



Molecular characterization, developmental expression and immunolocalization of clathrin heavy chain in the ovary of the American cockroach, *Periplaneta americana* during oogenesis

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Abstract: Clathrin is the principal protein involved in receptor mediated endocytosis and the main component of the coated vesicles. It is composed of three identical clathrin heavy chains (*CHC*), each with an attached light chain. We characterized the deduced amino acid sequence of the partial cDNA clone of the American cockroach, *Periplaneta americana* (*Pam*) *CHC*. The analysis showed that this sequence is represented as multiple alpha helical repeats occurred in the arm region of the *CHC* and displayed a high level of identity and similarity to mosquitoes and *Drosophila melanogaster* *CHCs*. This is the first report on *CHC* from a hemimetabolous insect. The amplified *CHC* probe could hybridize two *CHC* transcripts in the current preparations, 6.3 kb and 7.3 kb. The Northern blot analysis confirmed that a 6.3 kb transcript is specifically expressed in ovarian tissues at high levels throughout the ovarian development, especially in previtellogenic ovaries (Days 1-4) but dropped during the vitellogenic period (days 5-7) and ultimately no transcript was detected in fully vitellogenic ovaries (days 9-13). Immunoblot analysis detected an ovary specific *CHC* protein of ~175 kDa that was present in previtellogenic ovaries on the day of female emergence and after initiation of vitellogenesis and onset of *Vg* uptake. Immunocytochemistry localized *CHC* protein to germ-line derived cells, oocytes, and revealed that *CHC* translation begins very early during oocyte differentiation in the germarium. The present work suggested a possible role for clathrin in the early fluid phase endocytosis (pinocytosis) in addition to its role in receptor-mediated endocytosis.

Keywords: Clathrin, Receptor-mediated endocytosis, Vitellogenin, Insect oocyte, *Periplaneta americana*.

1. Introduction

Endocytosis is a carefully orchestrated process required by all cells for nutrition and defense. Through this process, massive amounts of the major extraovarian yolk protein precursors, vitellogenins (*Vgs*), are internalized by oviparous animals during egg maturation (1, 2). This uptake is achieved by a membrane bound receptor through receptor-mediated endocytosis (3). The principal cellular organelles involved in receptor mediated endocytosis are the coated vesicles (4). The major component of these specific organelles is clathrin, a unique protein occurring as a characteristic three legged structure (triskelions or

trimmers) which polymerizes into a polyhedral lattice on the cellular membrane (5). Clathrin trimmers are composed of three identical clathrin heavy chains (*CHC*), each with an attached light chain. These triskelions associate with membrane receptor-ligand complexes through adaptor proteins or adaptins (6). The detailed molecular characterization of the major components of coated vesicles is of great importance for understanding the cellular transport machinery in eukaryotes.

In insects, the process of yolk protein uptake by developing oocytes has been the subject of early and intensive research, especially in holometabolous species, like mosquitoes (3, 7, 8) and *Drosophila*

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melanogaster (9, 2). Conversely, studies based on less modified hemimetabolous species, like cockroaches in which ovaries are of panoistic type (no nurse cells associated with oocytes), are scarcer.

So far, complete cDNA for *CHC* has been cloned from four insect species: *Culex quinquefasciatus*, *Aedes aegypti* (10, 11), GenBank accession numbers: XM001864895 and XM001656826.1, respectively, *Drosophila melanogaster* (accession no.: Z14133.1). However, only a partial cDNA clone sequence for the American cockroach, *Periplaneta americana* is available in the GenBank database under the accession number: GQ887261.1.

In an attempt to characterize all the structural elements of the American cockroach, *P. americana* (*Pam*) *Vgs* transport machinery, two major components of the coated vesicles, the ligand-vitellogenin and its receptor (*VgR*), were previously cloned and characterized at both biochemical and molecular levels, including developmental expression, localization and sequencing analysis (12, 13, 14, 15, 16, 17). In this study, we address the molecular characterization of the database available partial *Pam CHC*, the most basal insect *CHC* yet examined, and show its comparison to other insects *CHCs*. Based on this analysis, we described the expression pattern, developmental characteristics and cellular distribution of *Pam CHC* during oogenesis in *P. americana*.

2. Materials and Methods

2.1 Insect rearing and sample collection

P. americana stock cultures were maintained in the laboratory as described elsewhere (17). Newly emerged females were collected from the stock colonies, kept separately under constant light conditions at 26°C and used when required. Ovaries, at different developmental periods, were isolated in phosphate buffered saline (1x PBS: 2mM KH₂PO₄, 137mM NaCl, 10mM Na₂HPO₄, 2.7mM KCl, pH 7.4), fixed or frozen immediately in liquid nitrogen and stored at -80°C, until required.

