Overrepresentation of the \textit{EBAG9} Gene at 8q23 Associated with Early-Stage Breast Cancers\textsuperscript{1}

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\textbf{ABSTRACT}

\textit{EBAG9}, an estrogen-responsive gene located at 8q23 was identified in an effort to clone CpG-binding sites. Its product was later found to be identical to \textit{RCAS1}, a cancer cell-surface antigen implicated in immune escape. We determined the sequence of the complete cDNA and the genomic structure for \textit{EBAG9}. \textit{EBAG9} gene copy number in 21% (27 of 129) primary breast cancers we examined; \textit{EBAG9} mRNA was consistently expressed in cancer cell lines. Detailed physical mapping of the 8q arm, including polymorphic markers for \textit{EBAG9} and the \textit{CMYC} loci, revealed allelic gain of either \textit{EBAG9}, \textit{CMYC}, or both, in 45% (58 of 129) of the breast cancers we examined. The \textit{EBAG9} gene was increased exclusively in 16 of the 27 tumors showing gain at that locus; the outer 11 showed gain of a larger chromosomal region containing both \textit{EBAG9} and \textit{CMYC}. Analysis of subsequent series of 144 primary breast cancers for allelic gain at \textit{EBAG9} and \textit{CMYC} locus showed a similar degree of gain at \textit{EBAG9}, \textit{CMYC}, or both. When a total of 273 breast cancers from two series were combined and analyzed for clinicopathological correlation, almost all of the tumors with \textit{EBAG9} increased but not those with \textit{CMYC}. Twenty-eight of 29 were T1/T2 stage carcinomas (<5 cm in diameter), whereas one third (21 of 61) of the tumors in which \textit{CMYC} was increased but \textit{EBAG9} was not, were advanced T3-stage tumors ($P = 0.0012$). These data suggest that \textit{EBAG9} and \textit{CMYC} gene are independent targets of gain and that over-representation of \textit{EBAG9} may play a specific role in early stages of breast carcinogenesis.

\textbf{INTRODUCTION}

Numerous genetic alterations identified to date in human breast cancers include gains of specific chromosomal regions (some containing known proto-oncogenes) and/or loss of DNA at other loci in tumor cells. Other changes can include allelic losses (LOH),\textsuperscript{3} which imply inactivation of tumor suppressor genes. Frequent LOH for certain polymorphic DNA markers has been well documented in primary breast cancers on chromosomes 1p, 3p, 7p, 11p, 13q, 16q, 17, 18q, and 22q; however, little is known about other types of chromosomal alterations that may be involved in breast carcinogenesis (1–9). Attempts to study large numbers of primary breast cancers by cytogenetic methods have been limited because of technical difficulties involved in the direct preparation of chromosomes in solid tumors.

Recently the usefulness of polymorphic markers for detecting both LOH and modest increases of chromosomal copy number in solid tumor tissues was proven by careful comparative studies of karyotypic and RFLP analyses. Partial trisomy of chromosome 5q in renal cell carcinomas (10) and trisomy of chromosome 7 in malignant mesotheliomas (11) were unambiguously demonstrated in autoradiographs of hybridization experiments. The degrees of chromosome-specific numerical changes and the sizes of the regions involved indicate that the chromosomal changes in those tumors represent trisomy, tetrasomy, or polysomy of all or parts of a chromosome, rather than the “gene amplification” phenomenon represented by double-minutes or heterogenously staining regions in which a minute segment of a chromosome containing a drug resistance gene or an oncogene, for example, is amplified up to several hundred fold (12, 13).

Through a CpG-binding site cloning approach, we previously cloned a partial cDNA for \textit{EBAG9}, a novel estrogen-responsive gene (14). \textit{EBAG9} mRNA is up-regulated by estrogen treatment in MCF-7 breast cancer cells within 6 h (14). We subsequently located the estrogen-responsive element (ERE) in the 5’ regulatory region of \textit{EBAG9}, and localized the gene to 8q23 by fluorescence \textit{in situ} hybridization (15). One year after the previous work was published, Nakashima \textit{et al}. (16) recently

\textsuperscript{1}The abbreviations used are: LOH, loss of heterozygosity; RACE, rapid amplification of cDNA end; SSCP, single-strand conformational polymorphism; BAC, bacterial artificial chromosome; RT-PCR, reverse transcription-PCR; ER, estrogen receptor; PgR, progesterone receptor; CHLC, Cooperative Human Linkage Center; UTR, untranslated region; IL, interleukin.

