Expression, purification and characterization of methyl DNA binding protein from *Bombyx mori*

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Received 17 May 2004, Accepted 9 October 2004, Published 28 March 2005

Abstract

A cDNA clone encoding methyl DNA binding domain-containing protein (bMBD2/3) was obtained by homology searches using a *Bombyx mori* fat body cDNA library. The cDNA encoded a polypeptide with 249 amino acids sharing 54% similarity with the methyl DNA binding protein from *Drosophila melanogaster*. To characterize the biochemical properties of bMBD2/3, the clone was expressed in *Escherichia coli* as His-tagged protein. The recombinant protein was purified to homogeneity using Ni-NTA superflow resin and heparin agarose. The protein showed specific methyl DNA binding activity and was phosphorylated by protein kinase *in vitro*. Immunoblotting using the purified antibody indicated that bMBD2/3 was expressed in almost all tissues. Using west-western blotting analysis, some proteins that interact with bMBD2/3 were identified in the brain. This is the first report that insect MBD is phosphorylated and is present in adult tissues. These results suggest that bMBD2/3 plays important roles in the DNA methylation-specific transcription of *Bombyx mori*.

Keywords: DNA methylation, phosphorylation

Abbreviation:
EMSA  Electro Phoretic Mobility Shift Assay

Introduction

In mammals, cytosine methylation at CpG dinucleotides represents the most common form of DNA modification (Rein et al. 1998). Approximately 2–10% of all cytosine residues in genomic DNA are methylated. This methylation has been implicated in the regulation of a number of genetic activities during mammalian cell differentiation and embryonic development (Li et al. 1992; Okano et al. 1999). These activities include tissue-specific gene transcription, cellular defense against viral agents, tumorigenesis, genomic imprinting and X-chromosome inactivation (Bartolemes et al. 1997; Constancia et al. 1998; Heard et al. 1997).

DNA methylation in several invertebrate species including insects have been reported (Field et al. 2000; Patel et al. 1987). Recently DNA methylation was also detected in *Drosophila melanogaster* by highly sensitive chemical means (Lyko et al. 2000; Gowher et al. 2000). Cytosine methylation in *D. melanogaster* is reported to be considerably more abundant during very early development. Further, the enzyme responsible for this methylation, DNA cytosine methyl transferase, was identified from *D. melanogaster* using database searches (Hung et al. 1999). Overexpression of this clone resulted in genomic DNA methylation of *D. melanogaster* S2 cells (Reddy et al. 2003). This result suggests that DNA methylation in insects is important during embryonic development.

In vertebrates the regulatory information encoded by DNA methylation is interpreted by a family of proteins with a conserved DNA binding surface termed methyl-CpG binding domain, or MBD (Bird et al. 1999; Siegfried et al. 1997; Hendrich et al. 1998). MeCP2, MBD1, MBD2, MBD3, and MBD4 constitute a family of vertebrate proteins that have a methyl binding domain. These MBD proteins could preferentially bind to methyl CpG-containing DNA, recruit histone deacetylase-containing complexes and thus cause chromatic condensation. This is very likely one major scheme involved in the functioning of vertebrate DNA methylation.

Several recent reports have also noted the identification of insect MBD proteins in *D. melanogaster* (Ballestar et al. 2001; Roder et al. 2000). Only one type of MBD protein was found, compared
to the five types of vertebrate MBD proteins described above. The MBD protein of Drosophila was expressed during early development as two alternative spliced types, and repressed transcription in both mammalian and insect cells. Further MBD2/3 from Acheta domestica (aMBD2/3) was isolated by degenerate RT-PCR (Tweedie et al. 1999). The expressed protein in E. coli showed methyl DNA binding, but its function and distribution in tissues is unknown.

Bombyx mori is a major experimental insect for genetic and biochemical analysis. Because a B. mori data base (silk base) has been established, transgenic insects can be produced and various genetic mutants have been isolated. Cytosine residues in genomic DNA of the silk gland of B. mori were reported to be methylated at a level of 0.15–0.2%. However, little detectable genome 5-methyl cytosine has been found in adult D. melanogaster (Patel et al. 1987). B. mori is, therefore, useful to clarify the molecular mechanism of insect DNA methylation.

