HIST1H2BF and HIST1H2BC are differentially expressed in human metastatic breast cancer, in the brain and in the lymph nodes.

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Metastasis to the brain is a clinical problem in patients with breast cancer¹⁻³. We mined published microarray data^{4,5} to compare primary and metastatic tumor transcriptomes for the discovery of genes associated with brain metastasis in humans with metastatic breast cancer. We found that both HIST1H2BF and HIST1H2BC, encoded by the histone H2B type 1-C/E/F/G/I gene cluster, were among the genes whose expression was most different in the brain and lymph node metastases of patients with metastatic breast cancer. HIST1H2BF and HIST1H2BC mRNA were present at increased quantities in brain metastatic tissues as compared to primary tumors of the breast. Importantly, expression of both HIST1H2BF and HIST1H2BC in primary tumors was significantly correlated with patient overall survival in patients with breast cancer. Modulation of HIST1H2BF and HIST1H2BC expression may be relevant to the biology by which tumor cells metastasize from the breast to the brain while evading immune clearance in the lymph nodes in humans with metastatic breast cancer. These data are one piece of evidence suggesting a common ancestor or tumor clone for brain and lymph node metastases that originate from the primary tumor, alluding to patterns in developmental origin and migratory pathways through the lymph node in human brain metastatic breast cancer.

Keywords: breast cancer, metastasis, brain metastases, central nervous system metastases, lymph node metastases, histone H2B type 1-C/E/F/G/I , HIST1H2BF, HIST1H2BC, systems biology of breast cancer, targeted therapeutics in breast cancer.

One report described a 34% incidence of central nervous system metastases in patients treated with trastuzumab for breast cancer². More recently, the NEfERT-T clinical trial⁶ which compared administration of either neratinib or trastuzumab in conjunction with paclitaxel demonstrated that in a randomized, controlled setting, in breast cancer patients treated with neratinib, not only was the incidence of central nervous system recurrence significantly lower, the time to central nervous system metastasis was significantly delayed as compared to patients administered trastuzumab⁶. The alarmingly high rate of central nervous system metastasis described, as well as data, both anecdotal² and from a randomized, controlled setting⁶ illustrating that treatment with trastuzumab may be associated with these events demands an enhanced understanding of the transcriptional makeup of brain metastatic tissues to support identification of therapeutic targets, whether they are treatment related or not. We performed a global comparative analysis of primary and metastatic tumors in patients with brain metastatic breast cancer^{4,5}. We discovered differential and increased expression of the gene encoding histone H2B type 1-C/E/F/G/I, HIST1H2BF, in brain metastatic tissues of patients with metastatic breast cancer.

Methods

We used datasets GSE10893⁴ and GSE124648⁵ for this global differential gene expression analysis of brain metastatic breast cancer in conjunction with GEO2R. GSE10893 was generated using Agilent-011521 Human 1A Microarray G4110A technology with $n=11$ primary breast tumors and $n=3$ brain metastases from patients with breast cancer; analysis was performed using platform GPL885. GSE124648 was generated using Affymetrix Human Genome U133A array technology with $n=10$ normal breast tissues and $n=44$ lymph node metastases from patients with breast cancer; analysis was performed using platform GPL96. 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 HIST1H2BF and HIST1H2BC gene expression was significantly different between primary tumors of the breast and brain metastases in humans with breast cancer using a two-tailed t-test. For Kaplan-Meier survival analysis, we used the Kaplan-Meier plotter online tool⁷ for correlation of HIST1H2BF and HIST1H2BC mRNA expression levels in primary tumors of the breast with overall survival in $n=1402$ breast cancer patients.

Results

We performed global comparative transcriptome analysis of metastatic and primary tumor tissues of patients with metastatic breast, as well as normal tissues of the breast using published microarray data^{4,5} to describe the transcriptional landscape of brain metastasis in human breast cancer in an unbiased fashion and for the discovery of novel therapeutic targets.

HIST1H2BF is differentially expressed in the brain metastases of patients with brain metastatic breast cancer.

