8 genes) with nodal status and tumor size. EP was successfully assayed in 555 (98%) of 566 tumor samples. Twenty-five percent ($n = 141$) of samples were classified as low risk by EP score, and 75% ($n = 414$) were high risk; 10-year metastasis-free survival was 93% in the low-risk group and 70% in the high-risk group (HR for metastasis or death in the high- vs low-risk group, 4.8 [95% CI, 2.5 to 9.6]; log-rank test, $p < 0.001$). Thirteen percent ($n = 74$) of samples were classified as low risk by EPclin score, and 87% ($n = 481$) were classified as high-risk; 10-year metastasis-free survival was 100% in the low-risk group and 72% in the high-risk group.

Dubsky et al (2013) examined predictive ability of EP and EPclin for early (0-5 years) and late (>5 years postdiagnosis) disease recurrence. (97) Tumor samples from chemotherapy-untreated, ER-positive, HER2-negative patients who participated in 1 of 2 RCTs (ABCSCG6 or ABCSCG8) were assayed (total $N = 1702$). In the trials, patients received either tamoxifen for 5 years or tamoxifen for 2 years followed by anastrozole for 3 years. Forty-nine percent ($n = 832$) of patients were classified as low risk by EP score, and 51% ($n = 870$) were classified as high risk. Only relative estimates (ie, HRs) of distant recurrence were reported. In comparison with low-risk patients, high-risk patients had an almost 3-fold increase in the risk of recurrence in the first 5 years after diagnosis (HR=2.80 [95% CI, 1.81 to 4.34]; log-rank test, $p < 0.001$) and a slightly increased risk after 5 years (in those who survived 5 years; HR=3.28 [95% CI, 1.48 to 7.24]; log-rank test, $p = 0.002$). By EPclin, 1066 (63%) of 1702 patients were classified as low risk, and 636 (37%) were classified as high risk. In comparison with low-risk patients, high-risk patients had an almost 5-fold risk of recurrence within the first 5 years (HR=4.82 [95% CI, 3.12 to 7.44]; log-rank test, $p < 0.001$) and a more than 6-fold increased risk of recurrence after 5 years (HR=6.26 [95% CI, 2.72 to 14.36]; log-rank test, $p < 0.001$). Given the discrepancy in risk classification between EP and EPclin, and the incomplete reporting of recurrence and survival outcomes by risk groups, this evidence is insufficient to demonstrate improved prognostic accuracy for individual patients with EndoPredict.

Test Comparison Studies

Sgroi et al (2013) compared the Breast Cancer IndexSM and Oncotype DX[®] in 665 lymph node-negative women receiving endocrine therapy but not chemotherapy in the ATAC trial.(76) The distribution of patients across risk groups was similar. For patients receiving tamoxifen alone or in combination with anastrozole, 10-year distant recurrence risk estimates by the 2 tests were similar within risk groups. In the anastrozole group, the Breast Cancer IndexSM was a better predictor of risk: 5% of Breast Cancer IndexSM low-risk patients had distant recurrence compared with 9% of Oncotype DX[®] low-risk patients, and 22% of Breast Cancer IndexSM high-risk patients had distant recurrence compared with 13% of Oncotype DX[®] high-risk patients. Importantly, these values were reported without 95% CIs; it is therefore not possible to assess the degree of overlap between risk groups.

Dowsett et al (2013) compared PAM50 ROR score to the Oncotype Dx[®] 21-gene RS, Breast IHC4, and a clinical treatment score (CTS).(88) Patients had ER-positive, primary breast disease treated with anastrozole or tamoxifen in the ATAC trial (a double-blinded, Phase 3 clinical trial that was designed to compare the ability of anastrozole, tamoxifen, and the 2 drugs in combination to prevent breast cancer recurrence in postmenopausal women with HR-positive tumors). Lymph node-negative and positive patients were included. mRNA from 1017 patients was assessed for ROR, and likelihood ratio tests and concordance indices were used to assess the prognostic information provided beyond that of a CTS, RS, ROR, or IHC4. The CTS integrated prognostic information from nodal status, tumor size, histopathologic grade, age and anastrozole or tamoxifen treatment. The authors concluded that the ROR added significant prognostic information beyond CTS in all patients ($p < 0.001$), and in all 4 subgroups: lymph node negative, lymph node positive, HER2 negative, and HER2 negative/node-negative, and that more information was added by ROR than RS. More patients scored as high risk of recurrence and fewer as intermediate risk by ROR than RS.

Hornberger et al (2012) conducted a systematic review on the clinical validity, clinical utility, change in clinical practice, and economic implications of early- stage breast cancer stratifiers.(98) Fifty-six articles published original evidence addressing the 21-gene recurrence score (Oncotype DX[®]) (n=31), 70-gene signature (MammaPrint[®]) (n=14), Adjuvant! Online (n=12), 5-antibody immunohistochemistry panel (Mammostrat[®]) (n=3), and 14-gene signature (BreastOncPx[™]) (n =1). Oncotype Dx[®] recurrence score satisfied level 1 evidence for estimating distant recurrence risk (DRR), OS, and response to adjuvant chemotherapy, and level 2 evidence for estimating local recurrence risk. Mammostrat[®] and MammaPrint[®] satisfied level 2 evidence for estimating DRR and OS. Adjuvant! Online satisfied level 2 evidence for estimating DRR, OS, and chemotherapy response. BreastOncPx[™] satisfied level 3 evidence for predicting DRR and OS. Ten studies reported changes in clinical practice patterns using Oncotype DX[®]; overall, Oncotype DX[®] was associated with change in treatment recommendations and/or decisions in 21% to 74% of cases.