In this report, we identified a clone as MBD protein from B. mori. This clone was expressed as a His-tagged thiorexin fusion protein in Escherichia coli and purified using affinity chromatography. The recombinant protein specifically bound methylated DNA, interacted with proteins in the brain and was phosphorylated by protein kinase. Immunoblotting indicates that this protein was expressed in almost all tissues, which is different from what is seen in D. melanogaster.

Materials and Methods

Materials

Thrombin, ECLplus Western blotting detection reagent and [γ-32P] ATP (>1,000 Ci/mmol) were from Amersham Pharmacia Biotech (www.apbiotech.com). Heparin agarose was from Sigma (www.sigmaaldrich.com). Calmodulin-dependent protein kinaseII and PKA were from New England BioLab, www.neb.com. Goat peroxidase-conjugated anti mouse IgG was from Cell Signaling Technology, Inc. (www.cellsignal.com) PKC was from Upstate Biotechnology (www.upstate.com). Ni-NTA superflow resin was from Qiagen (www.qiagen.com). The other chemicals were of the purest grade commercially available.

Construction of expression plasmid and expression in E. coli

The cDNA fragments containing the entire coding sequence of bMBD 2/3 were kindly provided by Dr. Mita of the National Institute of Entomological and Sericultural Science. Sequence analysis was done using an ABI sequencer 377 (www.appliedbiosystems.co.jp). Sequence homologies were done by BLAST search (Altschul et al. 1990). The cDNA fragments containing the entire coding sequence of bMBD2/3 were amplified by PCR with primers containing BamHI or EcoRI. The amplified fragments were digested with BamHI and EcoRI. The digested fragment was inserted into the BamHI and EcoRI sites of an expression vector, pET32a. This cDNA was transformed into E. coli strain BL21. Transformed E. coli cells (BL21) were incubated overnight in LB medium. The medium was diluted to 1:100 and incubated for 3 h. Expression of thioredoxin-fusion protein was then induced by adding 1 mM isopropyl β-D-thiogalactopyranoside (IPTG), followed by additional incubation for 24 h at 16 °C. The cells were collected by centrifugation at 5,000 g for 5 min, and then stored at –80 °C.

Purification of bMBD2/3 protein

All procedures were carried out at 4 °C. The frozen cells (26.5 g) were suspended in phosphate-buffered saline (PBS) [140 mM NaCl, 2.7 mM KCl, 10 mM Na2HPO4, and 1.8 mM KH2PO4 (pH 7.3)], disrupted by sonication and then cleared by centrifugation at 12,000 g for 30 min. The fusion protein was bound to a Ni-NTA superflow resin equilibrated with buffer A (50 mM NaH2PO4, 300 mM NaCl, and 10 mM imidazole; pH 8.0). After washing, proteins were eluted with a step-wise increase in imidazole. The 0.15 M imidazole eluate was dialyzed against PBS. To remove His-tagged thiorexin, the protein was incubated with thrombin at 22 °C for 16 hr. After centrifugation the supernatant was applied to a Ni-NTA column equilibrated with buffer A. The passed-through fraction was applied to a heparin agarose equilibrated with 25 mM Heps-NaOH (pH 7.6). After washing, proteins were eluted with a step-wise increase in NaCl. The 0.3 M NaCl eluate was recovered. The sample was stored at –80 °C. Proteins were determined using BSA (Fraction V, Sigma) as the standard by the method of Lowry et al. (1951).

SDS–PAGE

SDS–polyacrylamide gel analysis was performed according to the method of Laemmli (1970), using a 4.5% stacking gel and a 15% separating gel, at a constant current of 16 mA. The proteins in a gel were visualized with Coomassie Blue stain.

