Differential expression of protein phosphatase 2A activator in cancers of the breast.

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Breast cancer affects women at relatively high frequency¹. We mined published microarray datasets^{2,3} to determine in an unbiased fashion and at the systems level genes most differentially expressed in the primary tumors of patients with breast cancer. We report here significant differential expression of the gene encoding protein phosphatase 2A activator, PPP2R4, also known as PTPA (protein phosphatase 2 phosphatase activator) when comparing primary tumors of the breast to the tissue of origin, the normal breast. PPP2R4 mRNA was present at significantly higher quantities in tumors of the breast as compared to normal breast tissue. Analysis of human survival data revealed that expression of PPP2R4 in primary tumors of the breast was correlated with recurrence-free survival in patients with basal and luminal B type cancers, but in a contrary manner, demonstrating a complex relationship between correlation of primary tumor expression with recurrence-free survival based on molecular subtype. PPP2R4 may be of relevance to initiation, maintenance or progression of cancers of the female breast.

Keywords: breast cancer, PPP2R4, protein phosphatase 2A activator, systems biology of breast cancer, targeted therapeutics in breast cancer.

Invasive breast cancer is diagnosed in over a quarter of a million women in the United States each year¹ and in 2018, breast cancer was the leading cause of cancer death in women worldwide⁴. While patients with localized breast cancer are provided a 99% 5-year survival rate, patients with regional breast cancer, cancer that has spread to lymph nodes or nearby structures, are provided an 86% 5-year survival rate^{5,6}. Patients with metastasis to distant sites, like the brain, are provided a 27% 5-year survival rate^{5,6}. Understanding how primary tumors are most transcriptionally different from the tissue from which they originate, the breast, can facilitate development of novel diagnostic and therapeutics to promote early detection and enhanced treatment, and contribute to efforts to prevent progression to metastatic stages. We mined published microarray data^{2,3} to understand at the transcriptome level and in an unbiased fashion genes most differentially expressed in primary tumors of the breast as compared to normal breast tissue. protein phosphatase 2A activator emerged as among the most differentially expressed genes in cancer of the female breast.

Methods

We utilized datasets GSE109169² and GSE42568³ for this differential gene expression analysis of female breast cancer. GSE109169 was generated using Affymetrix Human Exon 1.0 ST Array technology with $n=25$ normal breast tissue and $n=25$ tumors of the breast; analysis was performed using platform GPL5175. The tissues from this first dataset are paired tissues (25 tumors matching 25 breast tissues from 25 patients). GSE42568 was generated using Affymetrix Human Genome U133 Plus 2.0 array technology with $n=17$ normal breast tissue biopsies and $n=104$ primary breast tumor biopsies from patients with breast cancer; analysis was performed using platform GPL570; the majority of patients whose tumors were analyzed were age 50 or older. The Benjamini and Hochberg method of p -value adjustment was used for ranking of differential expression but raw p -values were used to assess statistical significance of global differential expression. Log-transformation of data was auto-detected, and the NCBI generated category of platform annotation was used. A statistical test was performed to evaluate whether PPP2R4 expression was significantly different between primary breast tumors and breast tissue using a two-tailed t -test. For Kaplan-Meier survival analysis, we used the Kaplan-Meier plotter online tool⁷ for correlation of PPP2R4 mRNA expression levels with recurrence-free survival (OS) in $n=404$ patients with basal subtype cancer, $n=794$ patients with luminal A subtype cancer, $n=515$ patients with luminal B subtype cancer, and $n=166$ patients with HER2+ cancer.

Results

We performed discovery of genes associated with breast cancer in females by mining two independently published microarray datasets^{2,3}.

PPP2R4 is differentially expressed in primary tumors of the breast.

Comparison of 25 normal breast tissues to 25 tumors of the breast² from patients with early-onset breast cancer revealed that the gene encoding protein phosphatase 2A activator, encoded by the PPP2R4 gene, was among the genes most differentially expressed in tumors of the breast in human breast cancer (Chart 1). When sorting each of the genes expressed in tumors of the breast based on significance of difference as compared to normal breast tissue, PPP2R4 ranked 228 out of 19076 total transcripts, equating to 98.8% differential expression (Chart 1). Differential expression of PPP2R4 in female breast cancer was statistically significant (Chart 1; $p=8.05E-13$).