2.2 Poly (A⁺) RNA extraction and cDNA construction

Total RNA was extracted from previtellogenic ovaries using Isogen reagent (Nacalai Tesque, Kyoto, Japan) according to the manufacturer's instructions. Then, mRNA was purified from pooled total RNA using mRNA purification kit (Amersham-Pharmacia, Piscataway, NJ, USA). A total of 1.5µg of mRNA was used to generate ds cDNA using *Avian myeloblastosis* virus reverse transcriptase (20 units) and an oligo (dT) primer [a cDNA synthesis primer (10 IM)] with the dNTP mixture (10mM) from the Marathon cDNA amplification kit (Clontech, Palo Alto, CA, USA). For second strand synthesis, a 20x second strand enzyme cocktail (RNase H, *Escherichia coli* DNA polymerase I and *E. coli* DNA ligase) was used. The ds cDNA

constructed library was then used as a template for PCR.

2.3 Cloning of *CHC* probe

The cDNA prepared from female *P. americana* previtellogenic ovaries and two specific primers based on the partial cDNA sequence of *P. americana CHC*, available in the GenBank database under the accession number: GQ887261.1, were used to amplify approximately 218 bp of *Pam CHC* fragment (position: 543 – 761). Briefly, the designed specific primers were as follows: Forward primer 5'-ATTTCAAGGGGCAGTTGATG-3' (position: 543 – 562), and reverse primer 5'-AAACCTAGTGCTGCCTCCAA-3' (position: 742 – 761). The employed amplification conditions were heated to 94°C for 2 min, followed by 30 cycles of 94°C for 30 s, 59°C for 30 s, and 72°C for 2 min. The amplified fragment (~ 218 bp) was subcloned into pT7Blue vector (Novagen) and sequenced. Sequencing was performed by using an ABI Prism BigDye terminator cycle sequencing ready reaction kit (PE Applied Biosystems, Foster City, CA, USA) and a DNA sequence (ABI, Prism 3100 Genetic Analyzer, PE Applied Biosystems). The obtained sequence was checked for homology with the available sequence in the GenBank database for *P. americana CHC* using a BLAST homology search of the NCBI database. Sequence comparisons with other insects *CHCs* were performed using the CLUSTALW program and the GENETYX Ver. 5.1 program (Genetex Corporation, Tokyo, Japan).

2.4 Northern blot hybridization analysis

For the developmental expression profile assay, ovaries from 1 to 13 days post emergence adults female were used. Aliquots of 15µg of total RNA from ovaries were subjected to electrophoresis using 1% agarose / 0.66M formaldehyde gel in 3-morpholino-propanesulfonic acid (MOPS) buffer. The resolved RNAs were transferred to a Hybond N⁺ membrane (Amersham Pharmacia) through capillary transfer. The blots were then hybridized with the *Pam CHC* (PCR amplified) probe (Fig. 1) which was then fluorescein-labeled using a Gene Images Random Prime Labeling Module (Amersham Pharmacia), according to the kit instruction manual. The probe was hybridized based on the protocol from Hybond N⁺ (Amersham).

Briefly, the membranes was blocked for 30 min at the 68°C using Express-HybTM Hybridization solution (Clontech) and then probed for 1 h at 68°C, followed by repeated washes in 2x sodium chloride–sodium citrate in water (SSC) at 68°C and 0.1x SSC – 0.1% SDS at 55°C. The hybridization blots were visualized and analyzed by BAS 2000 (Fuji Photo Film, Tokyo, Japan). Samples were qualitatively normalized by determining ribosomal RNAs after staining with ethidium bromide.

