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**Biological subtypes of breast cancer: Prognostic and therapeutic implications**

Yersal O *et al*. Biological subtypes of breast cancer

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**Abstract**

Breast cancer represents a heterogeneous complex of diseases, a spectrum of many subtypes with distinct biological features that lead to differences in response patterns to various treatment modalities and clinical outcomes. Traditional classification systems, regarding biological characteristics may have limitations for patient-tailored treatment strategies. Tumors with similar clinical and pathological presentations may have different behaviors. Analyses of breast cancer with new molecular techniques now hold promise for the development of more accurate tests for the prediction of recurrence. Gene signatures have been developed as predictors of response to therapy, and protein gene products that have direct roles in driving the biology and clinical behavior of cancer cells are potential targets for the development of novel therapeutics. The present review summarizes current knowledge in breast cancer molecular biology focusing on novel prognostic and predictive factors.

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**Key words:** Breast cancer; Tumor biology; Subtypes; Predictive factors; Prognostic factors

**Core tip**:Breast cancer is a heterogeneous disease including many subtypes that have different treatment responses and clinical outcomes. The present review summarizes current knowledge in breast cancer molecular biology focusing on novel classification, prognostic and predictive factors.

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**INTRODUCTION**

Breast cancer represents a heterogeneous complex of diseases, a spectrum of many subtypes with distinct biological features that lead to differences in response patterns to various treatment modalities and clinical outcomes. Traditional classification systems, regarding biological characteristics such as; tumor size, lymph node involvement, histological grade, patient’s age, estrogen receptors (ER), progesterone receptors (PR) and human epidermal growth factor receptor 2 (HER2 or c-erbB2) status may have limitations for patient-tailored treatment strategies. Furthermore, the histological appearance of the tumors may not be sufficient to establish the underlying complex genetic alterations and the biological events involved in cancer development and progression. Tumors with similar clinical and pathological presentations may have different behaviors. Therefore recent studies are focused on defining biological characteristics more detailed to improve patient risk stratification and to ensure the highest chance of benefit and the least toxicity from a specific treatment modality. Global gene expression profiling (GEP) studies have provided evidence for classifying breast cancer into distinct biological classes associated with patient survival, based on gene expression patterns[1,2].

Population based screening programs have resulted in a significant shift to early stage disease and increased the interest in studying biological prognostic and predictive factors[3]. Novel molecular studies have opened a broad field in cancer research that allows basic and translational researchers to look for new potential targets. Analyses of breast cancer with new molecular techniques now hold promise for the development of more accurate tests for the prediction of recurrence. Gene signatures have been developed as predictors of response to therapy and protein gene products that have direct roles in driving the biology and clinical behavior of cancer cells are potential targets for the development of novel therapeutics[4].The present review summarizes current knowledge in breast cancer molecular biology focusing on novel classification, prognostic and predictive factors.

**IDENTIFICATION OF BREAST CANCER SUBTYPES BY GEP STUDIES**

Gene expression microarray studies have identified distinct molecular tumor classes based on simultaneous expression analyses of thousands of genes in a single experiment. Perou *et al*[5] first analyzed gene expression patterns in grossly dissected normal or malignant human breast tissues in 65 tumor samples from 42 individuals with locally advanced breast cancer treated with neoadjuvant doxorubicin, using complementary microarrays representing 8102 human genes. Authors have selected 496 genes based on the criteria of significantly greater variation in expression between different tumors and minimum variation between paired samples from the same patient and these genes were termed as intrinsic gene subset. Samples and genes were aggregated according to the similarity to each other (unsupervised clustering). Subset cluster analysis revealed a dendogram with two main branches that were clinically described as *ER-positive* and *ER-negative*. The tumors in the *ER-positive* group were characterized by the relatively high expression of many genes expressed by breast luminal cells(ER-responsive genes, luminal cytokeratins and other luminal associated markers), so they were termed as *luminal* group. The *ER-negative* group was further divided into *basal-like*, *ErbB2-positive* and *normal-like* subclasses. *Basal-like* tumors expressed many of the characteristics of breast basal epithelial cells that did not express ER and showed staining with basal keratins. Another cluster of tumors were characterized by the expression of high levels of HER2 oncogene which also showed low levels of ER expression and other genes associated with ER expression. Eventually, the authors identified four groups of samples using intrinsic gene set that might be related to different molecular features of mammary epithelial biology, and they named them as *ER-positive luminal-like*, *basal-like*, *ErbB2-positive* and *normal-like*. These results were confirmed in follow up experiments using larger numbers of cases[6].

Subsequent studies revealed that similar molecular subtypes of breast cancer could be identified in multiple cohorts of breast cancers and that *luminal* cancers could be subclassified into 2 or 3 groups and different molecular subtypes were shown to have distinct clinical outcomes. Sorlie *et al*[7] investigated the clinical relevance of gene expression profiles in 78 breast carcinoma patients. Of these patients, 51 were part of a prospective study with locally advanced (T3-T4 and/or N2) tumors and had received doxorubicin based chemotherapy before the surgery. The authors showed a highly significant difference in overall survival between the subtypes. Both the *basal-like* and *ErbB2-positive*subtypes were associated with the shortest survival times. Authors subclassified the *luminal-like* breast cancer into three subclasses comprising *luminal-A*, *luminal-B* and *luminal-C* and identified *luminal-A* subgroup of *ER-positive* tumors as associated with best outcome. Vant veer *et al*[8] also, investigated node-negative breast cancer patients and found 231 genes significantly associated with disease outcome as defined by the presence of distant metastasis at the 5th year. These data revealed that each breast tumor has its own unique molecular portrait, providing the basis for an improved molecular taxonomy of the disease.

**SUBCLASSIFICATION OF LUMINAL LIKE BREAST CANCER**

Approximately 75% of breast cancers are positive for ER and/or PR. The *ER-positive* tumors express ER, PR, ER responsive genes and other genes that encode typical proteins of luminal epithelial cells so they are termed as *luminal* group. Characterization of *luminal-like* breast cancer varied between various studies probably due to the identification and use of distinct intrinsic gene sets for cluster analysis. Hu *et al*[9]evaluated an intrinsic gene set derived from three independent studies(Sorlie *et al*[7], 2001; Vant Veer *et al*[8], 2002; Sotiriou *et al*[10], 2003) and joined together into a combined data set and identified two main *luminal-like* subclasses corresponding to *luminal-A* and *luminal-B*. Most subsequent studies have supported the concept of two *luminal-like* subclasses[10-12].

***Luminal-A***

The *luminal-A* is the most common subtype and represents 50%-60% of all breast cancers. These tumors frequently have low histological grade, low degree of nuclear pleomorphism, and low mitotic activity, and include special histological types (*i.e.*, tubular, invasive cribriform, mucinous and lobular) with good prognosis. *Luminal-A* is characterized by higher levels of ER and lower levels of proliferation related genes. It is characterized by the expression of luminal epithelial cytokeratins (CK) 8 and 18, other luminal associated markers including ER1, genes associated with ER function such as *LIV1* (zinc transporter *ZIP6* or *SLC39A6*; solute carrier family 39 zinc transporter, member 6), *hepatocyte nuclear factor 3 alpha (FOXA1), X-box binding protein 1 (XBP1), GATA binding protein 3 (GATA3), B cell lymphoma 2 (BCL2), erbB3 and erbB4*[13]. *Luminal-A* subtype is defined as ER-positive and/or PR-positive tumors with negative HER2 and low Ki67 (proliferating cell nuclear antigen) index by immunohistochemistry[14].

Patients with *luminal-A* breast cancer have a good prognosis; the relapse rate is significantly lower than the other subtypes. Recurrence is common in bone, whereas, liver, lung and central nervous system metastases occur in less than 10% of the patients and treatment is mainly based on hormonal therapy[15,16].

***Luminal-B***

*Luminal-B* tumors comprise 15%-20% of breast cancers and have a more aggressive phenotype, higher histologic grade, proliferative index and worse prognosis[17].This subtype has a higher recurrence rate and, lower survival rates after relapse as compared to *luminal-A* subtype[18].

The main difference between both *luminal* subgroups is increased expression of proliferation-related genes such as *avian myeloblastosis viral oncogene homolog (v-MYB), gamma glutamyl hydrolase (GGH), lysosome-associated transmembrane protein 4-beta (LAPTMB4), nuclease sensitive element binding* protein *1 (NSEP1)* and *cyclin E1 (CCNE1)* in *luminal-B* breast cancers. *Luminal-B* tumors also demonstrate increased expression of growth receptor signaling genes[19]. Approximately 30% of *HER2-positive* tumors defined by immunohistochemistry are assigned to the *luminal-B* subtype[20].