Analysis of a second microarray dataset³, here in 104 tumors from patients aged 31 to 89 at diagnosis, the majority of which were above age 50, again revealed significant differential expression of PPP2R4 in human breast cancer (Chart 2). When sorting each of the genes expressed in the tumors of

patients with breast cancer based on significance of difference as compared to normal breast tissue, PPP2R4 ranked 1244 out of 54675 total transcripts, equating to 97.7% differential expression (Chart 2). Differential expression of PPP2R4 in the tumors of patients with breast cancer was statistically significant (Chart 2; $p=3.53E-15$). These data suggested that differential expression of PPP2R4 was not an artifact of a single microarray dataset, nor was it strictly associated with early-onset breast cancer, rather a general feature of cancers of the breast.

PPP2R4 is expressed at significantly higher levels in breast tumors as compared to the breast.

We obtained exact mRNA expression levels for PPP2R4 from the breast and from breast tumors to understand the magnitude and direction of PPP2R4 expression change. PPP2R4 was expressed at higher levels in tumors of the breast as compared to normal breast tissue (Figure 1). Increased expression of PPP2R4 in primary breast tumors was statistically significant (Figure 1: $p<0.0001$). PPP2R4 was expressed at 7.64 ± 0.28 arbitrary units (AU) in normal breast tissue, while it was expressed at 8.47 ± 0.34 AU in tumors of the breast. We calculated a mean fold change of 1.11 in PPP2R4 mRNA levels when comparing primary tumors of the breast to normal breast tissues.

PPP2R4 expression correlates with survival outcomes in basal and luminal B human breast cancer.

We performed Kaplan-Meier survival analysis in an attempt to correlate PPP2R4 mRNA expression levels with survival outcomes in patients with breast cancer, evaluating interactions between molecular subtype and recurrence-free survival. We observed a correlation between PPP2R4 expression and recurrence-free survival (OS) in patients with basal subtype breast cancer which trended towards statistical significance (Figure 2; log rank p -value: 0.095 for recurrence-free survival, hazard ratio: 1.21 (0.97-1.51) (Fig. 2)). PPP2R4 mRNA levels were a negative prognostic indicator in basal subtype breast cancer patients. Median OS was 25 months for basal subtype patients with low tumor expression of PPP2R4 while median OS was 19.81 months for basal subtype patients with high tumor expression of PPP2R4 (Chart 3). We also observed a correlation between PPP2R4 expression and recurrence-free survival (OS) in patients with luminal B subtype breast cancer which trended towards statistical significance (Figure 2; log rank p -value: 0.096 for recurrence-free survival, hazard ratio: 0.86 (0.72-1.03) (Fig. 2)). PPP2R4 mRNA levels were a positive prognostic indicator in luminal B subtype breast cancer patients. Median OS was 38.4 months for luminal B patients with low tumor expression of PPP2R4 while median OS was 48 months for luminal B patients with high tumor expression of PPP2R4 (Chart 3). PPP2R4 primary tumor expression was not correlated with recurrence-free survival in luminal A subtype (Figure 2; log rank p -value: 0.25 for OS, hazard ratio: 0.91 (0.77-1.07) (Fig. 2) or in HER2+ breast cancer (Figure 2; log rank p -value: 0.99 for OS, hazard ratio: 1 (0.7-1.42) (Fig. 2)).

Thus, through comparative transcriptome analysis of primary tumors of the breast and normal breast tissue, we found that differential expression and up-regulation of PPP2R4 was among the most significant transcriptional features in primary tumors from patients with breast cancer. PPP2R4 expression in primary tumors of the breast was correlated with recurrence-free survival in patients with basal and luminal B subtype cancers, with patients whose primary tumors expressed low levels of PPP2R4 possessing superior survival in basal subtype cancers but with patients whose primary tumors expressed high levels of PPP2R4 possessing superior survival in luminal B subtype cancer.

