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Expression of nma, a novel gene, inversely correlates with the metastatic potential of human melanoma cell lines and xenografts

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nma, a novel gene, was isolated by using a subtractive hybridization technique in which the gene expression was compared in a panel of human melanoma cell lines with different metastatic potential. nma mRNA expression (1.5 kb) is high in poorly metastatic melanoma cell lines and xenografts and completely absent in highly metastatic human melanoma cell lines. Fluorescence in situ hybridization combined with the analysis of a panel of human–rodent somatic cell hybrids indicated that the nma gene is located on human chromosome 10, in the region p11.2–p12.3. Sequence analysis of nma showed no homologies with other known genes or proteins, except for several partially sequenced cDNAs. The predicted amino acid sequence suggests that the protein encoded by nma contains a transmembrane domain. Expression of nma is high in human kidney medulla, placenta and spleen, low in kidney cortex, liver, prostate and gut and absent in lung and muscle. Whereas nma is not expressed in normal skin tissue, expression is high in melanocytes and in 3 out of 11 melanoma metastases tested.

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Material and methods

Biological materials

Human melanoma cell lines 1F6, 530, BLM, MV3 and MV1 (van Muijen et al., 1991a, b, c) were cultured as described by Weterman et al. (1992). In this panel of cell lines, BLM and MV3 represent the highly metastatic cell lines, i.e., those in which metastases occur in more than 50% of the tumor-bearing mice. 1F6, 530 and MV1 produced metastases in less than 10% of the tumor-bearing mice, representing the poorly metastatic cell lines (van Muijen et al., 1991a); 3 × 10⁵ cells were used for s.c. inoculation into nude mice (nu/nu BALB/c; Bomholgaard, Ry, Denmark).

Excision and processing of the human tissues was performed as described by Weterman et al. (1995).

RNA isolation and northern blot analysis

Total RNA was isolated using the lithium-urea procedure described by Auffray and Rougeon (1980). RNA oligodeoxynucleotide selections were performed using oligodeoxynucleotide columns (type II; Collaborative Research, Bedford, MA). Total RNA (10 μg) was glyoxylated (McMaster, 1977), size fractionated on 1% agarose gels and blotted onto Hybond N-plus filters (Amersham, Aylesbury, UK). Northern blots were hybridized according to Church and Gilbert (1984), with the addition of 0.1 mg denatured herring sperm DNA/ml of hybridization mixture. To confirm that equal amounts of RNA were loaded in each lane, the blots were hybridized afterwards to an 18S ribosomal probe.

Construction of cDNA and subtraction libraries

cDNA libraries were constructed from 5 μg of oligodeoxynucleotide selected RNA using a cDNA cloning kit (Invitrogen, San Diego, CA) or a λZAP cDNA synthesis kit (Stratagene, La Jolla, CA). Construction of the MV3-MV1 subtraction library with a subtractor kit (Invitrogen) was performed as described before (Weterman et al., 1993). The poorly metastatic human melanoma cell line 530 was used for the construction of the 530 λZAP cDNA library.

DNA probes and hybridization of cDNA and genomic libraries

cDNA probes were radiolabeled using the random prime method as recommended by Boehringer Mannheim (Germany). Hybridization of cDNA libraries and the human fetal brain genomic library (kindly provided by Mr. A. van Bokhoven, Department of Urology, Nijmegen) was performed for

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was size fractionated on 1% agarose gels. DNA was transferred to Hybond N-plus filters and hybridized as described previously (Sanger and Lipman, 1988). DNA sequence analysis, including searches for motifs, alignments and structure predictions, was performed using the CAMMA programs MOTIFS, PILEUP, CLUSTAL V, BESTFIT, PEDITESTRUCTURE, PLOT-STRUCTURE and MEMBRANE PROPENSITY, which are all part of the Wisconsin Package V.7.0 (Devereux et al., 1984).

**Figure 1** – Northern blot analysis of human melanoma cell lines and xenografts; 10 μg of total RNA were loaded in each lane. Lanes A–E, cell lines; Lanes F–J, xenografts. Lanes A and F, BLM; B and G, MV3; C and H, MV1; D and I, 1F6; E and J, 530. The blot was hybridized to radiolabeled 1.5 kb BLM; B and G, MV3; C and H, MV1; D and I, 1F6; E and J, 530.