It should be noted that, expression levels of proliferation related genes in ER-positive disease form a continuum; therefore, the cutoffs to define *luminal-A* and *luminal-B* cancers are set in an arbitrary manner rather than emerge from a bimodal distribution of these genes’ expression levels[21].Various studies conducted to differentiate *luminal-A* and *luminal-B* subtypes, defined more pragmatic criteria that can be broadly applied to clinical practice. Ki67 index is suggested as a potential proliferation marker that could successfully differentiate *luminal-B* tumors from *luminal-A* in clinical practice. Cheang *et al*[22]studied 357 breast cancer subtypes by using microarray based gene expression profiling and the Ki67, hormone receptor and HER2 status by immunohistochemistry. The authors determined the Ki67 cut off point (14%) that distinguishes *luminal-A* from *luminal-B* tumors, then applied it to an independent microarray series of 4046 breast cancers and concluded that the two subtypes could be distinguished by the Ki67 index. However, Ki67 immunohistochemistry had known limitations, such as, low intra- and inter-laboratory reproducibility, arbitrary selection of optimal antibodies for testing and different methods of cell counting (manual versus automated) in addition to potential problems resulting from tumor heterogeneity[23]. There is also an urgent need to standardize the Ki67 expression analysis and validate its clinical utility.

From the immunohistochemical point of view, *luminal-B* subtype is defined as ER-positive, HER2-negative and Ki67high or ER and HER-2 positive tumors, but this definition does not include all *luminal-B* tumors, as up to 6% of them are negative for both ER and HER2. Moreover, the Ki67 cut off point to distinguish *luminal-A* and -*B* has not been standardized[24].

Overall survival in untreated *luminal-B* breast cancers is similar to the *basal-like* and *HER2-positive* subtypes which are widely recognized as high-risk tumors[9].*Luminal-B* tumors have poorer outcomes with hormonotherapy. Several studies have suggested that *luminal-B* breast cancer was relatively insensitive to endocrine therapy as compared to *luminal-A* breast cancer and to paclitaxel- and doxorubicin-containing preoperative chemotherapy compared with *HER2-positive* and *basal-like* breast cancers. However; *luminal-B* breast cancer responds better to neoadjuvant chemotherapy as compared to luminal-A subtype, achieving higher pathological complete response rates[25-29].Increased relapse rates observed in *luminal-B* tumors are limited to the first 5 years after diagnosis[30].

Recent evidence suggest that certain alternative growth factor pathways, such as *fibroblast growth factor receptor 1 (FGFR1), HER1, phosphoinositide 3 kinase (PI3K) catalytic alpha polypeptide*, and *sarcoma proto-oncogene (Src)* may contribute to the higher proliferation and poorer prognosis of the *luminal-B* breast cancer, and related therapeutic agents are in active clinical development[31].

In breast cancer changes to fibroblast growth factor signaling are considered important for oncogenesis, mainly through amplification of *FGFR1* and *FGFR2*. In 10% of all breast cancers *FGFR1* is amplified. Recent data suggest that the *luminal-B* subtype is enriched for *FGFR1* gene amplification[32]. Studies suggested that *FGFR1* gene amplification might be a contributor to the poor prognosis observed in *luminal-B* breast cancer through increased proliferation and resistance to endocrine therapy. Several antibodies and small molecule inhibitors of *FGFR* are currently under clinical study processes.

In breast cancer the PI3K pathway is frequently activated. Amplification of upstream receptors such as HER2, loss of negative regulators such as PTEN, amplification of downstream targets such as Protein Kinase B (PKB or Akt) and activating mutations or genetic amplification of the alpha catalytic subunit of PI3K have all been described in breast cancer. Targeting the PI3K pathway appears promising, though more extensive studies are required[33].

***HER2-positive***

Human epidermal growth factor receptor-2 is a member of the family of four membrane tyrosine kinases. The HER2 receptor is encoded by the HER2 gene, which is a proto-oncogene mapped in chromosome 17q21. Upon ligand binding to their extracellular domains, HER proteins undergo dimerization and transphosphorylation of their extracellular domains. HER2 does not have a ligand and relies on heterodimerization with another family member or homodimerization with itself when expressed at very high levels to be activated. These phosphorylated tyrosine residues interact with numerous intracellular signaling molecules leading to activation of downstream second messenger pathways and crosstalk with other membrane signaling pathways. Transcription factors activated by the pathway regulate many genes involved in cell proliferation, survival, differentiation, angiogenesis, invasion and metastasis[34-37].

In breast cancer subtypes, *HER2-positive* cancer correspond to 15-20%.HER2 positivity confers more aggressive biological and clinical behavior. These tumors are characterized by high expression of the HER2 gene and other genes associated with the HER2 pathway and/or HER2 amplicon located in the 17q12 chromosome. Morphologically these tumors are highly proliferative; 75% have a high histological and nuclear grade and more than 40% have p53 mutations[38].Nearly half of *HER2-positive* breast cancers are positive for ER, but they generally express lower ER levels.

The immunohistochemical profile of *ER-negative* and *HER2-positive* does not correspond perfectly with the intrinsic subtype, since only 70% of HER2 tumors by microarray have the protein over expressed by immunohystochemistry. Conversely, all tumors with HER2 amplification or over expression are not included in the HER2 cluster by microarray analysis[39,40].

Staaf *et al*[41] identified three separate subtypes of *HER2-positive* tumors, one with a clearly poor prognosis with a 12% 10-years survival; compared to the 50%-55% survival in the other two groups by using HER2 derived prognostic predictor (HDPP) gene analysis. The HDPP was not directly related to the expression of proliferation gene and HER2 pathway but was mostly associated with genes related to immune response to tumor invasion and metastasis.

In the absence of treatment, *HER2-positive* tumors have poor prognosis. They have increased sensitivity to certain cytotoxic agents such as doxorubicin, relative resistance to hormonal agents and propensity to metastasize to the brain and visceral organs. Doxorubicin sensitivity is possibly due to co amplification of the topoisomerase-2 gene which is near the HER2 locus on chromosome 17 and is the target of this drug[42,43].Advances in translational science have led to the development of a large spectrum of HER directed therapies.

***Basal-like***

The *basal-like* subtype represent from 8% to 37% of all breast cancers, depending on the proportion of poorly differentiated G3 cases included in the population studied[44]. *Basal-like* cancers are associated with high histological and nuclear grade, poor tubule formation, presence of central necrotic or fibrotic zones, pushing borders, conspicuous lymphocytic infiltrate and medullary features with exceptionally high mitotic and proliferative indices. Most of these tumors are infiltrating ductal tumors with solid growth pattern, aggressive clinical behavior and high rate of metastasis to the brain and lung[45].

Tumors belonging to the *basal-like* subgroup express high levels of basal myoepithelial markers such as CK5, CK 14,CK 17 and laminin and do not express ER,PR and HER2 and hence they are referred as *triple-negative*. They also over express P-cadherin,fascin,caveolins1 and 2, alpha-beta crystallin and epidermal growth factor receptor(EGFR). *Basal-like* cancers present frequent mutations in the *tumor protein 53 (TP53)* gene; evidence of genomic instability and inactivation of the *retinoblastoma (Rb)* pathway. Deregulated integrin expression has also been detected and may contribute to aggressive cell behaviors and progression in this subtype[45].

It is important to clarify that the terms *triple-negative* and *basal-like* are not completely synonymous and there is approximately 20%-30% discordance across studies. The term *triple-negative* refers to the immunohistochemical classification of breast tumors lacking ER, PR and HER2 protein expression whereas the *basal-like* subtype is defined via gene expression microarray analysis. The *basal-like* classification is available only in the research setting to date and thus the *triple-negative* phenotype currently is a reliable surrogate in the clinical setting[46].

There are several reported biomarkers associated with *basal-like* group as well as putative candidates suitable for immunohistochemical screening, however; currently, there is no specific international consensus on complementary biomarkers that can define *basal-like* cancers[47].

Several genes related to *basal-like* subtype have been implicated in promoting cellular proliferation, cell survival, cell migration and invasion. Despite the wide diversity of the involved pathways, signaling molecules such as the mitogen activated protein kinase(MAPK), PI3K, Akt and nuclear factor kappa B (NF-kB) are commonly deregulated as seen in other breast cancer subtypes. Other alterations such as cytoplasmic and nuclear accumulation of beta catenin were also observed in *basal-like* cancers, being the marker suggested as a potential therapeutic target for this cancer[48].

Microarray and immunohistochemical analyses demonstrated that basal-like subtype constitute approximately three quarters of *breast cancer 1 (BRCA1)* gene related breast cancers. This gene often termed as the *caretaker of the genome*, is located on chromosome 17 and is related with both inherent DNA damage sensing processes and DNA repair mechanisms. Breast cancers related with BRCA1 often express *triple-negative* phenotype and are frequently positive for Ki67 basal cytokeratins, TP53, EGFR and P cadherin and X chromosome abnormalities. Outcomes for women with *basal-like* tumors and BRCA1 related breast cancers are similar in particular for early relapse and pattern of metastatic disease[49]. *Basal-like* cancers with deficient BRCA1pathway may respond to specific therapeutic regimens such as poly-ADP ribose polymerase (PARP) enzyme inhibitors. Also BRCA1 deficient cells have defects in DNA double strand break repair mechanisms that could render them particularly sensitive to therapeutic agents that generate DNA double strand breaks such as PARP enzyme inhibitors[50]. As often over-expressed in *basal-like* cancer, EGFR may also represent another potential therapeutic target. Dong *et al*[51] identified notch pathway as one of the mechanisms of resistance to EGFR inhibition in *basal-like* breast cancer as a valuable information to overcome this resistance. Dual pathway inhibition may be a viable clinical strategy in *basal-like* cancers.