Fan et al (2006) used 5 gene expression classifiers to evaluate a single set of samples from 295 women with stage 1 or 2 breast cancer, variable node involvement, and variable endocrine or chemotherapy treatment.(99) The classifiers included the 21-gene recurrence score, the 70-gene signature, the H/I ratio, and the intrinsic subtype classifier (similar to the commercially available PAM50). Most highly correlated were the 21-gene recurrence score and the 70-gene signature, with a Cramer V of 0.6 (scale 0 to 1 with 1 indicating perfect agreement). More specifically, 81 (79%) of 103 samples with a recurrence score of low or intermediate risk were classified as having a low-risk 70-gene profile. Restricting the analysis to 225 ER-positive samples slightly reduced the correlation. Analysis was not further restricted to node-negative patients, the present indication for both tests.

Espinosa et al (2005) compared the 21-gene recurrence score (Oncotype DX[®]), the 70-gene signature (MammaPrint[®]), and the 2-gene ratio (H/I ratio) in 153 patients with ER-positive breast cancer treated with adjuvant tamoxifen.(41) Sixty-two percent of patients were node-negative, and 63% were additionally treated with chemotherapy. Estimated distant metastasis-free survival for recurrence score risk groups was 98% for low-risk, 81% for intermediate-risk, and 69% for high-risk patients; for the 70-gene signature, estimates were 95% for good prognosis and 66% for poor prognosis patients; and for the 2-gene ratio, estimates were 86% for favorable and 70% for unfavorable prognosis. Correlation between the 21-gene recurrence score and the 70-gene signature was good (Cramer V=0.6). Slightly

more variation in distant metastasis-free survival was explained by the combination of the 21-gene recurrence score and either Adjuvant! Online (25.8 ± 1.4) or the Nottingham Prognostic Index (NPI; 23.7 ± 1.5) than by the combination of the 70-gene signature with Adjuvant! Online (23.1 ± 1.2) or the NPI (22.4 ± 1.3), but differences were small and any combination was significantly better than any test or clinicopathologic classifier alone.

Two recent papers compared Oncotype DX® and other gene expression profiles. Kelly et al (2012) evaluated Oncotype DX® and PAM50 in 108 cases and found good agreement between the 2 assays for high- and low-prognostic risk assignment; PAM50 assigned about half of Oncotype DX® intermediate-risk patients to the PAM50 luminal A (low risk) category.(100) Prat et al (2012) evaluated several gene expression tests, including Oncotype DX®, PAM50, and MammaPrint®, in 594 cases and found all predictors were significantly correlated (Pearson correlation coefficient range, 0.36-0.79; $p < 0.001$ for each comparison).(22)

Additional Applications

Based on a study published in May 2008 that compared Oncotype DX® ER and PR results with traditional IHC results,(101) Genomic Health is now including quantitative ER and PR component results in Oncotype DX® 21-gene profile reports. The study reported 90% or better concordance between the 2 assays, but quantitative ER by Oncotype DX® was more strongly associated with disease recurrence than IHC results. However, ER and PR analysis is traditionally conducted during pathology examination of all breast cancer biopsies, whereas Oncotype DX® is indicated only for known ER-positive tumors, after the pathology examination is complete, the patient meets specific criteria, and patient and physician are considering preferences for risk and chemotherapy. Thus, Oncotype DX® should not be ordered as a substitute for ER and PR IHC. Additionally, accepted guidelines for ER and PR testing outline standards for high-quality IHC testing and do not recommend confirmatory testing; thus the 21-gene RS should not be ordered to confirm ER/PR IHC results. Similarly, guidelines for HER2 testing specify IHC and/or FISH methods.(1) In 1 large study, the HER2 component of the 21-gene assay was shown to strongly correlate with FISH results,(102) but another study noted significant discrepancies.(103) As a result, and without evaluation and support from guidelines, it has been recommended that the 21-gene assay not be ordered to determine or confirm HER2.(104)

No published literature on the use of gene expression profiling in men with breast cancer was identified.

Clinical Input Received Through Physician Specialty Societies and Academic Medical Centers

In response to requests, input was received from 1 physician specialty society and 4 academic medical centers while this policy was under review in 2008. 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. A clear majority of the reviewers agreed with the policy conclusions.

Summary

21-Gene Recurrence Score (Oncotype DX®): The assay is supported by strong evidence of clinical validity, ie, that the recurrence score (RS) is strongly associated with risk of distant recurrence in women with invasive breast cancer that is positive for hormone receptors, negative for HER2, and without lymph node involvement. Limited but sufficient evidence supports analytic validity and clinical utility in this population. Oncotype DX® adds additional risk information to conventional clinical classification of individual high-risk patients and identifies a subset of patients who would otherwise be recommended for chemotherapy but who are actually at lower risk of recurrence (average 7% to 9% risk at 10 years; upper 95% confidence interval [CI] limits, 11% to 15%). Thus, a woman who prefers to

avoid the toxicity and inconvenience of chemotherapy and whose Oncotype DX® RS value shows that she is at very low risk of recurrence might reasonably decline chemotherapy.

In similar women who are node-positive, evidence is less clear that the risk of recurrence in low-risk RS patients is sufficiently low or that the benefit of chemotherapy is insufficiently large, to recommend avoiding otherwise currently recommended treatment. Additional studies are necessary and ongoing.