Electrophoretic mobility shift assay (EMSA)

The sequence of oligonucleotides used in EMSA is 5′-ccgccggcggcggcgg-3′ as the methylated DNA probe and 5′-ccggcggcggcggcggg-3′ as the unmethylated DNA probe. The oligonucleotides were labeled with 32P at their 5′ ends and gel purified prior to EMSA. The purified protein was incubated in 10 mM Tris HCl (pH 8.0) containing 3 mM MgCl2, 50 mM NaCl, 0.1 mM EDTA, 1 mM dithiothreitol, 0.1% NP-40, 5% glycerol, 0.4 mg/ml BSA and one pico mole of radiolabeled probe. Samples were incubated for 30 min at 25 °C. Thirty picomoles of competitor DNA were used per binding reaction. To separate the protein-DNA complexes, the reaction mixtures were loaded onto a running nondenaturating 6% polyacrylamide gel. Electrophoresis was carried out. Gels were dried and band patterns were analyzed using a bioimaging analyzer (BAS 1000; FUJIX).

Preparation of brain crude homogenate from Bombyx mori

Crude protein kinase fraction was obtained from the brain of Bombyx mori. First, the brain was rapidly dissected out of 3-day-old larvae of 5th instar in Ringer’s solution. The brain was homogenized in the homogenization buffer (25 mM Tris-HCl [pH 7.5], 50 mM mercaptoethanol, 2 mM EGTA, 1 mM PMSF, and 0.25 M sucrose). The homogenate was used as the brain extract.

Protein kinase assay

The typical reaction mixture with a total volume of 20 µl contained 50 mM Tris-HCl (pH 7.5), 6.25 mM MgCl2, 0.125 mM CaCl2, 2 mM dithiothreitol, 0.1 mM EDTA, 0.1 µg bMBD2/3 protein, 50 units protein kinase and 50 µM [γ-32P] ATP. After incubation at
25 °C for 25 min, the samples were treated with SDS-sample buffer. After electrophoresis, the gel was stained with Coomassie Brilliant Blue and dried. The band patterns were analyzed using a bioimaging analyzer. The position of bMBD2/3 protein on a gel was identified by Coomassie Brilliant Blue staining. Protein kinase C was assayed by addition of phosphatidyl serine, and diolein. Ca/CaM dependent protein kinase II was assayed by addition of 1.2 µM calmodulin.

**Western blotting**

The recombinant protein was dialyzed against distilled water and freeze-dried. The protein was mixed with complete adjuvant and immunized into the rabbit. After boost injection, the serum was isolated. The antisera was subjected to immunoaffinity and immunized into the rabbit. After boost injection, the serum was isolated. The antiserum was subjected to immunoaffinity analyser. The position of bMBD2/3 protein on a gel was identified by Coomassie Brilliant Blue staining. Protein kinase C was assayed by addition of 1.2 µM calmodulin.

**Expression and purification of the recombinant protein**

To characterize bMBD2/3, cDNA for bMBD2/3 was expressed in *E. coli* and purified using affinity chromatography. The cDNA for bMBD2/3 was inserted into an expression vector pET32a and expressed in *E. coli* as a His-tagged thioredoxin fusion protein. The fusion protein recovered in the soluble fraction was bound by a Ni-superflow column. The fusion protein was eluted after washing. After dialysis, the fusion protein was cut to remove thioredoxin and the soluble fraction was recovered. This fraction was then applied to a heparin agarose. SDS–PAGE analysis showed that the purified protein was homogeneous (Figure 3). The evaluated molecular mass on SDS–PAGE was 26 kDa. About 0.1 mg protein was recovered from 10 liter culture of *E. coli*.

**EMSA of bMBD2/3**

Whether the purified bMBD2/3 specifically binds methyl DNA or not was examined. As shown in Figure 4, lane 5, and lane 6, bMBD2/3 did not bind non-methyl-DNA, but did bind to methyl-DNA (Figure 4, lane 1 and lane 2). The DNA binding was inhibited by methyl DNA, but not inhibited by non-methyl DNA (Figure 4, lane 3, and lane 4). This result indicates that bMBD2/3 specifically bound methyl DNA.