Chromosomal DNA isolation and Southern blot analysis

Chromosomal DNA was isolated using the method of Blin and Stafford (1976). DNA was digested with EcoRI, and 10 pig Aval DNA restriction fragment cloned in pGEM-3zf(-). This fragment also contains a putative TATA and CAAT box. Determination of the transcription start site of the nma gene

**Figure 2** – Complete nucleotide sequence of nma (GenBank accession number U23070) and translated predicted protein. A putative polyadenylation signal is marked by asterisks. Starting points of exons II and III (see also Fig. 4 and the Results section) are also indicated.

**DNA sequencing and computer analysis**

DNA fragments were sequenced according to the dideoxy method described by Sanger et al. (1980) using a Sequenase sequencing kit (USB, Cleveland, OH). Large fragments were sequenced by constructing a set of deletion clones using exonuclease III (Erase-a-base kit, Promega, Madison, WI). Searches for known DNA sequences were performed using the GenBank and EMBO databases (Devereux et al., 1984; Pearson and Lipman, 1988). DNA sequence analysis, including searches for motifs, alignments and structure predictions, was performed using the CAMMA programs MOTIFS, PILEUP, CLUSTAL V, BESTFIT, PEDITESTRUCTURE, PLOT-STRUCTURE and MEMBRANE PROPENSITY, which are all part of the Wisconsin Package V.7.0 (Devereux et al., 1984).

**Determination of the transcript start site of the nma gene by S1 mapping**

Nuclease S1 mapping was performed using the method of van Lcn et al. (1986). Briefly, 50 μg of total 530 RNA or yeast tRNA was hybridized with 1 × 10⁷ cpm of a ³²P-labeled antisense ssDNA probe derived from the human genomic nma subclone pW1D117. Subclone pW1D117 consists of a 418 bp Aval DNA restriction fragment subcloned in pGEM-3zf(-). Nuclease positions 304 to 418 of this Aval fragment correspond to positions 1 to 115 of the human nma cDNA sequence. This fragment also contains a putative TATA and CAAT box.

The insert was labeled using the method of Sanger et al. (1980), and a single stranded DNA probe was isolated following SauI digestion and electrophoresis on a 4% polyacrylamide/7 M urea gel. Annealing was performed at 40°C overnight. Nuclease S1 (Boehringer Mannheim) was used at 1000 units/ml for 1 hr at 37°C. The remaining product was electrophoresed on a 6% polyacrylamide/7 M urea gel.

**Chromosomal localization of the nma gene**

The initial chromosomal assignment of the nma gene was carried out by using a panel of monocromosomal human-
rodent somatic cell hybrids (Coriell Repository, Camden, NJ) and the complete nma cDNA clone as a probe for Southern blot analysis. Further refinement of the localization was obtained through fluorescence in situ hybridization (FISH) on normal human metaphase spreads using the complete nma-1 genomic clone as a probe. Brefly, probe DNA was nick translated with digoxigenin-11-dUTP (Boehringer Mannheim). For efficient hybridizations, 10 ng of labeled probe were applied under a 20 \times 20 \text{mm} carrier slip onto normal lymphocyte-derived metaphase spreads. Visualization of the hybridization signals was accomplished using fluorescein-conjugated sheep anti-digoxigenin and fluorescein-conjugated donkey anti-sheep antibodies (Jackson ImmunoResearch, West Grove, PA). Slides were immersed in antifade solution supplemented with DAPI (Sigma, St. Louis, MO) for counterstaining of the chromosomes. Digital images were captured using a cooled CCD-camera (Photometrics, Tucson, AZ) coupled to a Macintosh computer.