For women with ductal carcinoma in situ (DCIS), development and clinical validity studies of a subset of genes from the 21-gene recurrence score (ie, Oncotype DX® DCIS) to predict recurrence and inform treatment planning postexcision, have not yet been published to allow full evaluation. Moreover, no information is yet available on whether women are better categorized as to their recurrence risk by the Oncotype DX® DCIS Score compared with standard clinical risk indicators.

70-Gene Signature (MammaPrint®): A large number of studies of clinical validity, and a few attempting to address the clinical utility of the 70-gene signature have been published. Several studies have pooled and reanalyzed subsets of previously published data in attempts to arrive at more homogeneous patient samples. Nevertheless, MammaPrint® studies continue to suffer from confounding due to heterogeneous patient samples. Pooled reanalyses of subpopulations may control for 1 variable (eg, nodal status), but confounding remains from other variables (eg, treatment heterogeneity). Results for MammaPrint® good prognosis patients have confidence intervals that extend into ranges that likely confer too much risk for U.S. patients and providers. Because the test result is not a continuous numerical result, patients cannot view their result within the spectrum of good prognosis results and adjust their preferences accordingly. The recently published Microarray Prognostics in Breast Cancer (RASTER) study represents an improved study design; results suggested that MammaPrint® may accurately re-classify early, node-negative invasive breast cancer patients classified as high risk by clinical and pathologic variables to low risk, such that chemotherapy may not be necessary. However, patient numbers and events were too low to make firm conclusions, and follow-up is not yet sufficiently mature.

Blueprint® and TargetPrint®: The 80-gene expression assay Blueprint® discriminates among 3 breast cancer molecular subtypes, and TargetPrint® is a method to measure ER, PR, and HER2 as an alternative to immunohistochemistry and FISH. Clinical utility of Blueprint® is unknown, as it is unclear how this test will add to treatment decision making using currently available, accepted methods (eg, clinical and pathologic parameters). The incremental benefit of using TargetPrint® as an alternative to current standard methods of measuring ER, PR, and HER2 has not been demonstrated, nor is it included in recommendations for testing issued by ASCO and CAP.

Breast Cancer IndexSM, Mammostrat® Breast Cancer Test, BreastOncPxTM, NexCourse® Breast IHC4, ProsignaTM, BreastPRSTM, EndoPredictTM: Evidence supporting these tests comprises clinical validity data showing that the test is independently and significantly associated with distant recurrence and that the test can identify a lower risk population of women with early, invasive breast cancer who may not need chemotherapy. In almost all cases, the test is not added to and compared with a standard clinicopathologic classifier such as Adjuvant! Online. . The BreastOncPxTM validation study included a ROC analysis comparing the test with Adjuvant! Online, but no clear evidence supporting clinical utility was available. NexCourse® Breast IHC4 (immunohistochemical markers) was compared with standard clinicopathological prognostic classifiers in a reclassification analysis and was shown to accurately reclassify significant numbers of patients from high and intermediate risk to low risk, but sample size was small and insufficient for conclusions.

Practice Guidelines and Position Statements

National Comprehensive Cancer Network (NCCN)

Current NCCN guidelines for breast cancer (version 3.2014) do not include any gene expression signature tests.(12) However, pending results of prospective RCTs for Oncotype DX® (TAILORx) and

MammaPrint® (MINDACT), Oncotype DX® may be considered an option when evaluating patients who have invasive breast cancer with all of the following features: (category 2A recommendation)

- hormone receptor-positive;
- HER2-negative;
- node-negative OR not greater than 2 mm axillary node metastasis; AND
- tumor size 0.6 to 1.0 cm with unfavorable features OR larger than 1 cm.

The NCCN Guideline Panel emphasized that Oncotype DX® recurrence score should be used for decision making only in the context of other elements of risk stratification for an individual patient.

American Society of Clinical Oncology (ASCO)

ASCO guidelines from 2007 indicate that “In newly diagnosed patients with node-negative, estrogen-receptor positive breast cancer, the Oncotype DX® assay can be used to predict the risk of recurrence in patients treated with tamoxifen.” (105)

St. Gallen International Expert Consensus on the Primary Therapy of Early Breast Cancer

The 2013 St. Gallen expert panel emphasized the identification of intrinsic breast cancer subtype when deciding whether to use systemic adjuvant chemotherapy.(106) Panelists did not recommend any particular assay for this purpose. For patients with lymph node-negative luminal (HR-positive, HER2-negative) disease, Oncotype DX® and MammaPrint® were considered to provide “accurate and reproducible prognostic information.” Oncotype DX® also was considered predictive of response to chemotherapy. No consensus recommendation was made for lymph node-positive disease. Molecular diagnostic testing for patients with lymph node-negative, ER-positive, HER2-negative disease and low clinical risk (eg, tumor size ≤1 cm) was considered unnecessary; similarly, in patients at high risk due to clinicopathologic factors (eg, tumor size >5 cm, inflammatory breast cancer, ≥4 involved lymph nodes, or a very low ER positivity [eg, <5%]), molecular diagnostic testing was considered unnecessary.

U.S. Preventive Services Task Force

Gene expression testing and other prognostic tests (eg, immunohistochemistry) of breast cancer tumor tissue is not a preventive service.

Medicare National Coverage

Medicare does not have a national coverage determination for this testing.