Through blind, systems-level analysis of published microarray data⁴, we identified histone cluster 1, H2bf, encoding HIST1H2BF, as a differentially expressed gene in the brain metastatic tissues of humans with breast cancer (Chart 1). When sorting each of the genes expressed in brain metastases based on significance of difference as compared to primary tumors of the breast in patients with breast cancer, HIST1H2BF ranked 143 out of 17418 total transcripts (Chart 1), equating to 99.2% differential expression. Differential expression of HIST1H2BF in the brain metastases of patients with metastatic breast cancer was statistically significant (Chart 1; $p=5.29E-04$).

HIST1H2BC is differentially expressed in the brain metastases of patients with brain metastatic breast cancer.

In the same microarray data⁴, we identified histone cluster 1, H2bc, encoding HIST1H2BC, as a differentially expressed gene in the brain metastatic tissues of humans with breast cancer (Chart 2). When sorting each of the genes expressed in brain metastases based on significance of difference as compared to primary tumors of the breast in patients with breast cancer, HIST1H2BC ranked 196 out of 17418 total transcripts (Chart 2), equating to 98.9% differential expression. Differential expression of HIST1H2BC in the brain metastases of patients with metastatic breast cancer was statistically significant (Chart 2; $p=8.60e-04$).

HIST1H2BF/HIST1H2BC is differentially expressed in the lymph node metastases of patients with breast cancer.

To determine whether differential expression of HIST1H2BF and HIST1H2BC in human metastatic breast cancer could be validated in a second microarray dataset, and whether this was specific to brain metastases or could be observed in other anatomical locations, we queried a second microarray dataset⁵, here comparing normal breast tissues to lymph node metastases. Here, we identified the histone gene cluster encoding HIST1H2BC///HIST1H2BI///HIST1H2BE///HIST1H2BF///HIST1H2BG HIST1H2BF/HIST1H2BC as differentially expressed in the lymph node metastatic tissues of patients with breast cancer (Chart 2). When sorting each of the genes expressed in lymph node metastases based on significance of difference as compared to normal breast tissues, HIST1H2BC///HIST1H2BI///HIST1H2BE///HIST1H2BF///HIST1H2BG ranked 521 out of 22283 total transcripts (Chart 2), equating to 97.7% differential expression. Differential expression of HIST1H2BC///HIST1H2BI///HIST1H2BE///HIST1H2BF///HIST1H2BG in the lymph node metastases of patients with metastatic breast cancer was statistically significant (Chart 2; $p=9.50e-09$). Thus, differential expression of HIST1H2BF and HIST1H2BC, transcriptome-wide, in metastatic tissues of women with metastatic breast cancer was conserved across two independent microarray datasets, in the brain and in the lymph nodes.

HIST1H2BF is expressed at higher levels in the brain metastases of patients with metastatic breast cancer.

We obtained exact mRNA expression levels for HIST1H2BF, in primary tumors of the breast and in brain metastasis of patients with brain metastatic breast cancer to determine direction and statistical significance of change in HIST1H2BF expression in brain metastatic tissues. We observed significantly higher expression of HIST1H2BF in the brain metastases of patients with breast cancer as compared to primary tumors of the breast: HIST1H2BF was expressed at -0.66 ± 0.67 arbitrary units (AU) in primary tumors of the breast, while it was expressed at 1.24 ± 0.86 AU in brain metastatic tissues (Figure 1). The difference in HIST1H2BF mRNA levels between primary tumors of the breast and brain metastatic tissues was statistically significant (Figure 1; $p=0.001405$).

HIST1H2BC is expressed at higher levels in the brain metastases of patients with metastatic breast cancer.

We also obtained exact mRNA expression levels for HIST1H2BC, in primary tumors of the breast and in brain metastasis of patients with brain metastatic breast cancer to determine direction and statistical significance of change in HIST1H2BC expression in brain metastatic tissues. We observed significantly higher expression of HIST1H2BC in the brain metastases of patients with breast cancer as compared to primary tumors of the breast: HIST1H2BC was expressed at -0.88 ± 0.66 arbitrary units (AU)

in primary tumors of the breast, while it was expressed at 0.82 ± 0.69 AU in brain metastatic tissues (Figure 2). The difference in HIST1H2BC mRNA levels between primary tumors of the breast and brain metastatic tissues was statistically significant (Figure 1; $p=0.002046$).