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described cloning of a partial cDNA for RCAS1, as a cancer cell-surface antigen implicated in immune escape. This RCAS1 cDNA was then found to be identical to previously described EBAG9 cDNA. In the work reported here, because only partial cDNA sequence was described in either report, we cloned the complete structure of the EBAG9/RCAS1 cDNA by 3’ RACE experiments. We also cloned and determined the genomic structure of the EBAG9 gene. Because previous reports have shown that a large chromosomal region containing CMYC, 8q22–qter, was frequently amplified in various types of tumors including breast cancers (12, 13, 17–19), we constructed a detailed physical amplicon map of the 8q arm that encompasses the EBAG9 and CMYC loci.

**MATERIALS AND METHODS**

**Cloning a Full-Length cDNA.** To obtain the full-length cDNA sequence of the human EBAG9 cDNA, we carried out 3’ RACE experiments using the partial cDNA sequence that we had characterized earlier and a SMART RACE cDNA amplification kit (Clontech, Palo Alto, CA). In brief, polyadenylate RNA from human breast (Clontech, Inc., Gaithersburg, MD) was reverse-transcribed with Superscript II reverse transcriptase (Life Technologies, Inc., Gaithersburg, MD) using an oligo(dT) primer. First-strand cDNA was subjected to two rounds of PCR, and the products were resolved by electrophoresis in a 1% agarose gel. The specific PCR product visualized by ethidium-bromide staining was purified with a Gel Extraction kit (Qiagen) and subcloned using an AdvantAge PCR cloning kit (Clontech). The nucleotide sequence of the cDNA was determined by the BigDye Terminator cycle sequencing method using a 377 ABI Prism automated DNA sequencer (Perkin-Elmer).

**Genomic Cloning of the Human EBAG9 Gene.** A BAC library containing human DNA, pooled in a three-dimensional structure (Genome Systems, St. Louis, MO), was used to isolate genomic clones containing the human EBAG9 gene sequence. The BAC library was screened with two oppositely oriented oligonucleotides (forward, 5’-GGAGGCGTGTGATGCAACG-3’; reverse, 5’-AcTCTGCTGGTTAGGAAACT-3’). *Escherichia coli* cells containing the positive clone were cultured in the presence of chloramphenicol, and BAC DNA was isolated as described previously (20).

**Determination of Genomic Sequence.** Nucleotide sequences of exon/intron junctions, their boundaries, and the size of each intron were determined by directly sequencing BAC clones or PCR products by LA Taq (TAKARA, Tokyo, Japan), using oppositely oriented primers located in the exons flanking each intron. The primers were designed on the basis of the partial EBAG9 cDNA sequence determined earlier (Ref. 14; Table 1). Sequencing was performed by the BigDye Terminator cycle-sequencing method, using a 377 ABI Prism automated DNA sequencer (Perkin-Elmer).