As one of the *triple-negative* subtypes, *claudin-low* breast cancer was described by Herschkowitz *et al*[52]. This subtype is characterized by low expression of genes involved in tight junctions and cell-cell adhesions including claudins 3, 4 and 7, occludin and E cadherin showing high expression of epithelial to mesenchymal transition genes and stem cell features. Currently, it has been reported that patients with *claudin-low* tumors also have poor clinical outcomes like other *triple-negative* tumors.

***Normal breast-like***

These tumors account for about 5%-10% of all breast carcinomas. They are poorly characterized and have been grouped into the classification of intrinsic subtypes with fibroadenomas and normal breast samples. They express gene characteristics of adipose tissue presenting an intermediate prognosis between *luminal* and *basal-like* cancers and usually do not respond to neoadjuvant chemotherapy. They lack the expression of ER, PR and, HER2 so these tumors can also be classified as *triple-negative* but, they are not considered as *basal-like* cancers as they are negative for CK5 and EGFR. There are few studies on this subtype and their clinical significance remains undetermined. There are doubts about their existence as a breast cancer subtype and some researchers believe they could be a technical artifact from high contamination with normal tissue during the microarrays[53]. In fact, in a large series of samples where the neoplastic cells were isolated by microdissection, no cases of *normal breast-like* subtype were found supporting this hypothesis.

The implications of the molecular classification in the therapeutic era have been accepted by the international panels. In the 2011and the latest 2013 St. Gallen International Breast Cancer Conferences the expert panel members agreed that therapeutic decisions should be made based on the recognition of the intrinsic subtypes of breast cancer. Panel members agreed that the different breast cancer subtypes can be defined only by genetic array testing but by approximation to this classification can be made by immunohistochemistry[54-55] (Table 1).

Although molecular taxonomy of breast cancer has attracted great attention, to date, actual practical adaptation seems limited. Certain critical issues have been raised such as validation, reproducibility and clinical utility. The four main molecular classes frequently reported can be considered as an oversimplification of a novel molecular classification system and add little to our understanding of the biology and behavior of breast cancer. Sub classification of the largest *luminal* class remains unresolved. Most *luminal* tumors are hormone receptor positive and can be identified in routine practice using immunohistochemistry. Hormone receptor expression in *luminal* phenotype is recognized as a validated predictor to hormonal treatments. The difference between *basal-like* and *triple-negative* is disputed with triple negativity in clinical practice providing more practical and routinely applicable classification preferred. Similarly, strongly *HER2-positive* breast cancer patients by immunohistochemistry are likely to be offered anti-HER2 therapy, especially if their tumors show evidence of HER2 gene amplification, regardless of their molecular classification. Furthermore, *normal breast-like* class is not well defined and the proportion of some classes defined by GEP varied substantially. Finally, the contribution of this molecular taxonomy to current clinical practice is just the modification of treatment protocols related to ER, PR, HER2 and, Ki67 status of breast cancer. Molecular classification based on combination of the classical well-defined immunohistochemical markers can be considered as a simpler and more practical approach, and it is expected to remain as such unless novel target molecules driving individual classes are identified.

BIG 1-98 is a randomized, phase III study that compared five years of tamoxifen or letrozole, or their sequences in post-menopausal women with ER positive early breast cancer. Metzger *et al*[56] updated benefit of endocrine treatment among Luminal subgroups in this trial. ER positive subtypes were defined as Luminal A (ER+ and/or PR+ HER2– and Ki67 < 14%) or Luminal B (ER+ and/or PR+, HER2– and Ki67 ≥ 14%). In the invasive ductal carcinoma subset, 1436 (44%) and 1163 (36%) were classified as Luminal A and Luminal B, while in the invasive lobular carcinoma subset 237 (59%) and 87 (22%) were classified as Luminal A and Luminal B, respectively. In lobular carcinoma patients disease free survival hazard ratios for letrozole versus tamoxifen were 0.51 (95%CI: 0.33 to 0.79) for Luminal A and 0.35 (95%CI: 0.21 to 0.56) for Luminal B subtypes. The disease free survival hazard ratios for letrozole versus tamoxifen were 0.93 (95%CI: 0.74 to 1.77) for invasive ductal carcinoma Luminal A and 0.64 (95%CI: 0.52 to 0.78) and invasive ductal carcinoma-Luminal B. Greater reduction in risk of a disease free survival event was shown in women with Luminal B for both invasive ductal carcinoma and invasive lobular carcinoma[56].

Currently, the available molecular tests have offered the opportunity to challenge the molecular complexity of breast cancer, but do not provide sufficiently robust information to modify established treatment schemes. These tests require validation in large series and comparison with traditional classification systems in the context of comprehensive clinical trials.

**CLINICAL GENE EXPRESSION BASED ASSAYS**

Although up to 70% of patients with early breast cancer currently receive adjuvant chemotherapy, only a specific subgroup of these patients derive benefit from this treatment. Therefore, in parallel with the advances in the molecular sub classification of breast cancer several multigene predictors of outcome have been developed (Table 2). It was conceived that microarray based gene signatures were able to identify a subgroup of patients sufficiently with good prognosis that would not be treated with adjuvant chemotherapy. Currently, many classifiers have been generated by using various technologies such as cDNA and oligonucleotide arrays and multiplex polymerase chain reaction (PCR) analysis. These genomic tests assess expression of different but sometimes overlapping sets of genes. Despite differences in candidate genes in each of the assays most of them can quite reliably predict biology of tested tumors. In fact, when some of these tests were compared with each other, they were found to be quite similar in their abilities to predict metastases-free and overall survivals. Five different prognostic signatures were shown to have high correlation; even among tests utilizing expression of very few genes in common. One important finding from analyses of various genomic tests is the fact that they assign almost all patients with hormone receptor negative disease as high risk, in common. Therefore, most of these tests are more applicable to patients with ER-positive cancers who constitute a more heterogeneous group for prognosis and probability of response to chemotherapy. Given this distinction, utility of these tests in practice will still depend on clinical and histological assessments to identify specific patients who would then be appropriate for additional testing with gene expression signatures.

***PAM 50***

PAM 50, is a 50 gene expression assay based on microarray and quantitative real time (qRT)-PCR that was developed by analyzing 189 breast tumor samples to separate them into four molecular breast cancer subtypes (*luminal-A, luminal-B, HER2-positive* and, *basal-like*)[57].

PAM 50 assay can provide a risk of relapses core that predicts relapse free survival for node-negative breast cancer patients who had not received adjuvant systemic therapy. The validation study revealed that patients with *luminal-A* subtype had better prognosis in contrast to the other types and were less responsive to chemotherapy[58].

The most well described, albeit investigational classifier for the intrinsic subtypes that can be performed on the fixed tissue available in most pathology laboratories is the PAM 50 assay, however this assay requires further validation for routine clinical practice[59].

***Mammaprint***

Mammaprint is a microarray based gene expression profiling assay that was developed after analyzing data from 78 patients with ER-positive, node-negative breast cancer patients who hadn’t received adjuvant systemic therapy. Of those patients 34 developed distant metastases and 44 were disease free at the 5thyear. The tumors’ mRNA was extracted for reverse transcribe into cDNA, which was tested on microarray that contained 25000 human genes. Seventy genes that had the strongest association with outcome *i.e.*, predicted good and poor risk disease accurately were selected[60].The genes that comprise the mammaprint assay are proliferation genes and genes associated with invasion and angiogenesis. This test is based on microarrays’ results and hence requires high quality RNA from freshly collected tissues[61]. The expression of the selected genes, define a prognostic classification of patients as good or poor prognosis. This test was approved by Food and Drug Administration (FDA) for lymph node-negative breast cancer patients younger than 61 years of age with tumors of smaller than 5 cm in size.

The microarRAy-prognoSTics-in-breast-cancER (RASTER) study is the first study designed to prospectively evaluate the performance of the 70-gene signature. 427 patients with cT1–3N0M0 breast cancer were traeted based on the Dutch CBO 2004 guidelines, the 70-gene signature and doctors’ and patients’ preferences. Five-year distant-recurrence-free-interval probabilities were compared between subgroups based on the 70-gene signature and Adjuvant! Online. Fifteen percent (33/219) of the 70-gene signature low-risk patients and 81% (169/208) of the 70-gene signature high-risk patients received adjuvant chemotherapy. The 5-year distant-recurrence-free-interval probabilities for 70-gene signature low-risk (*n* = 219) and high-risk (*n* = 208) patients were 97.0% and 91.7%. The 5-year distant-recurrence-free-interval probabilities for adjuvant online low-risk (*n* = 132) and high-risk (*n* = 295) patients were 96.7% and 93.4% respectively . For 70-gene signature low-risk–adjuvant online high-risk patients (*n* = 124), of whom 76% (*n* = 94) had not received adjuvant chemtherapy , 5-year DRFI was 98.4%. In this prospective community-based observational study, the 5-year distant-recurrence-free-interval probabilities confirmed the additional prognostic value of the 70-gene signature to clinicopathological risk estimations[62].