References

1. Wolff AC, Hammond ME, Hicks DG et al. Recommendations for human epidermal growth factor receptor 2 testing in breast cancer: american society of clinical oncology/college of american pathologists clinical practice guideline update. *J Clin Oncol* 2013; 31(31):3997-4013.
2. Blue Cross and Blue Shield Association Technology Evaluation Center (TEC). Gene expression profiling in women with lymph node negative breast cancer to select adjuvant chemotherapy. *TEC Assessments* 2014; Volume 29; (Tab TBD).
3. Cronin M, Sangli C, Liu ML et al. Analytical validation of the Oncotype DX genomic diagnostic test for recurrence prognosis and therapeutic response prediction in node-negative, estrogen receptor-positive breast cancer. *Clin Chem* 2007; 53(6):1084-91.
4. Paik S, Tang G, Shak S et al. Gene expression and benefit of chemotherapy in women with node-negative, estrogen receptor-positive breast cancer. *J Clin Oncol* 2006; 24(23):3726-34.
5. Paik S, Shak S, Tang G et al. A multigene assay to predict recurrence of tamoxifen-treated, node-negative breast cancer. *N Engl J Med* 2004; 351(27):2817-26.
6. Paik S, Shak S, Tang G et al. Risk classification of breast cancer patients by the Recurrence Score assay: comparison to guidelines based on patient age, tumor size, and tumor grade. [Meeting Abstract]. *Breast Cancer Res Treat* 2004; 88(suppl 1):A104.
7. Bryant J. Toward a more rational selection of tailored adjuvant therapy data from the National Surgical Adjuvant Breast and Bowel Project. 2005 St. Gallen Breast Cancer Symposium. [Complete slide presentation via Genomic Health] 2005.

8. Habel LA, Shak S, Jacobs MK et al. A population-based study of tumor gene expression and risk of breast cancer death among lymph node-negative patients. *Breast Cancer Res* 2006; 8(3):R25.
9. Tang G, Shak S, Paik S et al. Comparison of the prognostic and predictive utilities of the 21-gene Recurrence Score assay and Adjuvant! for women with node-negative, ER-positive breast cancer: results from NSABP B-14 and NSABP B-20. *Breast Cancer Res Treat* 2011; 127(1):133-42.
10. Dowsett M, Cuzick J, Wale C et al. Prediction of risk of distant recurrence using the 21-gene recurrence score in node-negative and node-positive postmenopausal patients with breast cancer treated with anastrozole or tamoxifen: a TransATAC study. *J Clin Oncol* 2010; 28(11):1829-34.
11. Gennari A, Sormani MP, Pronzato P et al. HER2 status and efficacy of adjuvant anthracyclines in early breast cancer: a pooled analysis of randomized trials. *J Natl Cancer Inst* 2008; 100(1):14-20.
12. National Comprehensive Cancer Network (NCCN). Clinical practice guidelines in oncology: breast cancer, version 3.2014. Available online at: http://www.nccn.org/professionals/physician_gls/pdf/breast.pdf
13. Dowsett M. on Behalf of the ATAC Trialists Group. Analysis of time to recurrence in the ATAC (arimidex, tamoxifen, alone or in combination) trial according to estrogen receptor and progesterone receptor status. Twenty-sixth Annual San Antonio Breast Cancer Symposium 2003.
14. Dowsett M, Houghton J, Iden C et al. Benefit from adjuvant tamoxifen therapy in primary breast cancer patients according oestrogen receptor, progesterone receptor, EGF receptor and HER2 status. *Ann Oncol* 2006; 17(5):818-26.
15. Hefti MM, Hu R, Knoblauch NW et al. Estrogen receptor negative/progesterone receptor positive breast cancer is not a reproducible subtype. *Breast Cancer Res* 2013; 15(4):R68.
16. Early Breast Cancer Trialists' Collaborative G. Relevance of breast cancer hormone receptors and other factors to the efficacy of adjuvant tamoxifen: patient-level meta-analysis of randomised trials. *The Lancet*; 378(9793):771-84.
17. Tzeng JP, Mayer D, Richman AR et al. Women's experiences with genomic testing for breast cancer recurrence risk. *Cancer* 2010; 116(8):1992-2000.
18. Lo SS, Mumby PB, Norton J et al. Prospective multicenter study of the impact of the 21-gene recurrence score assay on medical oncologist and patient adjuvant breast cancer treatment selection. *J Clin Oncol* 2010; 28(10):1671-6.
19. Henry LR, Stojadinovic A, Swain SM et al. The influence of a gene expression profile on breast cancer decisions. *J Surg Oncol* 2009; 99(6):319-23.
20. Klang SH, Hammerman A, Liebermann N et al. Economic implications of 21-gene breast cancer risk assay from the perspective of an Israeli-managed health-care organization. *Value Health* 2010; 13(4):381-7.
21. Ademuyiwa FO, Miller A, O'Connor T et al. The effects of oncotype DX recurrence scores on chemotherapy utilization in a multi-institutional breast cancer cohort. *Breast Cancer Res Treat* 2011; 126(3):797-802.
22. Prat A, Parker JS, Fan C et al. Concordance among gene expression-based predictors for ER-positive breast cancer treated with adjuvant tamoxifen. *Ann Oncol* 2012.
23. Kelly CM, Krishnamurthy S, Bianchini G et al. Utility of oncotype DX risk estimates in clinically intermediate risk hormone receptor-positive, HER2-normal, grade II, lymph node-negative breast cancers. *Cancer* 2010; 116(22):5161-7.
24. Hassett MJ, Silver SM, Hughes ME et al. Adoption of gene expression profile testing and association with use of chemotherapy among women with breast cancer. *J Clin Oncol* 2012; 30(18):2218-26.
25. Joh JE, Esposito NN, Kiluk JV et al. The effect of Oncotype DX recurrence score on treatment recommendations for patients with estrogen receptor-positive early stage breast cancer and correlation with estimation of recurrence risk by breast cancer specialists. *Oncologist* 2011; 16(11):1520-6.
26. Carlson JJ, Roth JA. The impact of the Oncotype Dx breast cancer assay in clinical practice: a systematic review and meta-analysis. *Breast Cancer Res Treat* 2013; 141(1):13-22.
27. Fried G, Moskovitz M. Treatment decisions in estrogen receptor-positive early breast cancer patients with intermediate oncotype DX recurrence score results. *SpringerPlus* 2014; 3:71.