**Cell Culture.** The 94 cancer-cell lines analyzed were derived from 13 hepatocellular carcinomas (SK-HEP-1, CH-14-3, Hep-KANO CL-2, WRL68, Chang liver, Hep-TATE, Huh7, Hep G2, HT17, PLC/PRF5, Hep3b, and C3A), 10 breast cancers (MDA-MB-453, CRL1500, YM-1B-E, MCF7, HBL100, OCUB-M, BT-20, BT-474, MDA-MB-435S, and SK-BR-3), 10 uterine cancers (SIHA, HT-3, D98-AH-2, HeLa, HaLa, CaSpei, ME-180, HeLaP3, HEK1-A, and SK-UT-1B), 7 lung cancers (RERF-LC-AI, Lu65, Lu99, PC14, A549, EBC-1, and LK-2), 7 brain tumors (TE671 subNO.2, U-373 MG, T98G, u87 MG, u251 MG, SNB19, and uu228), 6 thyroid cancers (WRO, NPA, 8305c, ARO, FRO, and 8505c), 6 gastric cancers (HuGC-OHIRA, AZ251, HI-111-TC, SH-10-TC, MKN-7, and UNG-4), 5 ovarian cancers (CAOV-3, SKOV-3, NIH OVCAR-3, 0V-1063, and OV18), 4 renal cell carcinomas (OS-RC-2, VMRC-RCW, RCC10R, and Caki-1), 4 urinary bladder cancers (5637, T24, EJ-1, and Shimura), 4 osteosarcomas (MG-63, Saos-2, Hu0-3N1, and U-2 OS), 4 neuroblastomas (IMR-32, NH-12, SCCH-26, and NB-1), 4 colon cancers (DLD-1, SW480, HCT-15, and WiDr), 2 tongue cancers (HSC-3 and HSC-4), 2 bile ductal cancers (HuH-28 and TFK-1), 2 oral cancers (KB and HO-1-u-1), 2 pancreatic cancers (Mia Paca 2 and PK-8), 1 laryngeal cancer (HEp-2), and 1 gingival cancer (Ca9–22). The cell lines were either obtained by the Cell Resource Center for Biomedical Research at the Institute of Development, Aging and Cancer of Tohoku University or by Dr. Baba at Mie University (Tsu City, Mie, Japan), or were purchased from the American Type Culture Collection (Manassas, Virginia). Each cell line was cultured in optimized conditions recommended by its respective distributor.

**Analysis of EBAG9 and CMYC Expression.** We used RT-PCR experiments to examine levels of EBAG9 expression in 56 cell lines that originated from 7 kinds of cancers (13 hepatocellular carcinomas, 10 uterine cancers, 10 breast cancers, 7 lung cancers, 6 gastric cancers, 6 thyroid cancers, and 4 renal cell carcinomas) using primers EBAG9 (forward, exon 3 forward; reverse, exon 4 reverse; identified as such in Table 1). CMYC expression was also examined in all 10 breast cancer cell lines using primers CMYC (forward, 5’-TGGAGGCTCTCCCTGAGGACGT-3’; reverse, 5’-TCCATGAGAATACGGGCTG-3’). To quantify expression levels relative to other genes, we

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**Table 1** Oligonucleotide used to define exon/intron junction of human EBAG9 gene

<table>
<thead>
<tr>
<th>Exon</th>
<th>Forward</th>
<th>Reverse</th>
<th>Nucleotide position in cDNA (forward/reverse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5’-TGGTGACCTTTACTGCTCCGGCT-3’</td>
<td>5’-TCTTTAGGAATGGAATCATGGTGC-3’</td>
<td>95–119</td>
</tr>
<tr>
<td>2</td>
<td>5’-AGACATGGCTGAGAAAATCTGGA-3’</td>
<td>5’-TTTCACTGAGATGGAATCATGGTGC-3’</td>
<td>290–317/338–363</td>
</tr>
<tr>
<td>3</td>
<td>5’-AGTGAGGCTGAGAAAATCTGGA-3’</td>
<td>5’-TTTCACTGAGATGGAATCATGGTGC-3’</td>
<td>383–409/426–451</td>
</tr>
<tr>
<td>4</td>
<td>5’-ATGGTGACCTTTACTGCTCCGGCT-3’</td>
<td>5’-TCTTTAGGAATGGAATCATGGTGC-3’</td>
<td>459–484/571–595</td>
</tr>
<tr>
<td>5</td>
<td>5’-AGATCTGCTTGTAGTCTGCTACATCT-3’</td>
<td>5’-AGATCTGCTTGTAGTCTGCTACATCT-3’</td>
<td>620–644/679–703</td>
</tr>
<tr>
<td>6</td>
<td>5’-ACCTTCTGCTTGTAGTCTGCTACATCT-3’</td>
<td>5’-ACCTTCTGCTTGTAGTCTGCTACATCT-3’</td>
<td>734–759/783–808</td>
</tr>
<tr>
<td>7</td>
<td>5’-TCCATGAGAATACGGGCTG-3’</td>
<td>5’-TCCATGAGAATACGGGCTG-3’</td>
<td>/924–966</td>
</tr>
</tbody>
</table>
carried out duplex PCR experiments using primers to amplify G3PDH (forward, 5'-ACCACAGTCCATTGCACATACA-3'; reverse, 5'-TCCACACCCCTTGGCATGTA-3') as an internal control. Cycling conditions were 94°C for 4 min, then 27 cycles of 94°C for 1 min, 60°C for 1 min, and 72°C for 1 min, with a final extension step of 5 min at 72°C. The PCR products were electrophoresed in 1.5% agarose gels. Enough quantity of mRNA was unavailable for all of the 10 cell lines to perform Northern blot analysis.