Mammaprint has not yet been sufficiently evaluated as a predictive tool. MINDACT (microarray in node-negative and 1 to 3 lymph node-positive disease may avoid chemotherapy) is a large prospective randomized trial designed to document when chemotherapy can be omitted if genomic information and conventional clinical risk assignment system are discordant [63].

***Oncotype DX***

Oncotype Dx is the most widely used prognostic and predictive clinical 21 gene qRT-PCR based assay for women with hormone receptor positive, node-negative breast cancer[64]. The test is based on qRT-PCR technology that utilizes short and homogeneous amplicons. This method accurately measures gene expression even in the presence of mRNA fragmentation that occurs in archived formalin fixed paraffin embedded tissues. The test is based on 21 selected genes essentially related to proliferation, ER and HER2 signaling and was developed and validated through a retrospective analysis of formalin fixed paraffin embedded materials from three independent clinical trials[65,66]. The gene expression pattern was translated into a quantitative recurrence score used as a continuous variable to estimate the probability of recurrence. Recurrence score divided patients into 3 groups as low, intermediate and high risk categories. The 21 gene signature has been subsequently evaluated in other cohorts of breast cancer patients and was shown to be an independent prognostic parameter in patients with ER-positive tumors with up to 3 positive nodes receiving adjuvant chemotherapy and in postmenopausal patients with ER-positive tumors treated with anastrozole [67].

Multiple retrospective validation studies in various clinical settings established prognostic and predictive accuracy of Oncotype Dx assay. Examination of the genes of the 21 gene profile by intrinsic subtype suggests that virtually all *luminal-B* tumors would have high recurrence scores, whereas 29% of *luminal-A* tumors would have high recurrence scores due to relative endocrine resistance[68]. High recurrence score is able to predict poorer outcome among hormone receptor positive tumors despite endocrine therapy and it also predicts sensitivity to a variety of adjuvant cytotoxic regimens[69]. For this reason, the recurrence score is thought to predict general chemosensitivity in hormone receptor positive breast cancer and is a reasonable assay for decision making on chemotherapy, particularly in node-negative population.

Oncotype DX is suggested by the American Society of Clinical Oncology and by the National Comprehensive Cancer Network for the decision of adjuvant chemotherapy in ER-positive, node-negative breast cancer patients[70,71]. Tailor X is a large prospective randomized trial set to validate OncotypeDx in clinical practice by better defining the intermediate risk stratum[72].

**GENOMIC GRADE INDEX**

MapquantDx is a predictor test that defines the tumoral histological grade by gene expression features, used to assign a grade index to ER-positive breast cancers in attempt to refine their molecular classification. It was derived by identifying 97 genes from grade 1 and 3 breast tumors. The test was able to classify grade 2 tumors into low and high genomic grades having a statistically significant difference in relapse free survival[73-74]. Most of the genes in this signature are involved in cell cycle regulation and proliferation. Genomic grade index (GGI) was strongly associated with recurrence risk among patients with grade 2 tumors. This assay is microarray based and requires freshly prepared tissues.

**BREAST CANCER INDEX**

The breast cancer index (BCI) prognostic assay provides an assessment of the likelihood of distant recurrences in patients diagnosed with ER-positive, node-negative breast cancer. This assay has been developed from the combination of two indices: the ratio of HOXB13/IL17BR genes, which predicts distant recurrence in ER-positive patients treated with tamoxifen, and a proliferation related five gene molecular grade index, which discriminates grade 1 from grade 3 disease. The test is based on qRT-PCR using RNA from paraffin embedded tissues[75-76].

The biological roles of the genes included in most of these tests are not completely understood and it is often unclear which clinical or tumor characteristics are being measured. Although proliferation related genes are essential components of most classifiers, there is little overlap and, instabilities exist among different gene series.

These prognostic profiles have been far better examined in node-negative population, as estimating the risk according to signature may be more difficult in node-positives. Especially the expression patterns of hormone receptors and Ki67 may show differences in the tumor cells at the lymph nodes and the primary lesion probably due to tumor cell heterogeneity in parallel to increased tumor burden[77].

Although research results indicate that these multigene molecular assays can reclassify some breast cancer patients who are ranked as high risk using the traditional classification systems into low risk (*i.e*., reducing the number of patients who might unnecessarily undergo chemotherapy) and vice versa; available data are insufficient to challenge classical classification systems and to justify withholding chemotherapy for high risk patients if classified as low risk using multigene assays. However it should be realized that these assays can potentially provide important prognostic information in clinically indeterminate subgroups and in such situations combining these tests with conventional predictors may yield valuable information. For instance, high grade but small(10 mm) sized, node-negative breast cancer may be offered systemic therapy if it is classified as high risk using multigene assays, as staging information in such cases may be insufficient to reflect the behavior of these early detected tumors.

**NEXT GENERATIPN SEQUENCING**

Gene expression profiling and microarray analysis led to new molecular classification systems in breast cancer. In recent years research has moved from gene expression profiling to a more detailed overview through biological mechanism of carcinogenesis and tumor progression by mutational profiling. Technological advances such as array comparative genomic hybridization (array-CGH), single nucleotide polymorphism (SNP), high throughput screening (HTS) are applied to further in vitro and in vivo researches in order to improve knowledge on breast cancer biology and understand the complex process of metastasis[78].

Next generation sequencing is based on deep sequencing, which produces billions of short sequences at a time. It is quantitative and can analyze the entire genome at base repair resolution without the limitations of microarrays[79].

Sanger sequencing is the first approach for sequencing of genome, but it was both expensive and time consuming. Next generation sequencing (NGS) known as massive parallel sequencing can be applied to study the whole genome (exons, introns, and intergenic regions for about 22000 genes) more specifically to whole exome or to the 200-400 potentially targetable exons. High sensitivity of this technique allows the evaluation of single nucleotide variants, small insertions, deletions, copy number alternations (gain and losses) and structural variations (translocations, inversions). NGS can also be applied to the RNA for expression level analysis and to alternative splicing, RNA editing, and fusion transcripts. NGS can be applied to tumor to identify somatic mutations as compared to normal tissues or to the peripheral blood samples to investigate germ line alterations. The study of germ line aberrations may give more information about germ line actionable mutations, toxicity susceptibility, drug metabolism, and familial disease susceptibility[80].

Application of NGS has led to extent of knowledge to produce a comprehensive catalogue of likely genomic drivers of the most common breast cancer subtypes. The Cancer Genome Atlas Network analyzed more than 800 primary breast cancers by using all the cutting edge technologies. They demonstrated four main breast cancer classes each of which shows significant molecular heterogeneity. They showed that somatic mutations in only three genes (TP 53, PIK3A and GATA 3) occurred at 10% incidence across all breast cancers. There were numerous subtype associated novel gene mutations including the enrichment of specific mutations in GATA3, PIK3CA and MAP3K1 with the luminal A subtype[81].

Although NGS create a massive amount of information, each mutation/alteration is not good candidates to become a target for specific therapeutics. Molecular Taxonomy of Breast Cancer International Consortium (METABRICK) study revealed ten different subtypes each characterized by common genetic alterations such as PPR2A, MAP2K4 and MTAP deletions those are potentially targetable and linked to survival[82]. Alterations in the gene expression landscape can also be useful to guide the treatments with conventional and experimental therapeutics.

Recently the prospective multicenter molecular screening trial SAFIR 01 (High Throughput Technologies to Drive Breast Cancer Patients to Specific Phase I/II Trials of Targeted Agents) analyzed 423 patients with metastatic breast cancer. Metastatic sites were biopsied and profiled using the copy number changes array and Sanger sequencing PIK3CA (exon 10/21) and AKT1 (exon 3). A targetable genomic alteration was identified in 204 patients. The most frequent genomic alterations were PIK3CA mutations, CCND1, FGF4 and FGFR1 amplifications. In this study 46 out of 277 (17%) patients with genomic analyses received a targeted therapy matched to the genomic alteration, covering twelve different targets[83].

Clinical applications of NGS have many difficulties. It is uncertain to search for every single gene alteration or pathway abnormality. There are biological issues due to tumor heterogeneity, clonal evaluation, and the difficulty of discriminating between driver and passenger mutations. There are also some technical problems in terms of tumor tissue availability, stromal interferences and laboratory reproducibility of the results.

**CONCLUSION**

One of the main contributions of the breakthrough in cancer research is the integration of molecular studies into clinical trials. Advances in molecular biology of breast cancer over the past decade, have led to the classification of the disease from a molecular point of view. Incorporation of multigene molecular classifiers to conventional breast cancer classification systems seems more realistic and practical to support more effective tailoring of therapy. These multigene classifiers can complement traditional methods through provision of additional biological prognostic and predictive information by identifying important clinically relevant biological processes better than that determined using morphologic factors or individual molecular markers.