**Western blotting of bMBD2/3**

The availability of an antibody against dMBD2/3, which shows weak methyl DNA binding, was shown, but the identification of aMBD2/3 using immuno blotting, which shows a strong binding, was not done. To ascertain the distribution of bMBD2/3 in the tissues of *B. mori*, immunoblotting of several tissues was done using the purified antibody as the primary antibody (Figure 5). One band around 27 kDa was detected in almost all tissues examined including the brain and silk gland (lanes 4 and 8).

**Results and Discussion**

**Molecular cloning of bMBD2/3**

Multiple EST clones were identified by Blast search using the MBD2h sequence. One of the clones, bMBD2/3, originating from a Baculovirus-infected *Bombyx mori* fat body cDNA library was identified and sequenced (Figure 1). Its insert is 2.4 kbp long, including the poly A tail. The carboxyl terminal non-coding region was 1.5 kbp long. bMBD2/3 bears an open reading frame corresponding to aa 249. In insects, two MBDs (from *A. domesticus* [aMBD 2/3] and *D. melanogaster* [dMBD2/3]) were previously isolated and cloned. The expressed recombinant proteins were characterized (Ballestar et al. 2001; Roder et al. 2000; Tweedie et al. 1999). bMBD2/3 showed 67.6 and 53.7% similarity to aMBD2/3 and dMBD2/3, respectively. The methyl-CpG-binding domain of bMBD2/3 closely resembles that of aMBD 2/3 but differed from that of dMBD2/3 (Figure 2). However, the carboxyl-terminal domain was almost conserved among them. The carboxyl-domain is a transcripational repression domain, which changes the local chromatin structure, mainly through recruitment of histone deacetylase. bMBD was suggested to bind DNA and regulate the transcription of *B. mori*.

**Expression and purification of the recombinant protein**

To characterize bMBD2/3, cDNA for bMBD2/3 was expressed in *E. coli* and purified using affinity chromatography. The cDNA for bMBD2/3 was inserted into an expression vector pET32a and expressed in *E. coli* as a His–tagged thioredoxin fusion protein. The fusion protein recovered in the soluble fraction was bound by a Ni-superflow column. The fusion protein was eluted after washing. After dialysis, the fusion protein was cut to remove thioredoxin and the soluble fraction was recovered. This fraction was then applied to a heparin agarose. SDS–PAGE analysis showed that the purified protein was homogeneous (Figure 3). The evaluated molecular mass on SDS–PAGE was 26 kDa. About 0.1 mg protein was recovered from 10 liter culture of *E. coli*.
Figure 1. Nucleotide and deduced amino acids sequences of bMBD2/3. The nucleotide and predicted amino acid sequences of the cDNA clone encoding the protein, bMBD2/3 are shown.

Figure 2. Comparison of the deduced amino acid sequence of Bombyx mori bMBD2/3 with those of Drosophila melanogaster (dMBD2/3) and Acheta domesticus (aMBD2/3). Identical amino acids are indicated by asterisks. The methyl-CpG binding domain is highlighted in yellow.
methylation and the transcription of neuropeptides in the brain of *B. mori* because mammalian methyl DNA binding protein regulates the transcription of brain-derived neurotrophic factor (BDNF) (Chen et al. 2003).

**West-western blotting analysis using bMBD2/3**

In mammals, some functional proteins that interact with methyl DNA binding protein have been identified using a two hybrid system (Kokura et al. 2001; Screaton et al. 2003; Lembo et al. 2003). But there are no reports of such proteins in insects. We tried a west-western blotting analysis to determine if interacting proteins for bMBD2/3 exist in *B. mori*. In the mammalian brain, methyl DNA binding proteins play important roles in gene expression (Chen et al. 2003). So brain extracts were used as proteins to interact with bMBD2/3. As shown in Figure 6, 10 protein bands interacting with bMBD2/3 were detected. Their molecular weights were 25, 29.5, 30, 31, 33, 41, 46, 55, and 65, respectively. One protein band was detected around 27 kDa. This protein was suggested to be bMBD2/3 because western blotting showed the band at about 27 kDa (Figure 6, lane 2). These results suggest that proteins that interact with bMBD2/3 exist in the insect brain.