Isolation of DNA from Normal and Tumor Tissues. Tumors and corresponding normal tissues were obtained from 129 patients who underwent surgery for primary ductal breast cancers at the Cancer Institute Hospital, Tokyo. Resected tissue samples were immediately frozen and stored at −80°C. DNA was extracted from frozen tissues according to methods described previously (21). Informed consent was obtained from all of the participating patients prior to surgery. For additional genotyping of EBAG9 and CMYC loci in an independent panel of 144 breast cancer patients, genomic DNA was isolated from tumor and corresponding normal tissues in a procedure as described above.

SSCP Analysis. To look for alterations in the EBAG9 gene in tumor cells, we divided the coding region into six fragments and amplified each exon and its flanking sequences with appropriate primers. PCR experiments were performed with genomic DNA from the 94 tumor cell lines described above. For each reaction, about 10 ng of PCR product was heat-denatured in the presence of 80% of deionized formamide and electrophoresed in 8% polyacrylamide gels, with or without 10% glycerol, in 0.5× TBE at 8 V/cm for 10 h at room temperature. DNA fragments were visualized by silver staining using the Plus One DNA silver staining kit (Pharmacia Biotech, Tokyo, Japan). Each fragment showing that an altered SSCP band pattern was subcloned with an AdvanTAge PCR cloning kit (Clontech) and sequenced.

Microsatellite Analysis by the Differential-PCR Method. DNA from 129 primary breast tumors was examined for allelic gain or loss at eight highly polymorphic microsatellite loci ordered along the distal long arm of chromosome 8 according to the comprehensive human linkage map (22–24). The linear order of these markers is (centromere)-CHLC-GATA26A08-CHLC-ATA23G06-EBAG9-AMF200VC7-CHLC-GATA72D08-D8S522-D8S1179-D8S1128 (telomere). Marker D8S522 is in the vicinity of the CMYC gene on 8q24.1. A microsatellite marker for the EBAG9 region on 8q23, described previously (25). The IL-1β (2q13-q21) gene was chosen as a single-copy control marker to obtain a reference for equal quantities of DNA, because this region of chromosome 2 has never shown chromosomal alterations in breast cancers. Primers IL1B.PCR2.1 and IL1B.PCR2.2 (26) were used to amplify this control gene.

Each microsatellite was amplified with the single-copy control in the PCR using 20 ng of genomic DNA, 10 mM Tris-HCl (pH 8.4), 50 mM KCl, 1.5 mM MgCl₂, 0.01% of gelatin, 200 mM dNTPs, 2.5 pmol each of [γ-32P]ATP-end-labeled primer and nonlabeled primer, 0.8 to 2.5 pmol each of [γ-32P]ATP-end-labeled IL1B.PCR2.1 and nonlabeled IL1B.PCR2.2, and 0.25 units of Taq polymerase in a volume of 10 μl. The amount of end-labeled control primer was adjusted to roughly equalize signal intensities of both target and control markers. Cycle conditions were 94°C for 4 min, then 25 cycles of 94°C for 45 s, 60°C for 45 s, and 72°C for 1 min, with a final extension step of 5 min at 72°C, in a GeneAmp PCR 9600 System (Perkin-Elmer Corp. Instruments, Norwalk, CT). PCR products were electrophoresed in 0.3 mm-thick denaturing 6% polyacrylamide gels containing 36% formamide and 8M urea, at 8000 V for 20 h. Gels were transferred to filter papers, dried at 80°C, and exposed to autoradiographic film at room temperature for 16–20 h.