New molecular techniques hold promise for improving diagnosis and sub typing, better assessment of recurrence risk, careful selection of therapy, and identification of targets involved in carcinogenesis and function of tumor cells, leading to the discovery of selective drugs. Understanding the pathways regulating the processes involved in neoplastic development helps in the design of clinical trials aimed at patients with specific characteristics that are candidates to benefit from specific treatments. Protein gene products that have direct roles in driving the biology and clinical behavior of cancer cells are potential targets for the development of novel therapeutics. Research efforts have focused on the investigation and identification of new molecular factors, which can improve the predictability of risk of metastasis and the likelihood of response to therapies.

In the near future, probably, the tumoral key mechanisms of regulation will be identified individually and that treatments will be more specific and affective, with minimal toxicity. Numerous agents targeting various biological pathways are currently under clinical development to achieve an ideal, personalized medical therapeutic approach in breast cancer.

**REFERENCES**

1 **Eroles P**, Bosch A, Pérez-Fidalgo JA, Lluch A. Molecular biology in breast cancer: intrinsic subtypes and signaling pathways. *Cancer Treat Rev* 2012; **38**: 698-707 [PMID: 22178455 DOI: 10.1016/j.ctrv.2011.11.005]

2 **Rakha EA**, Ellis IO. Modern classification of breast cancer: should we stick with morphology or convert to molecular profile characteristics. *Adv Anat Pathol* 2011; **18**: 255-267 [PMID: 21654357 DOI: 10.1097/PAP.0b013e318220f5d1]

3 **Fracheboud J**, Otto SJ, van Dijck JA, Broeders MJ, Verbeek AL, de Koning HJ. Decreased rates of advanced breast cancer due to mammography screening in The Netherlands. *Br J Cancer* 2004; **91**: 861-867 [PMID: 15292936 DOI: 10.1038/sj.bjc.6602075]

4 **Wirapati P**, Sotiriou C, Kunkel S, Farmer P, Pradervand S, Haibe-Kains B, Desmedt C, Ignatiadis M, Sengstag T, Schütz F, Goldstein DR, Piccart M, Delorenzi M. Meta-analysis of gene expression profiles in breast cancer: toward a unified understanding of breast cancer subtyping and prognosis signatures. *Breast Cancer Res* 2008; **10**: R65 [PMID: 18662380 DOI: 10.1186/bcr2124]

5 **Perou CM**, Sørlie T, Eisen MB, van de Rijn M, Jeffrey SS, Rees CA, Pollack JR, Ross DT, Johnsen H, Akslen LA, Fluge O, Pergamenschikov A, Williams C, Zhu SX, Lønning PE, Børresen-Dale AL, Brown PO, Botstein D. Molecular portraits of human breast tumours. *Nature* 2000; **406**: 747-752 [PMID: 10963602 DOI: 10.1038/35021093]

6 **Naderi A**, Teschendorff AE, Barbosa-Morais NL, Pinder SE, Green AR, Powe DG, Robertson JF, Aparicio S, Ellis IO, Brenton JD, Caldas C. A gene-expression signature to predict survival in breast cancer across independent data sets. *Oncogene* 2007; **26**: 1507-1516 [PMID: 16936776 DOI: 10.1038/sj.onc.1209920]

7 **Sørlie T**, Perou CM, Tibshirani R, Aas T, Geisler S, Johnsen H, Hastie T, Eisen MB, van de Rijn M, Jeffrey SS, Thorsen T, Quist H, Matese JC, Brown PO, Botstein D, Lønning PE, Børresen-Dale AL. Gene expression patterns of breast carcinomas distinguish tumor subclasses with clinical implications. *Proc Natl Acad Sci U S A* 2001; **98**: 10869-10874 [PMID: 11553815 DOI: 10.1073/pnas.191367098]

8 **van 't Veer LJ**, Dai H, van de Vijver MJ, He YD, Hart AA, Mao M, Peterse HL, van der Kooy K, Marton MJ, Witteveen AT, Schreiber GJ, Kerkhoven RM, Roberts C, Linsley PS, Bernards R, Friend SH. Gene expression profiling predicts clinical outcome of breast cancer. *Nature* 2002; **415**: 530-536 [PMID: 11823860 DOI: 10.1038/415530a]

9 **Hu Z**, Fan C, Oh DS, Marron JS, He X, Qaqish BF, Livasy C, Carey LA, Reynolds E, Dressler L, Nobel A, Parker J, Ewend MG, Sawyer LR, Wu J, Liu Y, Nanda R, Tretiakova M, Ruiz Orrico A, Dreher D, Palazzo JP, Perreard L, Nelson E, Mone M, Hansen H, Mullins M, Quackenbush JF, Ellis MJ, Olopade OI, Bernard PS, Perou CM. The molecular portraits of breast tumors are conserved across microarray platforms. *BMC Genomics* 2006; **7**: 96 [PMID: 16643655 DOI: 10.1186/1471-2164-7-96]

10 **Abd El-Rehim DM**, Ball G, Pinder SE, Rakha E, Paish C, Robertson JF, Macmillan D, Blamey RW, Ellis IO. High-throughput protein expression analysis using tissue microarray technology of a large well-characterised series identifies biologically distinct classes of breast cancer confirming recent cDNA expression analyses. *Int J Cancer* 2005; **116**: 340-350 [PMID: 15818618 DOI: 10.1002/ijc.21004]

11 **Sotiriou C**, Neo SY, McShane LM, Korn EL, Long PM, Jazaeri A, Martiat P, Fox SB, Harris AL, Liu ET. Breast cancer classification and prognosis based on gene expression profiles from a population-based study. *Proc Natl Acad Sci U S A* 2003; **100**: 10393-10398 [PMID: 12917485 DOI: 10.1073/pnas.1732912100]

12 **Habashy HO**, Powe DG, Abdel-Fatah TM, Gee JM, Nicholson RI, Green AR, Rakha EA, Ellis IO. A review of the biological and clinical characteristics of luminal-like oestrogen receptor-positive breast cancer. *Histopathology* 2012; **60**: 854-863 [PMID: 21906125 DOI: 10.1111/j.1365-2559.2011.03912.x]

13 **Carey LA**. Through a glass darkly: advances in understanding breast cancer biology, 2000-2010. *Clin Breast Cancer* 2010; **10**: 188-195 [PMID: 20497917 DOI: 10.3816/CBC.2010.n.026]

14 **Carey LA**, Perou CM, Livasy CA, Dressler LG, Cowan D, Conway K, Karaca G, Troester MA, Tse CK, Edmiston S, Deming SL, Geradts J, Cheang MC, Nielsen TO, Moorman PG, Earp HS, Millikan RC. Race, breast cancer subtypes, and survival in the Carolina Breast Cancer Study. *JAMA* 2006; **295**: 2492-2502 [PMID: 16757721 DOI: 10.1001/jama.295.21.2492]

15 **Kennecke H**, Yerushalmi R, Woods R, Cheang MC, Voduc D, Speers CH, Nielsen TO, Gelmon K. Metastatic behavior of breast cancer subtypes. *J Clin Oncol* 2010; **28**: 3271-3277 [PMID: 20498394 DOI: 10.1200/JCO.2009.25.9820]

16 **Guarneri V**, Conte P. Metastatic breast cancer: therapeutic options according to molecular subtypes and prior adjuvant therapy. *Oncologist* 2009; **14**: 645-656 [PMID: 19608638 DOI: 10.1634/theoncologist.2009-0078]

17 **Creighton CJ**. The molecular profile of luminal B breast cancer. *Biologics* 2012; **6**: 289-297 [PMID: 22956860 DOI: 10.2147/BTT.S29923]

18 **Ellis MJ**, Tao Y, Luo J, A'Hern R, Evans DB, Bhatnagar AS, Chaudri Ross HA, von Kameke A, Miller WR, Smith I, Eiermann W, Dowsett M. Outcome prediction for estrogen receptor-positive breast cancer based on postneoadjuvant endocrine therapy tumor characteristics. *J Natl Cancer Inst* 2008; **100**: 1380-1388 [PMID: 18812550 DOI: 10.1093/jnci/djn309]

19 **Reis-Filho JS**, Weigelt B, Fumagalli D, Sotiriou C. Molecular profiling: moving away from tumor philately. *Sci Transl Med* 2010; **2**: 47ps43 [PMID: 20811040]

20 **Loi S**, Sotiriou C, Haibe-Kains B, Lallemand F, Conus NM, Piccart MJ, Speed TP, McArthur GA. Gene expression profiling identifies activated growth factor signaling in poor prognosis (Luminal-B) estrogen receptor positive breast cancer. *BMC Med Genomics* 2009; **2**: 37 [PMID: 19552798 DOI: 10.1186/1755-8794-2-37]

21 **Geyer FC**, Rodrigues DN, Weigelt B, Reis-Filho JS. Molecular classification of estrogen receptor-positive/luminal breast cancers. *Adv Anat Pathol* 2012; **19**: 39-53 [PMID: 22156833 DOI: 10.1097/PAP.0b013e31823fafa0]

