ASAM is a differentially expressed gene in brain metastatic human breast cancer.

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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 the adipocyte-specific adhesion molecule, encoded by ASAM, was among the genes whose expression was most different in the brain metastases of patients with metastatic breast cancer as compared to primary tumors of the breast. ASAM mRNA was present at increased quantities in brain metastatic tissues as compared to primary tumors of the breast. Importantly, expression of ASAM in primary tumors was significantly correlated with patient overall survival. Modulation of ASAM expression may be relevant to the biology by which tumor cells metastasize from the breast to the brain in humans with metastatic breast cancer.

Keywords: breast cancer, metastasis, brain metastases, central nervous system metastases, adipocyte-specific adhesion molecule, ASAM, 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 adipocyte-specific adhesion molecule, ASAM, in brain metastatic tissues of patients with metastatic breast cancer.

Methods

We used datasets GSE10893⁴ and GSE100534⁵ 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. GSE100534 was generated using Affymetrix Human Gene 1.0 ST Array with $n=16$ primary breast tumors and $n=3$ brain metastases from patients metastatic breast cancer; analysis was performed using platform GPL6244. 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 ASAM 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 ASAM mRNA expression levels with overall survival in $n=1402$ breast cancer patients.

Results

We performed global comparative transcriptome analysis of metastatic tumor tissues of patients with metastatic breast cancer 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.

ASAM 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 the adipocyte-specific adhesion molecule, encoded by ASAM, as a differentially expressed gene in the breast metastatic tissues of humans with breast cancer (Table 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, ASAM ranked 31 out of 17418 total transcripts (Chart 1), equating to 99.8% differential expression. Differential expression of ASAM in the brain metastases of patients with metastatic breast cancer was statistically significant (Chart 1; $p=4.28e-05$).

To attempt to validate transcriptome-wide differential expression of ASAM in brain metastatic tissues of patients with metastatic breast cancer, we queried a second microarray dataset⁵, here comparing primary tumors from patients with breast cancer to brain metastases. Again, we identified ASAM, also known as CLMP, as a differentially expressed gene in human brain metastatic breast cancer (Chart 2). When sorting each of the genes expressed in brain metastases based on significance of difference as compared to normal breast tissues, ASAM ranked 2697 out of 41093 total transcripts (Chart 2), equating to 93.4% differential expression. Differential expression of ASAM in the brain metastases of patients with metastatic breast cancer was statistically significant (Chart 2; $p=3.27\text{e-}03$). Thus, differential expression of ASAM, transcriptome-wide, in the brain metastases of women with metastatic breast cancer was conserved across two independent microarray datasets. This suggests that ASAM differential expression in human brain metastatic breast cancer is a *bona fide* biological process.

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

We obtained exact mRNA expression levels for ASAM, 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 ASAM expression in brain metastatic tissues. We observed significantly higher expression of ASAM in the brain metastases of patients with breast cancer as compared to primary tumors of the breast: ASAM was expressed at -1.71 ± 0.95 arbitrary units (AU) in primary tumors of the breast, while it was expressed at -4.46 ± 0.74 AU in brain metastatic tissues. The difference in ASAM mRNA levels between primary tumors of the breast and brain metastatic tissues was statistically significant (Figure 1; $p=0.000175$).

ASAM expression is significantly correlated with survival outcomes in human breast cancer.

We performed Kaplan-Meier survival analysis⁷ in $n=1402$ breast cancer patients in total, to evaluate whether ASAM tumor expression was correlated with survival outcomes in breast cancer. We observed a statistically significant correlation between primary tumor expression of ASAM and overall survival (OS) in patients with breast cancer (Figure 2). Patients whose primary tumors expressed low levels of ASAM possessed median OS of 135.88 months, while patients whose tumors expressed high levels of ASAM possessed median OS of 70.44 months. This difference in OS based on ASAM tumor expression in patients with breast cancer was statistically significant (Figure 2, Chart 3; logrank p -value $6.6\text{e-}05$; hazard ratio: 1.55 (1.25-1.92)).

Thus, by mining published microarray data^{4,5} in an unbiased and systematic fashion, we identified the adipocyte-specific adhesion molecule, encoded by ASAM, as among the genes whose expression was most different, transcriptome-wide, in the brain metastases of patients with breast cancer when compared to primary tumors of the breast; we observed significantly increased expression of ASAM in brain metastases as compared to primary tumors of the breast. Further, we found a significant correlation between ASAM expression and patient survival outcomes, as overall survival was significantly greater in patients whose primary tumors expressed lower levels of ASAM as compared to patients whose primary tumors expressed higher levels of ASAM.

Discussion

We provided evidence here that the adipocyte-specific adhesion molecule, encoded by ASAM, is among the genes whose expression is most different in the brain metastases of patients with brain metastatic breast cancer, that ASAM mRNA is present at significantly increased quantities

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2 in brain metastatic tissues as compared to primary tumors of the breast, and that primary tumor ASAM
3 expression is significantly correlated with patient survival outcomes in human breast cancer. Evaluation of
4 the effects of genetic depletion of ASAM in mouse models of metastatic breast cancer on metastasis to the
5 central nervous system is merited. Modulation of ASAM expression may be relevant to the processes by
6 which breast cancer cells exit the breast, enter the vasculature and/or lymphatics, reside in the lymph
7 nodes, evade immune clearance, breach the blood-brain barrier and colonize the brain.
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Rank: 31
Probe ID: 3255
p-value: 4.28e-05
t: 5.59
B: 2.298376
Gene: ASAM
Gene name: adipocyte-specific adhesion molecule

Chart 1: ASAM 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: 2697
probe ID: 7952341
p-value: 3.27e-03
t: 3.3371586
B: -1.959435
Gene: CLMP
Gene name: CXADR like membrane protein

Chart 2: ASAM, also known as CLMP, is differentially expressed in brain metastatic breast cancer when comparing brain metastases to primary tumors of the breast.

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: ASAM 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 ASAM 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 ASAM expression between primary tumors of the breast and brain metastases, a *p*-value, is *p*=0.000175.

Figure 2: Significant correlation between ASAM 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 patients stratified into two groups, based on low or high expression of ASAM 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 ASAM 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.

Low ASAM expression: 135.88 months

High ASAM expression: 70.44 months

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

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