Determination of Allelic Dosage. Methods of measuring allelic copy number gain using polymorphic microsatellite markers had been established previously (12, 13). In brief, signal intensities of the control marker and each polymorphic allele of the microsatellites were quantified by a Hoefer GS-300 scanning densitometer; peak areas corresponding to each signal were calculated by electronic integration using the GS-370 electrophoresis data system (Hoefer Scientific Instruments, San Francisco, CA). An analysis of allelic dosage consisted of comparing signal intensities of four bands, two derived from the

Fig. 1  Nucleotide sequence of human EBAG9 cDNA. Bold, the novel sequence of the 3'-UTR determined in the present study; underlined, the polyadenylation site.
polymorphic alleles on 8q in normal DNA and the other two derived from the same pair of alleles in tumor DNA. They were normalized to the signal intensity of the control marker to adjust for subtle differences in PCR amplification efficiency between normal and tumor samples. The extent of increase of an allele that had gained signal was calculated by dividing the ratio of the intensity of the increased allele:the intensity of the normal allele in tumor DNA by the corresponding ratio measured in normal DNA; when the results exceeded 1.8, the allele was considered to be overrepresented.

Clinicopathological Parameters. The following parameters were examined: histological type, tumor size, lymph-node metastasis (status), and status of ER and PgR in each of the 129 breast cancer patients. The tumors, all of them ductal carcinomas, were classified by pathologists according to the histological WHO classification and the histological typing scheme of the Japanese Breast Cancer Society (27). Tumor size and lymph-node metastasis (status) were classified by pathologists according to UICC TNM classification. ER and PgR were measured by radioreceptor assay according to a standard dextran-coated charcoal (DCC) method, using [125I]-labeled estradiol as labeled ligand on homogenates of fresh-frozen tissue (Otsuka Pharmaceutical, Tokushima, Japan). All samples containing /H110225 fmol of ER or PgR per mg protein were considered receptor positive.

RESULTS

Cloning and Structural Analysis of the EBAG9 Gene. By carrying out 3'-RACE experiments, we determined the complete sequence of the 3'-UTR of the human EBAG9 cDNA (Fig. 1). The full-length cDNA for human EBAG9 consists of a 293-bp 5'-UTR, 642 bp of coding elements, and 599 bp of 3'-UTR.

After obtaining the genomic clone containing the EBAG9 gene, BAC477n12, we found the entire gene to consist of seven exons interrupted by six introns (Fig. 2). The sequences of exon/intron boundaries were determined as described in “Materials and Methods.” The lowercase letters refer to intron sequences and the uppercase letters to exon sequences.

Table 2  Exon/intron organization of the human EBAG9 gene

<table>
<thead>
<tr>
<th>Exon number</th>
<th>Exon size (bp)</th>
<th>3' splicing acceptor</th>
<th>5' splice donor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>278</td>
<td>tctttccacagGTTTTGATTC</td>
<td>TATGCAGTGgtatgattttt</td>
</tr>
<tr>
<td>2</td>
<td>98</td>
<td>tttggtttcagATCTGGCAGA</td>
<td>TAAATGCAGGttaaataagt</td>
</tr>
<tr>
<td>3</td>
<td>79</td>
<td>ttgasatgtagACAGATGGTG</td>
<td>TACCTGAGAAgtatatgtaag</td>
</tr>
<tr>
<td>4</td>
<td>159</td>
<td>aatccctctcagATTGTTATTA</td>
<td>TCATCGACGttaaaggtat</td>
</tr>
<tr>
<td>5</td>
<td>108</td>
<td>ttctttctcagATCTGGCAGA</td>
<td>GCACGACGttatgtagt</td>
</tr>
<tr>
<td>6</td>
<td>92</td>
<td>ttctttcagACAGCAGAAA</td>
<td>TTTACTCTTGttaaatc</td>
</tr>
<tr>
<td>7</td>
<td>720</td>
<td>ttctttccacagGTTTTGATTC</td>
<td>TATGCAGTGgtatgattttt</td>
</tr>
</tbody>
</table>

Fig. 2 Schematic structure of the human EBAG9 gene. Shading within the exons, coding sequence. A single BAC clone (above the map) covers the entire gene.