22 **Cheang MC**, Chia SK, Voduc D, Gao D, Leung S, Snider J, Watson M, Davies S, Bernard PS, Parker JS, Perou CM, Ellis MJ, Nielsen TO. Ki67 index, HER2 status, and prognosis of patients with luminal B breast cancer. *J Natl Cancer Inst* 2009; **101**: 736-750 [PMID: 19436038 DOI: 10.1093/jnci/djp082]

23 **Dowsett M**, Nielsen TO, A'Hern R, Bartlett J, Coombes RC, Cuzick J, Ellis M, Henry NL, Hugh JC, Lively T, McShane L, Paik S,Penault-Llorca F, Prudkin L, Regan M, Salter J, Sotiriou C, Smith IE, Viale G, Zujewski JA, Hayes DF; International Ki-67 in Breast Cancer Working Group. Assessment of Ki67 in Breast Cancer: Recommendations from the International Ki67 in Breast Cancer Working Group. *J Natl Cancer Inst* 2011; **16**: 1656-1664

24 **Nishimura R**, OsakoT, Okumura Y, Hayashi M, ToyozumiY. Ki-67 as a prognostic marker according to breast cancer subtype and a predictor of recurrence time in primary breast cancer. *Exp Ther Med* 2010; **1**: 747-754 [PMID: 22993598 DOI: 10.3892/etm.2010.133]

25 **Paik S**, Shak S, Tang G, Kim C, Baker J, Cronin M, Baehner FL, Walker MG, Watson D, Park T, Hiller W, Fisher ER, Wickerham DL, Bryant J, Wolmark N. A multigene assay to predict recurrence of tamoxifen-treated, node-negative breast cancer. *N Engl J Med* 2004; **351**: 2817-2826 [PMID: 15591335 DOI: 10.1056/NEJMoa041588]

26 **Rouzier R**, Perou CM, Symmans WF, Ibrahim N, Cristofanilli M, Anderson K, Hess KR, Stec J, Ayers M, Wagner P, Morandi P, Fan C, Rabiul I, Ross JS, Hortobagyi GN, Pusztai L. Breast cancer molecular subtypes respond differently to preoperative chemotherapy. *Clin Cancer Res* 2005; **11**: 5678-5685 [PMID: 16115903 DOI: 10.1158/1078-0432.CCR-04-2421]

27 **Bhargava R**, Beriwal S, Dabbs DJ, Ozbek U, Soran A, Johnson RR, Brufsky AM, Lembersky BC, Ahrendt GM. Immunohistochemical surrogate markers of breast cancer molecular classes predicts response to neoadjuvant chemotherapy: a single institutional experience with 359 cases. *Cancer* 2010; **116**: 1431-1439 [PMID: 20131351 DOI: 10.1002/cncr.24876]

28 **Esserman L**, Perou C, Cheang M, DeMichele A, Carey L, Van ’t Veer L, Gray J, Petricoin E, Conway K, Hylton N, Berry D. Breast cancer molecular profiles and tumor response of neoadjuvant doxorubicin and paclitaxel: the I-SPY TRIAL (CALGB 150007/150012, ACRIN 6657). *J ClinOncol* 2009; **27**: LBA515 [DOI: 10.1007/s10549-011-1895-2]

29 **Parker JS,** Prat A,Cheang MCU, Lenburg M, Paik S,Perou C. Breast cancer molecular subtypes predict response to anthracycline taxane based chemotherapy. *Cancer Res* 2009; **69**: Suppl 3 [DOI: 10.1158/0008-5472.SABCS-09-2019]

30 **Ignatiadis M**, Bedard P, HaibeKains B, Singhal S, Loi S, Criscitiello C, Desmedt C, Bontempi G, Piccart M, Piccart M, SotiriouC. A meta analysis of gene expression profiling studies identifies clinically relevant oncogenic pathways in basal like breast cancer. *Cancer Res* 2009; **69**: 106 [DOI: 10.1158/0008-5472.SABCS-09-106]

31 **Tran B**, Bedard PL. Luminal-B breast cancer and novel therapeutic targets. *Breast Cancer Res* 2011; **13**: 221 [PMID: 22217398 DOI: 10.1186/bcr2904]

32 **Turner N**, Grose R. Fibroblast growth factor signalling: from development to cancer. *Nat Rev Cancer* 2010; **10**: 116-129 [PMID: 20094046 DOI: 10.1038/nrc2780]

33 **Fu X**, Osborne CK, Schiff R. Biology and therapeutic potential of PI3K signaling in ER+/HER2-negative breast cancer. *Breast* 2013; **22 Suppl 2**: S12-S18 [PMID: 24011769 DOI: 10.1016/j.breast.2013.08.001]

34 **Barnes CJ**, Kumar R. Biology of the epidermal growth factor receptor family. *Cancer Treat Res* 2004; **119**: 1-13 [PMID: 15164870 DOI: 10.1007/1-4020-7847-1\_1]

35 **Bazley LA**, Gullick WJ. The epidermal growth factor receptor family. *Endocr Relat Cancer* 2005; **12 Suppl 1**: S17-S27 [PMID: 16113093 DOI: 10.1677/erc.1.01032]

36 **Moasser MM**. The oncogene HER2: its signaling and transforming functions and its role in human cancer pathogenesis. *Oncogene* 2007; **26**: 6469-6487 [PMID: 17471238 DOI: 10.1038/sj.onc.1210477]

37 **Gutierrez C**, Schiff R. HER2: biology, detection, and clinical implications. *Arch Pathol Lab Med* 2011; **135**: 55-62 [PMID: 21204711 DOI: 10.1043/2010-0454-RAR.1]

38 **Tsutsui S**, Ohno S, Murakami S, Kataoka A, Kinoshita J, Hachitanda Y. Prognostic significance of the coexpression of p53 protein and c-erbB2 in breast cancer. *Am J Surg* 2003; **185**: 165-167 [PMID: 12559449 DOI: 10.1016/S0002-9610(02)01203-5]

39 **de Ronde JJ**, Hannemann J, Halfwerk H, Mulder L, Straver ME, Vrancken Peeters MJ, Wesseling J, van de Vijver M, Wessels LF, Rodenhuis S. Concordance of clinical and molecular breast cancer subtyping in the context of preoperative chemotherapy response. *Breast Cancer Res Treat* 2010; **119**: 119-126 [PMID: 19669409 DOI: 10.1007/s10549-009-0499-6]

40 **Prat A**, Perou CM. Deconstructing the molecular portraits of breast cancer. *Mol Oncol* 2011; **5**: 5-23 [PMID: 21147047 DOI: [10.1016/j.molonc.2010.11.003](http://dx.doi.org/10.1016/j.molonc.2010.11.003)]

41 **Staaf J**, Ringnér M, Vallon-Christersson J, Jönsson G, Bendahl PO, Holm K, Arason A, Gunnarsson H, Hegardt C, Agnarsson BA, Luts L, Grabau D, Fernö M, Malmström PO, Johannsson OT, Loman N, Barkardottir RB, Borg A. Identification of subtypes in human epidermal growth factor receptor 2--positive breast cancer reveals a gene signature prognostic of outcome. *J Clin Oncol* 2010; **28**: 1813-1820 [PMID: 20231686 DOI: 10.1200/JCO.2009.22.8775]

42 **Ross JS**, Fletcher JA, Linette GP, Stec J, Clark E, Ayers M, Symmans WF, Pusztai L, Bloom KJ. The Her-2/neu gene and protein in breast cancer 2003: biomarker and target of therapy. *Oncologist* 2003; **8**: 307-325 [PMID: 12897328 DOI: 10.1634/theoncologist.8-4-307]

43 **Gabos Z**, Sinha R, Hanson J, Chauhan N, Hugh J, Mackey JR, Abdulkarim B. Prognostic significance of human epidermal growth factor receptor positivity for the development of brain metastasis after newly diagnosed breast cancer. *J Clin Oncol* 2006; **24**: 5658-5663 [PMID: 17102066 DOI: 10.1200/JCO.2006.07.0250]

44 **Rakha EA**, Elsheikh SE, Aleskandarany MA, Habashi HO, Green AR, Powe DG, El-Sayed ME, Benhasouna A, Brunet JS, Akslen LA, Evans AJ, Blamey R, Reis-Filho JS, Foulkes WD, Ellis IO. Triple-negative breast cancer: distinguishing between basal and nonbasal subtypes. *Clin Cancer Res* 2009; **15**: 2302-2310 [PMID: 19318481 DOI: 10.1158/1078-0432.CCR-08-2132]

45 **Heitz F**, Harter P, Lueck HJ, Fissler-Eckhoff A, Lorenz-Salehi F, Scheil-Bertram S, Traut A, du Bois A. Triple-negative and HER2-overexpressing breast cancers exhibit an elevated risk and an earlier occurrence of cerebral metastases. *Eur J Cancer* 2009; **45**: 2792-2798 [PMID: 19643597 DOI: 10.1016/j.ejca.2009.06.027]

46 **Kreike B**, van Kouwenhove M, Horlings H, Weigelt B, Peterse H, Bartelink H, van de Vijver MJ. Gene expression profiling and histopathological characterization of triple-negative/basal-like breast carcinomas. *Breast Cancer Res* 2007; **9**: R65 [PMID: 17910759 DOI: 10.1186/bcr1771]