28. Yamauchi H, Nakagawa C, Takei H et al. Prospective study of the effect of the 21-gene assay on adjuvant clinical decision-making in Japanese women with estrogen receptor-positive, node-negative, and node-positive breast cancer. *Clinical breast cancer* 2014; 14(3):191-7.
29. Sparano JA, Solin LJ. Defining the clinical utility of gene expression assays in breast cancer: the intersection of science and art in clinical decision making. *J Clin Oncol* 2010; 28(10):1625-7.
30. Zujewski JA, Kamin L. Trial assessing individualized options for treatment for breast cancer: the TAILORx trial. *Future Oncol* 2008; 4(5):603-10.
31. Albain KS, Barlow WE, Shak S et al. Prognostic and predictive value of the 21-gene recurrence score assay in postmenopausal women with node-positive, oestrogen-receptor-positive breast cancer on chemotherapy: a retrospective analysis of a randomised trial. *Lancet Oncol* 2010; 11(1):55-65.
32. Goldstein LJ, Gray R, Badve S et al. Prognostic utility of the 21-gene assay in hormone receptor-positive operable breast cancer compared with classical clinicopathologic features. *J Clin Oncol* 2008; 26(25):4063-71.
33. Chang JC, Makris A, Gutierrez MC et al. Gene expression patterns in formalin-fixed, paraffin-embedded core biopsies predict docetaxel chemosensitivity in breast cancer patients. *Breast Cancer Res Treat* 2008; 108(2):233-40.
34. Gianni L, Zambetti M, Clark K et al. Gene expression profiles in paraffin-embedded core biopsy tissue predict response to chemotherapy in women with locally advanced breast cancer. *J Clin Oncol* 2005; 23(29):7265-77.
35. Oratz R, Kim B, Chao C et al. Physician Survey of the Effect of the 21-Gene Recurrence Score Assay Results on Treatment Recommendations for Patients With Lymph Node–Positive, Estrogen Receptor–Positive Breast Cancer. *Journal of Oncology Practice* 2011; 7(2):94-9.
36. Mamounas EP, Tang G, Fisher B et al. Association between the 21-gene recurrence score assay and risk of locoregional recurrence in node-negative, estrogen receptor-positive breast cancer: results from NSABP B-14 and NSABP B-20. *J Clin Oncol* 2010; 28(10):1677-83.
37. Solin LJ, Gray R, Baehner FL et al. A multigene expression assay to predict local recurrence risk for ductal carcinoma in situ of the breast. *J Natl Cancer Inst* 2013; 105(10):701-10.
38. van de Vijver MJ, He YD, van't Veer LJ et al. A gene-expression signature as a predictor of survival in breast cancer. *N Engl J Med* 2002; 347(25):1999-2009.
39. Drukker CA, van Tinteren H, Schmidt MK et al. Long-term impact of the 70-gene signature on breast cancer outcome. *Breast Cancer Res Treat* 2014; 143(3):587-92.
40. van 't Veer LJ, Dai H, van de Vijver MJ et al. Gene expression profiling predicts clinical outcome of breast cancer. *Nature* 2002; 415(6871):530-6.
41. Espinosa E, Vara JA, Redondo A et al. Breast cancer prognosis determined by gene expression profiling: a quantitative reverse transcriptase polymerase chain reaction study. *J Clin Oncol* 2005; 23(29):7278-85.
42. Buyse M, Loi S, van't Veer L et al. Validation and clinical utility of a 70-gene prognostic signature for women with node-negative breast cancer. *J Natl Cancer Inst* 2006; 98(17):1183-92.
43. Glas AM, Floore A, Delahaye LJ et al. Converting a breast cancer microarray signature into a high-throughput diagnostic test. *BMC Genomics* 2006; 7:278.
44. Haibe-Kains B, Desmedt C, Piette F et al. Comparison of prognostic gene expression signatures for breast cancer. *BMC Genomics* 2008; 9:394.
45. Mook S, Knauer M, Bueno-de-Mesquita JM et al. Metastatic potential of T1 breast cancer can be predicted by the 70-gene MammaPrint signature. *Ann Surg Oncol* 2010; 17(5):1406-13.
46. Mook S, Schmidt MK, Weigelt B et al. The 70-gene prognosis signature predicts early metastasis in breast cancer patients between 55 and 70 years of age. *Ann Oncol* 2010; 21(4):717-22.
47. Knauer M, Cardoso F, Wesseling J et al. Identification of a low-risk subgroup of HER-2-positive breast cancer by the 70-gene prognosis signature. *Br J Cancer* 2010; 103(12):1788-93.
48. Knauer M, Mook S, Rutgers EJ et al. The predictive value of the 70-gene signature for adjuvant chemotherapy in early breast cancer. *Breast Cancer Res Treat* 2010; 120(3):655-61.
49. Bueno-de-Mesquita JM, Sonke GS, van de Vijver MJ et al. Additional value and potential use of the 70-gene prognosis signature in node-negative breast cancer in daily clinical practice. *Ann Oncol* 2011; 22(9):2021-30.