**Phosphorylation of bMBD2/3 in vitro**

DNA binding proteins such as nuclear receptors, are well known to be phosphorylated by protein kinase such as PKC, cdk/cyclin, MAPK and PKA (Rochette-Egly 2003). Phosphorylation changes DNA binding, ligand binding, recruitment of chromatin remodelers and modifiers to decompact repressive chromatin. Finally
Uno T, Nomura Y, Nakamura M, Nakao A, Tajima S, Kanamaru K, Yamagata H, Iwanaga Y. 2005. Expression, purification and characterization of methyl DNA binding protein from Bombyx mori. 8pp. Journal of Insect Science, 5:8, Available online: insectscience.org/5.8

Phosphorylations can regulate transcription positively or negatively. Recently, methyl DNA binding protein was reported to be phosphorylated by protein kinase (Sakai et al. 2002). MeCP2, which is abundantly expressed in the central nervous system, was phosphorylated by calcium-dependent protein kinase (Chen et al. 2003). We examined the phosphorylation of bMBD2/3 by protein kinase and brain extract in vitro. The brain extract from the B. mori exhibited protein kinase activity of bMBD2/3 (Figure 7, lane 5). Using mammalian protein kinase, PKC and CaM kinase phosphorylated bMBD2/3 (Figure 7; lanes 3 and 4).

What is the significance of the phosphorylation of bMBD2/3 in vitro? Phosphorylation may change the affinity for the methylated DNA and interactions with proteins. Phosphorylation of the DNA binding region may produce the release of bMBD2/3 from methylated-DNA and activate transcription. Actually, mammalian MeCP2 was phosphorylated in the brain and released from the promoter of BDNF. The determination of phosphorylated amino acid residues of bMBD2/3 must be determined. Further, in vivo phosphorylation of bMBD2/3 must be defined using radiolabeled insect brain.

MBD protein, except MBD4, interact to the various transcriptional regulatory protein such as histone deacetylase, ATPase, and DNA methyl transferase (Tatematsu et al. 2000; Brehm et al. 2000). Activated PKC was known to enter the nucleus from the cytosol and function. Phosphorylation of bMBD2/3 in the nucleus may change the interaction of these proteins. Regulatory proteins...
such as ATPase and deacetylase have been shown to be present in insects by enzymatic assays (Tweedie et al. 1999). As described above, bMBD2/3 was distributed in almost all tissues of adult B. mori (Figure 5) and some proteins that interact with bMBD2/3 in the insect tissues were detected using west-western blotting analysis (Figure 6). So it would be possible to identify and purify the regulatory proteins that interact with bMBD2/3 directly, using bMBD-bound affinity chromatography. Such information may clarify the relationship between the phosphorylated bMBD2/3 and the regulatory proteins.

Methylation of DNA has been reported in various insects. Insect MBD protein was reported to be only one type, although vertebrates have five types. The mammalian proteins each have specific characters. Mutations in MeCP2 are the cause of Rett syndrome, an X-linked progressive neurological disorder, and MeCP2 functions as a selective regulator of neuronal gene expression (Armstrong 1997; Chen et al. 2001). MDB3 plays an important role in embryo development and MDB2 influences some forms of behavior (Jung et al. 2003; Hendrich 2001). MDB4 regulates the removal of thymine or uracil from a mismatched CpG site (Hendrich et al. 2003). Recently, proteins that specifically interact with MBD were identified using a two hybrid system (Kokura et al. 2001; Screaton et al. 2003; Lembo et al. 2003). These interacting proteins probably determine the physiological specificity of MBD proteins as described above. Identification of interacting proteins with bMBD2/3 will help to clarify the physiological role of bMBD2/3 in the insect cell and discover new functions specific to insect MBD.

Acknowledgments

We thank Dr. Mita of National Institute of Entomological and Sericultural Science for providing cDNA clones of bMBD2/3.

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