47 **Anders CK**, Carey LA. Biology, metastatic patterns, and treatment of patients with triple-negative breast cancer. *Clin Breast Cancer* 2009; **9 Suppl 2**: S73-S81 [PMID: 19596646 DOI: 10.3816/CBC.2009.s.008]

48 **Criscitiello C**, Azim HA, Schouten PC, Linn SC, Sotiriou C. Understanding the biology of triple-negative breast cancer. *Ann Oncol* 2012; **23 Suppl 6**: vi13-vi18 [PMID: 23012296 DOI: 10.1093/annonc/mds188]

49 **Foulkes WD**, Brunet JS, Stefansson IM, Straume O, Chappuis PO, Bégin LR, Hamel N, Goffin JR, Wong N, Trudel M, Kapusta L, Porter P, Akslen LA. The prognostic implication of the basal-like (cyclin E high/p27 low/p53+/glomeruloid-microvascular-proliferation+) phenotype of BRCA1-related breast cancer. *Cancer Res* 2004; **64**: 830-835 [PMID: 14871808 DOI: 10.1158/0008-5472.CAN-03-2970]

50 **Fong PC**, Boss DS, Yap TA, Tutt A, Wu P, Mergui-Roelvink M, Mortimer P, Swaisland H, Lau A, O'Connor MJ, Ashworth A, Carmichael J, Kaye SB, Schellens JH, de Bono JS. Inhibition of poly(ADP-ribose) polymerase in tumors from BRCA mutation carriers. *N Engl J Med* 2009; **361**: 123-134 [PMID: 19553641 DOI: 10.1056/NEJMoa0900212]

51 **Dong Y**, Li A, Wang J, Weber JD, Michel LS. Synthetic lethality through combined Notch-epidermal growth factor receptor pathway inhibition in basal-like breast cancer. *Cancer Res* 2010; **70**: 5465-5474 [PMID: 20570903 DOI: 10.1158/0008-5472.CAN-10-0173]

52 **Herschkowitz JI**, Simin K, Weigman VJ, Mikaelian I, Usary J, Hu Z, Rasmussen KE, Jones LP, Assefnia S, Chandrasekharan S, Backlund MG, Yin Y, Khramtsov AI, Bastein R, Quackenbush J, Glazer RI, Brown PH, Green JE, Kopelovich L, Furth PA, Palazzo JP, Olopade OI, Bernard PS, Churchill GA, Van Dyke T, Perou CM. Identification of conserved gene expression features between murine mammary carcinoma models and human breast tumors. *Genome Biol* 2007; **8**: R76 [PMID: 17493263 DOI: 10.1186/gb-2007-8-5-r76]

53 **Weigelt B**, Mackay A, A'hern R, Natrajan R, Tan DS, Dowsett M, Ashworth A, Reis-Filho JS. Breast cancer molecular profiling with single sample predictors: a retrospective analysis. *Lancet Oncol* 2010; **11**: 339-349 [PMID: 20181526 DOI: 10.1016/S1470-2045(10)70008-5]

54 **Goldhirsch A**, Wood WC, Coates AS, Gelber RD, Thürlimann B, Senn HJ. Strategies for subtypes--dealing with the diversity of breast cancer: highlights of the St. Gallen International Expert Consensus on the Primary Therapy of Early Breast Cancer 2011. *Ann Oncol* 2011; **22**: 1736-1747 [PMID: 21709140 DOI: 10.1093/annonc/mdr304]

55 **Goldhirsch A**, Winer EP, Coates AS, Gelber RD, Piccart-Gebhart M, Thürlimann B, Senn HJ. 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**: 2206-2223 [PMID: 23917950 DOI: 10.1093/annonc/mdt303]

56 **Metzger O**, Giobbie-Hurder A, Mallon E, Viale G, Winer E, Thürlimann B, Gelber RD, Colleoni M, Ejlertsen B, Bonnefoi H, Coates AS, Goldhirsch A, Gusterson B, BIG 1-98 Collaborative Group, and International Breast Cancer Study Group. Relative effectiveness of letrozole compared with tamoxifen for patients with lobular carcinoma in the BIG 1-98 trial. *Cancer Res* 2012; **72**: Supp 3 [DOI: 10.1158/0008-5472]

57 **Wesolowski R**, Ramaswamy B. Gene expression profiling: changing face of breast cancer classification and management. *Gene Expr* 2011; **15**: 105-115 [PMID: 22268293 DOI: 10.3727/105221611X13176664479241]

58 **Parker JS**, Mullins M, Cheang MC, Leung S, Voduc D, Vickery T, Davies S, Fauron C, He X, Hu Z, Quackenbush JF, Stijleman IJ, Palazzo J, Marron JS, Nobel AB, Mardis E, Nielsen TO, Ellis MJ, Perou CM, Bernard PS. Supervised risk predictor of breast cancer based on intrinsic subtypes. *J Clin Oncol* 2009; **27**: 1160-1167 [PMID: 19204204 DOI: 10.1200/JCO.2008.18.1370]

59 **Guiu S**, Michiels S, André F, Cortes J, Denkert C, Di Leo A, Hennessy BT, Sorlie T, Sotiriou C, Turner N, Van de Vijver M, Viale G, Loi S, Reis-Filho JS. Molecular subclasses of breast cancer: how do we define them? The IMPAKT 2012 Working Group Statement. *Ann Oncol* 2012; **23**: 2997-3006 [PMID: 23166150 DOI: 10.1093/annonc/mds586]

60 **Van de Vijer MJ**, He YD, van’t Veer LJ, Dai H, Hart AA, Voskuil DW, Schreiber GJ, Peterse JL, Roberts C, Marton MJ, Parrish M, Atsma D, Witteveen A, Glas A, Delahaye L, van der Velde T, Bartelink H, Rodenhuis S, Rutgers ET, Friend SH, Bernards R. A gene-expression signature as a predictor of survival in breast cancer. *N Engl J Med* 2002; **347**: 1999–2009 [DOI: [10.1056/NEJMoa021967](http://dx.doi.org/10.1056/NEJMoa021967)]

61 **Fumagalli D**, Andre F, Piccart-Gebhart MJ, Sotiriou C, Desmedt C. Molecular biology in breast cancer: should molecular classifiers be assessed by conventional tools or by gene expression arrays? *Crit Rev Oncol Hematol* 2012; **84 Suppl 1**: e58-e69 [PMID: 22964299 DOI: 10.1016/j.critrevonc.2012.08.003]

62 **Drukker CA** , Bueno-de-Mesquita JM , Retèl VP , van Harten WH , van Tinteren H , Wesseling J , Roumen RMH , Knauer M , van 't Veer LJ , Sonke GS , Rutgers EJT , van de Vijver MJ , Linn SC. A prospective evaluation of a breast cancer prognosis signature in the observational RASTER study. *Int J Cancer* 2013; **133**: 929–936 [PMID: 23371464]

63 **Albain KS**, Carey L, Gradishar WJ, Gralow JR, Lipton A, Rugo H, Tripathy D, Peck S, Abair T, Pegram M. Proceedings of the First Global Workshop on Breast Cancer: pathways to the evaluation and clinical development of novel agents for breast cancer. *Clin Breast Cancer* 2010; **10**: 421-439 [PMID: 21147685 DOI: 10.3816/CBC.2010.n.056]

64 **Prat A**, Ellis MJ, Perou CM. Practical implications of gene-expression-based assays for breast oncologists. *Nat Rev Clin Oncol* 2012; **9**: 48-57 [PMID: 22143140 DOI: 10.1038/nrclinonc.2011.178]

65 **Kim C**, Paik S. Gene-expression-based prognostic assays for breast cancer. *Nat Rev Clin Oncol* 2010; **7**: 340-347 [PMID: 20440284 DOI: 10.1038/nrclinonc.2010.61]

66 **Sparano JA**, Paik S. Development of the 21-gene assay and its application in clinical practice and clinical trials. *J Clin Oncol* 2008; **26**: 721-728 [PMID: 18258979 DOI: 10.1200/JCO.2007.15.1068]

67 **Goldstein LJ**, Gray R, Badve S, Childs BH, Yoshizawa C, Rowley S, Shak S, Baehner FL, Ravdin PM, Davidson NE, Sledge GW, Perez EA, Shulman LN, Martino S, Sparano JA. Prognostic utility of the 21-gene assay in hormone receptor-positive operable breast cancer compared with classical clinicopathologic features. *J Clin Oncol* 2008; **26**: 4063-4071 [PMID: 18678838 DOI: 10.1200/JCO.2007.14.4501]

68 **Fan C**, Oh DS, Wessels L, Weigelt B, Nuyten DS, Nobel AB, van't Veer LJ, Perou CM. Concordance among gene-expression-based predictors for breast cancer. *N Engl J Med* 2006; **355**: 560-569 [PMID: 16899776 DOI: 10.1056/NEJMoa052933]