50. Sapino A, Roepman P, Linn SC et al. MammaPrint molecular diagnostics on formalin-fixed, paraffin-embedded tissue. *J Mol Diagn* 2014; 16(2):190-7.
51. Wittner BS, Sgroi DC, Ryan PD et al. Analysis of the MammaPrint breast cancer assay in a predominantly postmenopausal cohort. *Clin Cancer Res* 2008; 14(10):2988-93.
52. Bueno-de-Mesquita JM, Linn SC, Keijzer R et al. Validation of 70-gene prognosis signature in node-negative breast cancer. *Breast Cancer Res Treat* 2009; 117(3):483-95.
53. Bueno-de-Mesquita JM, van Harten WH, Retel VP et al. Use of 70-gene signature to predict prognosis of patients with node-negative breast cancer: a prospective community-based feasibility study (RASTER). *Lancet Oncol* 2007; 8(12):1079-87.
54. Drukker CA, Bueno-de-Mesquita JM, Retel VP et al. A prospective evaluation of a breast cancer prognosis signature in the observational RASTER study. *Int J Cancer* 2013; 133(4):929-36.
55. Drukker CA, Nijenhuis MV, Bueno-de-Mesquita JM et al. Optimized outcome prediction in breast cancer by combining the 70-gene signature with clinical risk prediction algorithms. *Breast Cancer Res Treat* 2014; 145(3):697-705.
56. Mook S, Schmidt MK, Viale G et al. The 70-gene prognosis-signature predicts disease outcome in breast cancer patients with 1-3 positive lymph nodes in an independent validation study. *Breast Cancer Res Treat* 2009; 116(2):295-302.
57. Rutgers E, Piccart-Gebhart MJ, Bogaerts J et al. The EORTC 10041/BIG 03-04 MINDACT trial is feasible: results of the pilot phase. *Eur J Cancer* 2011; 47(18):2742-9.
58. Esserman LJ, Berry DA, Cheang MC et al. Chemotherapy response and recurrence-free survival in neoadjuvant breast cancer depends on biomarker profiles: results from the I-SPY 1 TRIAL (CALGB 150007/150012; ACRIN 6657). *Breast Cancer Res Treat* 2012; 132(3):1049-62.
59. Kunz G. Use of a genomic test (MammaPrint) in daily clinical practice to assist in risk stratification of young breast cancer patients. *Arch Gynecol Obstet* 2011; 283(3):597-602.
60. Bighin C, Del Mastro L, Canavese G et al. Use in current clinical practice of 70-gene signature in early breast cancer. *Int J Cancer* 2010; 127(11):2736-7.
61. Retel VP, Joore MA, Knauer M et al. Cost-effectiveness of the 70-gene signature versus St. Gallen guidelines and Adjuvant Online for early breast cancer. *Eur J Cancer* 2010; 46(8):1382-91.
62. Saghatchian M, Mook S, Pruneri G et al. Additional prognostic value of the 70-gene signature (MammaPrint((R))) among breast cancer patients with 4-9 positive lymph nodes. *Breast* 2013; 22(5):682-90.
63. Ahn SG, Lee HM, Lee HW et al. Prognostic discrimination using a 70-gene signature among patients with estrogen receptor-positive breast cancer and an intermediate 21-gene recurrence score. *International journal of molecular sciences* 2013; 14(12):23685-99.
64. Cusumano PG, Generali D, Ciruelos E et al. European inter-institutional impact study of MammaPrint. *Breast* 2014.
65. Krijgsman O, Roepman P, Zwart W et al. A diagnostic gene profile for molecular subtyping of breast cancer associated with treatment response. *Breast Cancer Res Treat* 2012; 133(1):37-47.
66. Nguyen B, Cusumano PG, Deck K et al. Comparison of molecular subtyping with BluePrint, MammaPrint, and TargetPrint to local clinical subtyping in breast cancer patients. *Ann Surg Oncol* 2012; 19(10):3257-63.
67. Viale G, Slaets L, Bogaerts J et al. High concordance of protein (by IHC), gene (by FISH; HER2 only), and microarray readout (by TargetPrint) of ER, PgR, and HER2: results from the EORTC 10041/BIG 03-04 MINDACT trial. *Ann Oncol* 2014; 25(4):816-23.
68. Goetz MP, Suman VJ, Ingle JN et al. A two-gene expression ratio of homeobox 13 and interleukin-17B receptor for prediction of recurrence and survival in women receiving adjuvant tamoxifen. *Clin Cancer Res* 2006; 12(7 Pt 1):2080-7.
69. Ma XJ, Hilsenbeck SG, Wang W et al. The HOXB13:IL17BR expression index is a prognostic factor in early-stage breast cancer. *J Clin Oncol* 2006; 24(28):4611-9.
70. Reid JF, Lusa L, De Cecco L et al. Limits of predictive models using microarray data for breast cancer clinical treatment outcome. *J Natl Cancer Inst* 2005; 97(12):927-30.
71. Jansen MP, Sieuwerts AM, Look MP et al. HOXB13-to-IL17BR expression ratio is related with tumor aggressiveness and response to tamoxifen of recurrent breast cancer: a retrospective study. *J Clin Oncol* 2007; 25(6):662-8.