Table 2 Exon/intron organization of the human EBAG9 gene

The sequences of exon/intron boundaries were determined as described in “Materials and Methods.” The lowercase letters refer to intron sequences and the uppercase letters to exon sequences.

N 1 2 3 4 5 6 7 8 9 10

G3PDH

EBAG9

CMYC

Fig. 3 EBAG9 gene and CMYC gene expression in the cell lines by RT-PCR. N, normal breast; Lanes 1–10, breast cancer cell lines (Lane 1, MDA-MB-453; Lane 2, CRL1500; Lane 3, YMB-1-E; Lane 4, MCF7; Lane 5, HBL100; Lane 6, OCUB-M; Lane 7, BT-20; Lane 8, BT-474; Lane 9, MDA-MB-435S; Lane 10, SK-BR-3).
whereas CMYC gene was overexpressed in only a fraction of breast cancer cell lines (Fig. 3). A correlation between gene expression and gene copy number could not be determined because normal counterpart cells necessary for this comparison were unavailable among these cell lines. To screen cancer cells for sequence variations in the EBAG9 gene, we amplified by PCR its entire coding region in DNA from each of the 94 cell lines and analyzed the products for SSCP. Products with potential variations were sequenced directly by automated instruments. No somatic mutations or polymorphisms were observed in any of those tumor cells.

**Physical Mapping around the EBAG9 Gene.** The signal intensity of at least one marker on chromosome 8q was increased 2- to 3-fold in 58 (45%) of the 129 breast tumors examined in this study. The frequencies of allelic gain observed at each of the eight tested markers described above are shown, in descending order from proximal to distal (Fig. 4). Allelic gains involving both CMYC and EBAG9, indicating polysomy, were observed in 11 tumors; the other 47 showed gain of only part of the examined portion of 8q. LOH was rare at any locus on 8q.

Representative autoradiograms are presented in Fig. 5. In cases 106, 94, and 48, for example, marker CHLC. GATA26A08, EBAG9, and CHLC. GATA72D08 revealed increased intensity of alleles in tumor DNA compared with its counterpart in normal DNA. Densitometric quantification showed that the intensities of the other alleles and the single-copy control marker in tumor DNA were almost equal to those of normal DNA.

Of the 58 breast cancers showing a gain in copy number of loci on 8q, we observed an increase of the EBAG9 locus in 27 (20.9%) informative tumors. Copy number gain at the CMYC locus (D8S522) was observed in 42 (32.6%) of the 129 tumors. Fig. 4 displays a physical map of the distal 8q region for the 58 tumors having partial allelic gain of the region. Among them, 16 (28%) showed gain of at the EBAG9 locus but not CMYC (Fig. 4, left panel). Eleven (19%) of these 58 tumors showed allelic gain at both EBAG9 and CMYC loci (Fig. 4, middle panel). Increased copy number of CMYC but not EBAG9 was observed in 31 tumors (Fig. 4, right panel). These data clearly demonstrate that EBAG9 and CMYC are independent targets of gene amplification in breast cancers that contain chromosomal gains on the 8q arm.

Correlation of the physical mapping data with clinicopathological parameters for those tumors is summarized in Table 3. All of the tumors with increase of EBAG9 copy number but without gain of CMYC were T1- or T2-stage tumors (< or = 5 cm in diameter). No tumors with this combined genotype were advanced T3-stage tumors, whereas one-third of the tumors in which CMYC was overrepresented but EBAG9 was not, were advanced (T4-stage) tumors (P = 0.0204; Table 4, Initial panel). No other clinicopathological parameter showed significant association with changes on chromosome 8.