HIST1H2BF expression is correlated with survival outcomes in human breast cancer.

We performed Kaplan-Meier survival analysis⁷ in 1402 breast cancer patients in total, to evaluate whether HIST1H2BF tumor expression was correlated with survival outcomes in breast cancer. We observed a correlation between primary tumor expression of HIST1H2BF and overall survival (OS) in patients with breast cancer (Figure 3). Patients whose primary tumors expressed low levels of HIST1H2BF possessed median OS of 118.62 months, while patients whose tumors expressed high levels of HIST1H2BF possessed median OS of 81 months. This difference in OS based on HIST1H2BF tumor expression in patients with breast cancer was statistically significant (Figure 3, Chart 4; logrank p -value 0.054; hazard ratio: 1.23 (1-1.53)).

HIST1H2BC expression is correlated with survival outcomes in human breast cancer.

We also performed Kaplan-Meier survival analysis⁷ in 1402 breast cancer patients in total, to evaluate whether HIST1H2BC tumor expression was correlated with survival outcomes in breast cancer. We observed a correlation between primary tumor expression of HIST1H2BC and overall survival (OS) in patients with breast cancer (Figure 4). Patients whose primary tumors expressed low levels of HIST1H2BC possessed median OS of 110.4 months, while patients whose tumors expressed high levels of HIST1H2BC possessed median OS of 81.87 months. This difference in OS based on HIST1H2BC tumor expression in patients with breast cancer was statistically significant (Figure 4, Chart 5; logrank p -value 0.082; hazard ratio: 1.21 (0.98-1.5)).

Thus, by mining published microarray data^{4,5} in an unbiased and systematic fashion, we identified HIST1H2BF and HIST1H2BC, encoding the histone H2B type 1-C/E/F/G/I gene cluster, as among the genes whose expression was most different, transcriptome-wide, in the brain and lymph node metastases of patients with breast cancer, when compared to primary tumors of the breast and to normal breast tissues, respectively; we observed significantly increased expression of both HIST1H2BF and HIST1H2BC in brain metastases as compared to primary tumors of the breast. Further, we found a correlation between HIST1H2BF and HIST1H2BC expression and patient survival outcomes, as overall survival was greater in patients whose primary tumors expressed lower levels of either HIST1H2BF or HIST1H2BC as compared to patients whose primary tumors expressed higher levels of HIST1H2BF or HIST1H2BC.

Discussion

We provided evidence here that HIST1H2BF and HIST1H2BC are among the genes whose expression is most different in the brain and lymph node metastases of patients with metastatic breast cancer, that HIST1H2BF and HIST1H2BC mRNA are present at significantly increased quantity in brain metastatic tissues as compared to primary tumors of the breast, and that primary tumor HIST1H2BF and HIST1H2BC expression is significantly correlated with patient survival outcomes in human breast cancer. Evaluation of the effects of genetic depletion of HIST1H2BF and HIST1H2BC in mouse models of metastatic breast cancer on metastasis to the central nervous system is merited. Modulation of HIST1H2BF and HIST1H2BC expression may be relevant to the processes by which breast cancer cells exit the breast, enter the vasculature and/or lymphatics, reside in the lymph nodes, evade immune clearance, breach the blood-brain barrier and colonize the brain. These data are one piece of evidence that allude to a common cell or cell(s) of origin for brain and lymph node metastases in human metastatic breast cancer

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Rank: 143
Probe ID: 4015
p-value: 5.29E-04
t: -4.41
B: 0.0202
Gene: HIST1H2BF
Gene name: histone cluster 1, H2bf

Chart 1: HIST1H2BF is differentially expressed in brain metastatic breast cancer when comparing brain metastases to primary tumors of the breast.