72. Jerevall PL, Brommesson S, Strand C et al. Exploring the two-gene ratio in breast cancer-- independent roles for HOXB13 and IL17BR in prediction of clinical outcome. *Breast Cancer Res Treat* 2008; 107(2):225-34.
73. Ma XJ, Salunga R, Dahiya S et al. A five-gene molecular grade index and HOXB13:IL17BR are complementary prognostic factors in early stage breast cancer. *Clin Cancer Res* 2008; 14(9):2601-8.
74. Jerevall PL, Ma XJ, Li H et al. Prognostic utility of HOXB13:IL17BR and molecular grade index in early-stage breast cancer patients from the Stockholm trial. *Br J Cancer* 2011; 104(11):1762-9.
75. Jankowitz RC, Cooper K, Erlander MG et al. Prognostic utility of the breast cancer index and comparison to Adjuvant! Online in a clinical case series of early breast cancer. *Breast Cancer Res* 2011; 13(5):R98.
76. Sgroi DC, Sestak I, Cuzick J et al. Prediction of late distant recurrence in patients with oestrogen-receptor-positive breast cancer: a prospective comparison of the breast-cancer index (BCI) assay, 21-gene recurrence score, and IHC4 in the TransATAC study population. *Lancet Oncol* 2013.
77. Ring BZ, Seitz RS, Beck R et al. Novel prognostic immunohistochemical biomarker panel for estrogen receptor-positive breast cancer. *J Clin Oncol* 2006; 24(19):3039-47.
78. Ross DT, Kim CY, Tang G et al. Chemosensitivity and stratification by a five monoclonal antibody immunohistochemistry test in the NSABP B14 and B20 trials. *Clin Cancer Res* 2008; 14(20):6602-9.
79. Bartlett JM, Thomas J, Ross DT et al. Mammostrat as a tool to stratify breast cancer patients at risk of recurrence during endocrine therapy. *Breast Cancer Res* 2010; 12(4):R47.
80. Tutt A, Wang A, Rowland C et al. Risk estimation of distant metastasis in node-negative, estrogen receptor-positive breast cancer patients using an RT-PCR based prognostic expression signature. *BMC Cancer* 2008; 8:339.
81. Welsh AW, Moeder CB, Kumar S et al. Standardization of estrogen receptor measurement in breast cancer suggests false-negative results are a function of threshold intensity rather than percentage of positive cells. *J Clin Oncol* 2011; 29(22):2978-84.
82. Allred DC, Carlson RW, Berry DA et al. NCCN Task Force Report: Estrogen Receptor and Progesterone Receptor Testing in Breast Cancer by Immunohistochemistry. *Journal of the National Comprehensive Cancer Network : JNCCN* 2009; 7 Suppl 6:S1-S21; quiz S22-3.
83. Cuzick J, Dowsett M, Pineda S et al. Prognostic value of a combined estrogen receptor, progesterone receptor, Ki-67, and human epidermal growth factor receptor 2 immunohistochemical score and comparison with the Genomic Health recurrence score in early breast cancer. *J Clin Oncol* 2011; 29(32):4273-8.
84. Barton S, Zabaglo L, A'Hern R et al. Assessment of the contribution of the IHC4+C score to decision making in clinical practice in early breast cancer. *Br J Cancer* 2012; 106(11):1760-5.
85. Nielsen T, Wallden B, Schaper C et al. Analytical validation of the PAM50-based Prosigna Breast Cancer Prognostic Gene Signature Assay and nCounter Analysis System using formalin-fixed paraffin-embedded breast tumor specimens. *BMC Cancer* 2014; 14:177.
86. Gnant M, Filipits M, Greil R et al. Predicting distant recurrence in receptor-positive breast cancer patients with limited clinicopathological risk: using the PAM50 Risk of Recurrence score in 1478 postmenopausal patients of the ABCSG-8 trial treated with adjuvant endocrine therapy alone. *Ann Oncol* 2014; 25(2):339-45.
87. Filipits M, Nielsen TO, Rudas M et al. The PAM50 risk-of-recurrence score predicts risk for late distant recurrence after endocrine therapy in postmenopausal women with endocrine-responsive early breast cancer. *Clin Cancer Res* 2014; 20(5):1298-305.
88. Dowsett M, Sestak I, Lopez-Knowles E et al. Comparison of PAM50 Risk of Recurrence Score With Oncotype DX and IHC4 for Predicting Risk of Distant Recurrence After Endocrine Therapy. *J Clin Oncol* 2013; 31(22):2783-90.
89. Parker JS, Mullins M, Cheang MC et al. Supervised risk predictor of breast cancer based on intrinsic subtypes. *J Clin Oncol* 2009; 27(8):1160-7.
90. Nielsen TO, Parker JS, Leung S et al. A comparison of PAM50 intrinsic subtyping with immunohistochemistry and clinical prognostic factors in tamoxifen-treated estrogen receptor-positive breast cancer. *Clin Cancer Res* 2010; 16(21):5222-32.
91. Cheang MC, Voduc KD, Tu D et al. Responsiveness of Intrinsic Subtypes to Adjuvant Anthracycline Substitution in the NCIC.CTG MA.5 Randomized Trial. *Clin Cancer Res* 2012; 18(8):2402-12.