RESULTS

Cloning and characterization of a differentially expressed nma cDNA clone

During the isolation of cDNA clones differentially expressed in a panel of poorly metastatic versus highly metastatic human melanoma cell lines, 2 novel genes, designated nmb (Weteman et al., 1995) and nma, were identified that showed expression in the poorly metastatic human melanoma cell lines 1F6, 530 and MV1. The expression of nma is shown in Figure 1. nma mRNA expression is high in the poorly metastatic human melanoma cell lines 1F6, 530 and MV1 and derived xenografts. Expression was not detected in the highly metastatic cell lines BLM and MV3 and xenografts derived from these cell lines.

Sequencing revealed that nma represents a novel gene. Screening of a cDNA library derived from the poorly metastatic human melanoma cell line 530 resulted in the isolation of the nma cDNA clone pWD58. An S1 mapping experiment described below indicates that clone pWD58 contains the complete cDNA. The nma cDNA sequence with a putative polyadenylation signal, translation start site and open reading frame (260 amino acids) is shown in Figure 2. A consensus signal cleavage site located downstream of amino acid 27 (Glu) indicates that the predicted nma protein contains a signal sequence. A glycosylation site and a Kyte and Doolittle (1982) prediction of hydrophilicity are schematically depicted in Figure 3. The predicted amino acid sequence contains a transmembrane domain indicating, together with the other data, that nma codes for a transmembrane protein.

Sequence comparison showed no similarities with known genes or proteins, except for several partially sequenced cDNAs (150 to 500 bp) with accession numbers D25985, T73919, T85484, T90372, Z39158 and Z41678.

Isolation and partial sequencing of a genomic clone containing the nma gene

Screening of a human fetal brain genomic library with nma cDNA clone pWD58 yielded 1 positive clone with an insert of approximately 30 kb. Characterization of this genomic clone nma-1 was performed by producing a set of subclones using several restriction endonucleases. A 9 kb BamHI fragment was isolated that hybridized with both a 5' and a 3' nma cDNA probe and, thus, contained the complete coding sequence. Subclones of this 9 kb BamHI fragment were partially sequenced in order to locate exon-intron junctions. The gene consists of 3 exons, 448, 288 and 784 bp, respectively, separated by 2 introns of 3 kb and 435 bp (Fig 4; GenBank accession numbers for exon-containing sequences 1, U29188; II and III, U29189).

The 9 kb BamHI nma genomic fragment is flanked by 2 EcoRI restriction sites and also contains 1 EcoRI restriction site between exons II and III, and 1 EcoRI site in exon III (Fig 4). When hybridizing a Southern blot containing EcoRI digested genomic DNA from human melanoma cell lines to a complete nma cDNA probe, 3 bands are expected to hybridize. In Figure 5, the 3 EcoRI bands are indicated by arrows. An additional band of approximately 4 kb is visible in melanoma cell line BLM that may be the result of cross hybridization.

S1 mapping was performed with a genomic nma antisense ssDNA probe overlapping the putative transcription start site and total RNA from the poorly metastatic melanoma cell line 530, to define precisely the 5' transcription start site of the nma gene. Besides the first 115 nucleotides of the cDNA sequence, this genomic nma DNA fragment also contains a putative TATA and CAAT box. A transcription start region corresponding to protected transcripts of 113 to 115 nucleotides long is visible in Figure 6, indicating that 2 or 3 alternative transcription start sites are used.

Chromosomal localization of the nma gene

The initial chromosomal assignment of the nma gene was carried out via Southern blot analysis of a well-defined panel of monochromosomal human–rodent somatic cell hybrids with nma cDNA pWD58 as a probe. A single hybrid revealed a human-specific hybridizing fragment (not shown). This hybrid contains chromosome 10 as its only human constituent, thus mapping the gene to this human chromosome. Further refinement of the localization was obtained by using FISH with the genomic nma-1 clone. In this case, hybridization signals were observed in several (telomeric) chromosomal regions (not...
Expression of nma in cutaneous melanoma

A Northern blot containing several human melanocytic lesions was screened for nma expression (Fig. 7). Whereas nma expression in human melanoma cell lines; 10 μg of EcoRI digested chromosomal DNA were loaded in each lane. Lane A, MV1; Lane B, 530; Lane C, 1F6; Lane D, BLM; Lane E, MV3 DNA digested with EcoRI. The blot was hybridized to radiolabeled 1.5 kb nma cDNA. Hybridizing bands are indicated with arrows. The m.w. marker was HindIII digested λDNA. As a control, a chromosome 18-specific centromeric hybridization is shown (3 bands of approximately 20, 1.3 and 0.6 kb). Abnormalities involving chromosome 18 have not been described in relation to melanoma.