The rank of global differential expression, the probe/transcript ID, the *p*-value with respect to differential expression transcriptome-wide, *t*, a moderated *t*-statistic, *B*, the log-odds of differential expression between the groups compared, the gene and gene name are listed in this chart.

Rank: 196
Probe ID: 2695
p-value: 8.60e-04
t: -4.16
B: -0.4274
Gene: HIST1H2BC
Gene name: histone cluster 1, H2bc

Chart 2: HIST1H2BC is differentially expressed in brain metastatic breast cancer when comparing brain metastases to primary tumors of the breast.

The rank of global differential expression, the probe/transcript ID, the *p*-value with respect to differential expression transcriptome-wide, *t*, a moderated *t*-statistic, *B*, the log-odds of differential expression between the groups compared, the gene and gene name are listed in this chart.

Rank: 521
probe ID: 214455_at
p-value: 9.50e-09
t: -6.744752
B: 9.742443
Gene: HIST1H2BC///HIST1H2BI///HIST1H2BE///HIST1H2BF///HIST1H2BG
Gene name: histone cluster 1, H2bc///histone cluster 1, H2bi///histone cluster 1, H2be///histone cluster 1, H2bf///histone cluster 1, H2bg

Chart 3: The histone gene cluster including H2BC and H2BF is differentially expressed in the lymph node metastases of patients with breast cancer when comparing lymph node metastases to normal breast tissues.

The rank of global differential expression, probe/transcript ID, the *p*-value with respect to differential expression transcriptome-wide, *t*, a moderated *t*-statistic, *B*, the log-odds of differential expression between the groups compared, the gene and gene name are listed in this chart.

Figure 1: HIST1H2BF is expressed at significantly higher levels in the brain metastases of patients with metastatic breast cancer when compared to primary tumors of the breast.

The mRNA expression level of HIST1H2BF in primary tumors of the breast (left) and in brain metastases of women with metastatic breast cancer (right) is graphically depicted; the result of a statistical test evaluating significance of difference in HIST1H2BF expression between primary tumors and brain metastases is $p=0.001405$.

Figure 2: HIST1H2BC is expressed at significantly higher levels in the brain metastases of patients with metastatic breast cancer when compared to primary tumors of the breast.

The mRNA expression level of HIST1H2BC in primary tumors of the breast (left) and in brain metastases of women with metastatic breast cancer (right) is graphically depicted; the result of a statistical test evaluating significance of difference in HIST1H2BC expression between primary tumors and brain metastases is $p=0.002046$.

Figure 3: Significant correlation between HIST1H2BF primary tumor expression and overall survival in patients with breast cancer.

Depicted in this Kaplan-Meier plot is the probability of overall survival for $n=1402$ total breast cancer patients stratified into two groups, based on low or high expression of HIST1H2BF in patient primary tumors. The log rank p -value denoting statistical significance of difference in overall 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 HIST1H2BF 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.

1 Low HIST1H2BF expression: 118.62 months

2 High HIST1H2BF expression: 81 months

3
4 **Chart 4: Median overall survival is inferior in patients with high primary tumor expression of HIST1H2BF.**

5 The median OS (overall survival) of patients with low primary tumor expression of HIST1H2BF and high
6 primary tumor expression of HIST1H2BF is listed in this chart, for $n=1402$ breast cancer patients.

Figure 4: Significant correlation between HIST1H2BC primary tumor expression and overall survival in patients with breast cancer.

Depicted in this Kaplan-Meier plot is the probability of overall survival for $n=1402$ total breast cancer patients stratified into two groups, based on low or high expression of HIST1H2BC in patient primary tumors. The log rank p -value denoting statistical significance of difference in overall 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 HIST1H2BC 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.

1 Low HIST1H2BC expression: 110.4 months

2 High HIST1H2BC expression: 81.87 months

3
4 **Chart 5: Median overall survival is inferior in patients with high primary tumor expression of HIST1H2BC.**

5 The median OS (overall survival) of patients with low primary tumor expression of HIST1H2BC and high
6 primary tumor expression of HIST1H2BC is listed in this chart, for $n=1402$ breast cancer patients.