92. Sestak I, Dowsett M, Zabaglo L et al. Factors predicting late recurrence for estrogen receptor-positive breast cancer. *J Natl Cancer Inst* 2013; 105(19):1504-11.
93. Van Laar RK. Design and multiseres validation of a web-based gene expression assay for predicting breast cancer recurrence and patient survival. *J Mol Diagn* 2011; 13(3):297-304.
94. D'Alfonso TM, van Laar RK, Vahdat LT et al. BreastPRS is a gene expression assay that stratifies intermediate-risk Oncotype DX patients into high- or low-risk for disease recurrence. *Breast Cancer Res Treat* 2013; 139(3):705-15.
95. Varga Z, Sinn P, Fritzsche F et al. Comparison of EndoPredict and Oncotype DX test results in hormone receptor positive invasive breast cancer. *PLoS one* 2013; 8(3):e58483.
96. Martin M, Brase JC, Calvo L et al. Clinical validation of the EndoPredict test in node-positive chemotherapy-treated ER+/HER2- breast cancer patients: results from the GEICAM/9906 trial. *Breast Cancer Res* 2014; 16(2):R38.
97. Dubsy P, Brase JC, Jakesz R et al. The EndoPredict score provides prognostic information on late distant metastases in ER+/HER2- breast cancer patients. *Br J Cancer* 2013; 109(12):2959-64.
98. Hornberger J, Alvarado MD, Rebecca C et al. Clinical validity/utility, change in practice patterns, and economic implications of risk stratifiers to predict outcomes for early-stage breast cancer: a systematic review. *J Natl Cancer Inst* 2012; 104(14):1068-79.
99. Fan C, Oh DS, Wessels L et al. Concordance among gene-expression-based predictors for breast cancer. *N Engl J Med* 2006; 355(6):560-9.
100. Kelly CM, Bernard PS, Krishnamurthy S et al. Agreement in Risk Prediction Between the 21-Gene Recurrence Score Assay (Oncotype DX(R)) and the PAM50 Breast Cancer Intrinsic Classifier in Early-Stage Estrogen Receptor-Positive Breast Cancer. *Oncologist* 2012; 17(4):492-8.
101. Badve SS, Baehner FL, Gray RP et al. Estrogen- and progesterone-receptor status in ECOG 2197: comparison of immunohistochemistry by local and central laboratories and quantitative reverse transcription polymerase chain reaction by central laboratory. *J Clin Oncol* 2008; 26(15):2473-81.
102. Baehner FL, Achacoso N, Maddala T et al. Human epidermal growth factor receptor 2 assessment in a case-control study: comparison of fluorescence in situ hybridization and quantitative reverse transcription polymerase chain reaction performed by central laboratories. *J Clin Oncol* 2010; 28(28):4300-6.
103. Dabbs DJ, Klein ME, Mohsin SK et al. High false-negative rate of HER2 quantitative reverse transcription polymerase chain reaction of the Oncotype DX test: an independent quality assurance study. *J Clin Oncol* 2011; 29(32):4279-85.
104. Bartlett JM, Starczynski J. Quantitative reverse transcriptase polymerase chain reaction and the Oncotype DX test for assessment of human epidermal growth factor receptor 2 status: time to reflect again? *J Clin Oncol* 2011; 29(32):4219-21.
105. Harris L, Fritzsche H, Mennel R et al. American Society of Clinical Oncology 2007 update of recommendations for the use of tumor markers in breast cancer. *J Clin Oncol* 2007; 25(33):5287-312.
106. Goldhirsch A, Winer EP, Coates AS et al. Personalizing the treatment of women with early breast cancer: highlights of the St Gallen International Expert Consensus on the Primary Therapy of Early Breast Cancer 2013. *Ann Oncol* 2013; 24(9):2206-23.

Billing Coding/Physician Documentation Information

- S3854** Gene expression profiling panel for use in the management of breast cancer treatment
84999 Unlisted chemistry procedure
89240 Unlisted miscellaneous pathology test

Additional Policy Key Words

N/A

Policy Implementation/Update Information

- 1/1/06 New policy; considered investigational.
 1/1/06 No policy statement changes.
 1/1/07 No policy statement changes.

1/1/08	No policy statement changes.
1/10/08	Policy updated with June 2007 TEC Assessment; text and references extensively revised. Policy statement changed to indicate that use of Oncotype DX to determine recurrence risk for women who meet specific criteria may be considered medically necessary. Other indications for Oncotype DX or use of other gene expression markers are considered investigational.
1/1/09	Policy statements unchanged except for addition of newer assays that are considered investigational.
1/1/10	Policy statements revised to add more detail; specific statements added regarding testing of multiple ipsilateral primaries and timing of Oncotype DX testing (i.e., within six months following diagnosis).
1/1/11	No policy statement changes.
1/1/12	No policy statement changes.
1/1/13	No policy statement changes.
1/1/14	Policy statement changed to include newer assays BreastPRS, EndoPredict, BluePrint and TargetPrint as investigational. Policy statement added that the use of gene expression assays in men with breast cancer is considered investigational.
8/1/14	Policy statement changed to include newer assays BreastPRS, EndoPredict™, BluePrint® and TargetPrint® as investigational. Policy statement on PAM50 updated to Prosigna™. Policy statement added that the use of gene expression assays in men with breast cancer is considered investigational. Added patients with bilateral disease to investigational statement.

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