Subsequently, we took independent series of additional 144 primary breast cancers and analyzed for allelic gain at EBAG9 and CMYC loci with respective polymorphic markers to confirm our initial finding of independent increase of EBAG9 as well as of CMYC. Of the 31 tumors with EBAG9 increase, 15 showed gain at EBAG9 but not at CMYC. The remaining 16 showed gain of EBAG9 as well as of CMYC. Of the 48 tumors with CMYC
gain, 32 showed gain at CMYC but not at EBAG9. When a total of 273 breast cancers from initial and second panels were analyzed together for clinicopathological correlation, almost all (28 of 29) of the tumors with EBAG9 gain but not CMYC were T1/T2 stage carcinomas (<5 cm in diameter), whereas one-third (21 of 61) of the tumors in which CMYC was increased but EBAG9 was not, were advanced T3-stage tumors (P = 0.0012; Table 4, Total panel).

DISCUSSION

We have determined the complete cDNA sequence and the genomic structure of the human EBAG9 gene. Although no inactivating intragenic alterations were detected among 94 cancers examined by SSCP, we identified frequent gains of DNA in the genomic region around the EBAG9 gene (8q23) in primary breast cancers, as an event independent of CMYC amplification on the same chromosome arm.

Amplification of 8q, particularly involving the CMYC gene and its surrounding region at 8q24.1, has often been described in breast, lung, colon and gastric cancers, acute myeloid leukemias, and brain tumors (17, 29–33). In an earlier study, we also had detected frequent gains of chromosome region 8q24.1, centered by the CMYC gene, in primary breast carcinomas (13).

In the more focused study reported here, we demonstrated that increased copy number of the EBAG9 gene at 8q23, which lies several centimorgans proximal to the CMYC gene, is an independent genetic event associated with primary breast cancers. We detected an increase in copy number of the EBAG9 gene in 27 (21%) of the 129 primary breast cancers examined; 16 of those events involved the EBAG9 gene and not CMYC. Our results clearly indicate that at least two target regions for amplification on distal 8q are somatically associated with the development of primary breast cancers.

We studied a total of 273 breast cancers from two series and analyzed for clinicopathological correlation. Almost all of the tumors with EBAG9 increase but not CMYC (28 of 29) were T1/T2 stage carcinomas (<5 cm in diameter), whereas one-third (21 of 61) of the tumors in which CMYC was increased but EBAG9 was not, were advanced T3-stage tumors (P = 0.0012). These data suggest that the EBAG9 and CMYC genes are independent targets of DNA amplification, and that the gain of EBAG9 may play a specific role in early stages of breast carcinogenesis.

In the present study, we observed consistent expression of EBAG9 mRNA in cancer cell lines. Human breast cancer is a hormone-dependent tumor the growth of which is regulated by estrogen. In this connection, we note that human EBAG9 was originally identified as an estrogen-responsive locus, that EBAG9 mRNA was shown in vitro to be up-regulated by estrogen treatment in breast cancer cells, and that the 5' regulatory region of the EBAG9 gene contains an identifiable estrogen-responsive element. No statistical association was observed between EBAG9 copy number increase and responsiveness to ER and/or PgR, represented by ER/PgR positivity. Because EBAG9 is a downstream effector of ER, the results appear to imply the presence of at least two distinct pathways for hormone outgrowth of breast cancer cells: (a) activation of ER and up-regulated transcription of EBAG9 gene without its genetic alteration; and (b) EBAG9 copy number gain accompanied by its overexpression independent of ER signaling, in addition to other various hypothetical mechanisms. Furthermore, with respect to
immune escape mechanisms, it is relevant that the EBAG9 gene product is identical to RCAS1, a cancer-surface antigen identified in a human uterine adenocarcinoma cell line and implicated in immune escape. Moreover, overexpression of RCAS1 inhibits growth of tumor-stimulated host-immune cells and induces their apoptosis (16). These lines of evidence, together with the results obtained in the present study, imply that increased gene copy number and consequent overexpression of EBAG9 may play an etiological role in the development and progression of breast cancers, especially in early stages.

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