A specific signal was observed on the short arm of chromosome 10, in the region p11.2-p12.3. We conclude that the nma gene maps to this region. A number of other signals may be due to cross hybridization and/or the presence of other nma-like sequences in the human genome.

Expression of nma in human organs

The expression of nma in several human organs was tested using a Northern blot containing kidney cortex and kidney medulla, lung, muscle, liver, placenta, spleen, prostate and gut total RNA (Fig. 8). nma is expressed at high levels in kidney (indicated with an arrow) is highly expressed in melanocytes and in 3 out of 11 melanoma metastases, expression in the other metastases is low or absent. Remarkably, 3 out of 4 metastases with strong pigmentation (Lanes I, J, M) show high nma expression levels. nma does not seem to be expressed in normal skin tissue (Lane B). The upper 1.9 kb band may be the result of cross-hybridization of nma with the 1.9 kb 18S rRNA (compare with control hybridization).

Expression of nma in human organs

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human melanoma cell lines 1F6, 530 and MV3 and derived xenografts, and completely absent in the highly metastatic melanoma cell lines BLM and MV3 (Fig. 1). The differences in RNA expression of nma between poorly and highly metastatic melanoma cell lines cannot be explained by major chromosomal rearrangements, as demonstrated by Southern blot analysis (Fig. 5). The observed differences in nma mRNA expression may, therefore, reflect differences in promoter activity of the nma gene.

Sequence analysis revealed that nma is a new gene. The presence of a signal sequence and a hydrophilic area of 25 amino acid residues (positions 151 to 175) bordered by charged residues indicates that the gene encodes a transmembrane protein.

The nma gene is located on human chromosome 10 in the region p11.2-p12.3 (results not shown). Loss of heterozygosity (LOH) of chromosome 10 in relation to malignant melanoma has already been described. Ishikii et al. (1993) concluded from their results that a tumor suppressor gene may be located on 10q, although allelic losses on 10p were also found.

Although its expression pattern in cell lines and derived xenografts offers the perspective that nma could be a potential marker for early stages of melanoma progression (Fig. 1), its presence in a considerable number of human melanoma metastasis lesions is not in line with this suggestion (Fig. 7). Other (potential) early progression markers, notably nm23 and also nmb, display expression profiles similar to that of nma. Experimental evidence is available in support of a metastasis suppressor function for the nm23 gene (Leone et al., 1991) and an nmb clone encoding an N-terminally truncated product (Weterman et al., 1995). One could speculate that genes like nm23, nmb and also nma may be involved in attenuating metastatic properties of melanoma cells. Tumor progression may require that these genes are (temporarily) switched off in the course of metastasis but turned on again later in a secondary, distantly growing tumor. Alternatively, their expression may only partially inhibit the metastasis. Evidence for a transient role of a presumed suppressor of metastasis is given by the experiments of Florenes and colleagues (1992). They demonstrated that the level of nm23 mRNA was significantly lower in tumors from patients with a short interval between primary diagnosis and the appearance of metastases than in those with more prolonged relapse-free intervals. This observation was explained by assuming that the expression of nm23 in metastases is inversely correlated with aggressive behavior. This conclusion was strengthened by Xerlii et al. (1994) and Culigo et al. (1994), who found a correlation between high expression of nm23 in patients with a high overall survival following metastasis resection and in cell lines derived from these metastases. It is possible that nma and nmb follow the same pattern as nm23 does and, therefore, are found in some but not all metastases. Although clinical data were available on the melanoma metastases used in this study, no final conclusions can be drawn because of their small number.

Expression of nma in several human organs indicates that the expression is not melanocyte-specific: nma is expressed at variable levels in most organs tested, except in lung and muscle (Fig. 8).

Further characterization of nma, especially of its biological functions, should eventually clarify its role in melanoma metastasis.

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