Discussion

Invasive breast cancer is a medical problem with a 27% 5-year survival rate for women whose disease has spread to distant sites^{5,6}. To facilitate understanding of the basic transcriptional differences between primary tumors of the breast and the tissues from which these tumors originate, normal breast

1 tissues, we performed comparative transcriptome analysis using two independently published microarray
2 datasets^{2,3}, providing evidence here that differential expression of platelet activating factor acetylhydrolase
3 1 , encoded by PPP2R4, is a defining transcriptional feature of human breast cancer: in early onset-breast
4 cancer, and in patients diagnosed after age 50. PPP2R4 was expressed at significantly higher levels in
5 primary tumors from patients with breast cancer as compared to normal breast tissue. Importantly, in
6 patients with basal and luminal B subtype breast cancer, expression of PPP2R4 was correlated with patient
7 recurrence-free survival outcomes. Protein phosphatase 2A activator, and the molecular processes to
8 which it pertains to, may be relevant to the initiation or progression of human breast cancer.
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Rank: 228
Probe ID: 3190939
p-value: 8.05E-13
t: -9.47
B: 19.006885
Gene: PPP2R4
Gene name: protein phosphatase 2A activator

Chart 1: PPP2R4 is differentially expressed in the primary tumors of patients with early-onset human breast cancer.

Rank of differential expression, probe ID, p-value of global differential expression, t, a moderated t-statistic, B, the log-odds of differential expression between the groups compared, gene and gene name are listed in this chart.

Rank: 1244
Probe ID: 206452_x_at
p-value: 3.53E-15
t: -9.03
B: 23.9329591
Gene: PTPA
Gene name: protein phosphatase 2 phosphatase activator

Chart 2: PPP2R4, also known as PTPA, is differentially expressed in the primary tumors of patients with breast cancer.

Rank of differential expression, probe ID, p-value of global differential expression, t, a moderated t-statistic, B, the log-odds of differential expression between the groups compared, gene and gene name are listed in this chart.

Figure 1: PPP2R4 is expressed at significantly higher levels in primary breast tumors as compared to normal breast tissue.

The mRNA expression level of PPP2R4 in normal breast tissue (left) and in primary tumors of the breast (right) is graphically depicted with the result of a statistical test evaluating significance of difference in PPP2R4 expression between normal breast tissue and primary tumors of the breast, a p -value, is $p < 0.0001$.

Figure 2: PPP2R4 expression correlates with recurrence-free survival in patients with basal and luminal B subtype breast cancer, but not in patients with HER2+ or luminal A subtype cancer.

Depicted in this Kaplan-Meier plot is the probability of recurrence-free survival (OS) for $n=846$ patients with basal subtype breast cancer (upper left), $n=315$ patients with HER2+ breast cancer (upper right), $n=2277$ patients with luminal A breast cancer (lower left), and $n=1491$ patients with luminal B breast cancer (lower right), stratified into two groups, based on low or high expression of PPP2R4 in patient primary tumors. The log rank p-value denoting statistical significance of difference in recurrence-free survival when comparing the two groups, as well as hazard ratio for this comparison is listed above. Listed below is the number of patients at risk (number of patients alive) per interval, after stratification based on PPP2R4 expression; in the first interval, number at risk is number of patients alive; in each subsequent interval, number at risk is the number at risk less those who have expired or are censored.

Basal

Low PPP2R4 expression: 25 months

High PPP2R4 expression: 19.81 months

Luminal B

Low PPP2R4 expression: 38.4 months

High PPP2R4 expression: 48 months

Chart 3: In basal subtype patients, median recurrence-free survival is superior in breast cancer patients with low primary tumor expression of PPP2R4, but in luminal B patients, median recurrence-free survival is superior in breast cancer patients with high primary tumor expression of PPP2R4.

The recurrence-free survival of $n=846$ basal subtype breast cancer patients and $n=1491$ luminal B subtype breast cancer patients based on stratification into low or high tumor expression of PPP2R4 is listed in this chart.