69 **Albain KS**, Barlow WE, Shak S, Hortobagyi GN, Livingston RB, Yeh IT, Ravdin P, Bugarini R, Baehner FL, Davidson NE, Sledge GW, Winer EP, Hudis C, Ingle JN, Perez EA, Pritchard KI, Shepherd L, Gralow JR, Yoshizawa C, Allred DC, Osborne CK, Hayes DF. 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**: 55-65 [PMID: 20005174 DOI: 10.1016/S1470-2045(09)70314-6]

70 **Harris L**, Fritsche H, Mennel R, Norton L, Ravdin P, Taube S, Somerfield MR, Hayes DF, Bast RC. American Society of Clinical Oncology 2007 update of recommendations for the use of tumor markers in breast cancer. *J Clin Oncol* 2007; **25**: 5287-5312 [PMID: 17954709 DOI: 10.1200/JCO.2007.14.2364]

71 **NCCN Clinical Practice Guidelines in Oncology**. Breast Cancer. 2011 (online) http: //www.nccn.org/professionals/physician\_gls/pdf/breast.pd

72 **Zujewski JA**, Kamin L.Trial Assessing Individualized Options for Treatment for breast cancer: the TAILORx trial and. *Future Oncol* 2008; **4**: 603-610 [DOI: 10.2217/14796694.4.5.603]

73 **Sotiriou C**, Wirapati P, Loi S, Harris A, Fox S, Smeds J, Nordgren H, Farmer P, Praz V, Haibe-Kains B, Desmedt C, Larsimont D, Cardoso F, Peterse H, Nuyten D, Buyse M, Van de Vijver MJ, Bergh J, Piccart M, Delorenzi M. Gene expression profiling in breast cancer: understanding the molecular basis of histologic grade to improve prognosis. *J Natl Cancer Inst* 2006; **98**: 262-272 [PMID: 16478745 DOI: 10.1093/jnci/djj052]

74 **Loi S**, Haibe-Kains B, Desmedt C, Lallemand F, Tutt AM, Gillet C, Ellis P, Harris A, Bergh J, Foekens JA, Klijn JG, Larsimont D, Buyse M, Bontempi G, Delorenzi M, Piccart MJ, Sotiriou C. Definition of clinically distinct molecular subtypes in estrogen receptor-positive breast carcinomas through genomic grade. *J Clin Oncol* 2007; **25**: 1239-1246 [PMID: 17401012 DOI: 10.1200/JCO.2006.07.1522]

75 **Ma XJ**, Salunga R, Dahiya S, Wang W, Carney E, Durbecq V, Harris A, Goss P, Sotiriou C, Erlander M, Sgroi D. A five-gene molecular grade index and HOXB13: IL17BR are complementary prognostic factors in early stage breast cancer. *Clin Cancer Res* 2008; **14**: 2601-2608 [PMID: 18451222 DOI: 10.1158/1078-0432.CCR-07-5026]

76 **Jerevall PL**, Ma XJ, Li H, Salunga R, Kesty NC, Erlander MG, Sgroi DC, Holmlund B, Skoog L, Fornander T, Nordenskjöld B, Stål O. Prognostic utility of HOXB13: IL17BR and molecular grade index in early-stage breast cancer patients from the Stockholm trial. *Br J Cancer* 2011; **104**: 1762-1769 [PMID: 21559019 DOI: 10.1038/bjc.2011.145]

77 **Dikicioglu E**, Barutca S, Meydan N, Meteoglu I. Biological characteristics of breast cancer at the primary tumour and the involved lymph nodes. *Int J Clin Pract* 2005; **59**: 1039-1044 [PMID: 16115179 DOI: 10.1111/j.1742-1241.2005.00546.x]

78 **Schiavon G**, Smid M, Gupta G P., Redana S, Santini D, Martens J WM. Heterogeneity of Breast Cancer: Gene Signatures and BeyondA. Russo et al. (eds.), Diagnostic, Prognostic and Therapeutic Value of Gene Signatures. *Current Clin Pathol* 2012: 13-25 [DOI 10.1007/978-1-61779-358-5\_2]

79 **Previati M**, Manfrini M, Galasso M, Zerbinati C, Palatini J, Gasparini P, Volinia S. Next generation analysis of breast cancer genomes for precision medicine. *Cancer Lett* 2013; **339**: 1-7 [PMID: 23879964 DOI: 10.1016/j.canlet.2013.07.018]

80 **Tessari A**, Palmieri D, Di Cosimo S. Overview of diagnostic/targeted treatment combinations in personalized medicine for breast cancer patients. *Pharmacogenomics and Personalized Medicine* 2014; **7**: 1–19 [DOI: 10.2147/PGPM.S53304]

81 **The Cancer Genome Atlas Network.** Comprehensive molecular portraits of human breast tumours. *Nature*  2012; **490**: 61–70 [DOI: 10.1038/nature11412]

82 **Curtis C**, Shah SP, Chin SF, Turashvili G, Rueda OM, Dunning MJ, Speed D, Lynch AG, Samarajiwa S, Yuan Y, Gräf S, Ha G, Haffari G, Bashashati A, Russell R, McKinney S, Langerød A, Green A, Provenzano E, Wishart G, Pinder S, Watson P, Markowetz F, Murphy L, Ellis I, Purushotham A, Børresen-Dale AL, Brenton JD, Tavaré S, Caldas C, Aparicio S. The genomic and transcriptomic architecture of 2,000 breast tumours reveals novel subgroups. *Nature* 2012; **486**: 346-352 [PMID: 22522925 DOI: 10.1038/nature10983.]

83 **Fabrice Andre**, Thomas Denis Bachelot, Mario Campone, Monica Arnedos, Veronique Dieras, Magali Lacroix-Triki, Vladimir Lazar, David Gentien, Pascale Cohen, Anthony Goncalves, Ludovic Lacroix, Max Chaffanet, Florence Dalenc, Marie-Christine Mathieu, Ivan Bieche, Sylviane Olschwang, Qing Wang, Frederic Commo, Marta Jimenez, Herve R. Bonnefoi; Institut Gustave Roussy, Villejuif, France; Centre Léon Bérard, Lyon, France; Institut de Cancérologie de l'Ouest/René Gauducheau, Saint-Herblain, France; Institut Curie, Paris, France; Institut Claudius Regaud, Toulouse, France; Institut Paoli Calmettes, Marseille, France; Institut Curie - Hôpital René Huguenin, Saint-Cloud, France; Unicancer, Paris, France; Institut Bergonie Cancer Center, Bordeaux, France. Array CGH and DNA sequencing to personalize targeted treatment of metastatic breast cancer (MBC) patients: A prospective multicentric trial (SAFIR01). *J Clin Oncol* 2013; **31**: abstr 511

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**Table 1 2013 St. Gallen-intrinsic subtypes of breast cancer**

|  |  |  |
| --- | --- | --- |
| **Intrinsic subtype** | **Clinico-pathologic surrogate definition** |  |
| **Luminal A** | **“Luminal A-like”**all of:ER and PgR positiveHER2 negativeKi-67 “low”aRecurrence risk “low” based on  multi-gene-expression assay (if available) b | a A level of < 14% best correlated with the gene-expression definition of Luminal A based on the results in a single reference laboratoryb PgR cut-point of ≥ 20% to best correspond to Luminal A subtype |
| **Luminal B** | **Luminal B-like (HER 2 positive)**ER positiveHER2 negativeand at least one of:Ki-67 “high”PgR “negative or low”Recurrence risk “high” based on multi- gene-expression assay (if available)  |  |
| **Luminal B (HER 2 negative)**ER positiveHER2 over-expressed or amplifiedAny Ki-67Any PgR |  |
| **Erb-B2 overexpression** | **HER 2 positive (non-luminal)’**HER2 over-expressed or amplifiedER and PgR absent |  |
| **Basal-like’** | **Triple negative (ductal)’**ER and PgR absentHER2 negative | There is an 80% overlap between “triple-negative” and intrinsic “basal-like” subtype |

**Table 2 First generation gene expression signatures**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Gene signature** | **Mammaprint** | **OncotypeDX** | **MapQuantDX** | **Breast cancer ındex** | **PAM 50 assay** |
| **Starting material** | FF or stabilized RNA, FFPE | FFPE | FFPE, FF | FFPE | FFPE |
| **Analytical platform** | Microarray,RT-PCR | qRT-PCR | Microarray,qRT-PCR | qRT-PCR | nCounter |
| **Number of genes** | 70 | 21 | 97/9 | 7 | 50 |
| **Indications** | Stage I/II, 5 cm,ER(+), Node(-)/(1-3 Node(+) | ER(+), Node(-) | ER(+), G2 | ER(+) | All,Node(-) untreated |
| **Application**  | Clinicaloutcome | Clinical outcome, benefit from chemotherapy | Molecular grading prediction of response to TMX | Clinical outcome, prediction of responseto TMX | Subtype definition, risk of relapse without treatment |
| **FDA approved** | Yes | No  | No | No | No  |
| **ASCO and NCCN recommendation** | No | Yes | No | No | No |

FF: Fresh frozen; FFPE: Formalin fixed paraffin embedded; G: Grade; TMX: Tamoxifen.