AedesCHC	DHRNLQNLILITAIKADRSVMDYINRLDNYDPADPIANIAINNELYEEAFAI FKKFDVNT	1080
CulexCHC	DHRNLQNLILITAIKADRSVMDYINRLDNYDPADPIANIAINNELYEEAFAI FKKFDVNT	1067
PamCHC	-----ANIANNQLYEEAFAI FKKFDVNT	24
DmCHC	DHRNLQNLILITAIKADRTRVMDYINRLNYPADPIANIAISNQLYEEAFAI FKKFDVNT	1080
	*****,* , *****	
AedesCHC	SAIQVLIEQVHNLERANEFAERCNEPAVWSQLARAQLQQGLVKEAIDS YIKADDFSA YMD	1140
CulexCHC	SAIQVLIEQVHNLERANEFAERCNEPAVWSQLARAQLQQGLVKEAIDS YIKADDFSA YID	1127
PamCHC	SAIQVLIDNVNNLDRA YEFAERCNEPAVWSQLAKAQLQQGLVKEAIDSF IKA DDFSAYID	84
DmCHC	SAIQVLIDQVNNLERANEFAERCNEPAVWSQLAKAQLQQGLVKEAIDS YIKADDFSA YVD	1140
	* : ***** : ***** : ***** * *, * : ; *****	
AedesCHC	VVETASKNESWEDLVRYLQMARRKARESYIESELIYAARTGR LADLEEFVSGPNHADI Q	1200
CulexCHC	VVETASKNESWEDLVRYLQMARRKARESYIESELIYAARTGR LADLEEFVSGPNHADI Q	1187
PamCHC	VVETAHKTESWEDLVRYLQMARRKARESYIESELIYAARTNR LADLEEFVSGPNHADI Q	144
DmCHC	VVDVASKVESWDDLVRYLQMARRKARESYIESELIYAARTGR LADLEEFISGPNHADI Q	1200
	***** : ***** , ***** : ***** : * * * * *	
AedesCHC	KIGDRCFNDKMYYEAAKLLYNVSNFARLAITLVHLKE FQGAVDGARKANSTRTWKEVCFA	1260
CulexCHC	KIGDRCFNDKMYYEAAKLLYNVSNFARLAITLVHLKE FQGAVDGARKANSTRTWKEVCFA	1247
PamCHC	KIGDRCFDDGMYYDAKLLYNVSNFARLAITLVHLKE FQGAVDGARKANSTRTWKEVCFA	204
DmCHC	KIGNRCFSYDGMYYDAKLLYNVSNFARLAITLVHLKE FQGAVDSARKANSTRTWKEVCFA	1260
	***** : ***** , ***** : ***** : * * * . * * : * *	
AedesCHC	CVDAEEFRLAQMCGLHIVVHADELEDLITYYQDRGHFEELIGLLEAALGLERAHMGMFTE	1320
CulexCHC	CVDAEEFRLAQMCGLHIVVHADELEDLITYYQDRGHFEELIGLLEAALGLERAHMGMFTE	1307
PamCHC	CVDSEEFRLAQMCGLHIVVHADELEDLINYYQDRGYFEELINLLEAALGLERAHMGMFTE	264
DmCHC	CVDAEEFRLAQMCGLHIVVHADELEDLINYYQNRGYFDELIALLESALGLERAHMGMFTE	1320
	***** : ***** : * * * * * , * * * , * * * , * * * , * * * , * * * , * * *	
AedesCHC	LAILYSKYPAKMRHELELFWSRVNI PKVLRAAEQAHLWSELVF LYDKYEEYDNAVLAMM	1380
CulexCHC	LAILYSKYPAKMRHELELFWSRVNI PKVLRAAEQAHLWSELVF LYDKYEEYDNAVLAMM	1367
PamCHC	LAILYSKYPAKMRHELELFWSRVNI PKVLRAAEQAHLWAELVFL-----	309
DmCHC	LAILYSKFKP SKMRHELELFWSRVNI PKVLRAESAHLWSELVF LYDKYEEYDNAVLAMM	1380
	***** : ***** : ***** : ***** : ***** : *****	

2.5 Immunoblot analysis

agitation, with rabbit anti-Clathrin heavy chain antibody (CHC), (a kind gift from Prof. Dr. Alexander Raikhel, Department of Entomology, University of California, Riverside, CA, USA), diluted 1: 15.000 in 1% bovine serum albumin "BSA" (Nacalai) in TBST (B-TBST), followed by incubation for 1 h at RT with donkey anti-rabbit IgG HRP-conjugated secondary antibody (Amersham), diluted 1: 50.000 in B-TBST. The immune complexes were detected using the ECL plus detection system (Amersham) and exposed to Autoradiographic Hyperfilm ECL (Amersham).

2.6 Immunocytochemistry

The dissected ovaries were fixed overnight at 4°C in a modified Bouin-Holland solution supplemented with 0.7% mercuric chloride and without acetic acid, then dehydrated and embedded in paraffin. Sections 9µm thick were cut, mounted on poly-L-lysine-coated slides, deparaffinized and rehydrated. The sections were then treated with Lugol's iodine followed by a 7.5% solution of sodium thiosulphate to remove heavy metal ions and washed with distilled water and Tris-buffered saline (pH 7.6), containing 0.3% Tween 20 (TBST) for 5 min each. Sections were blocked with 5% normal goat serum in TBST for 30 min at RT, and incubated with rabbit anti-CHC, diluted 1:2000 in blocking

serum, in a humidified chamber overnight at 4°C. In control experiments, the primary antibody was replaced with preimmune rabbit serum. After rinsing with TBST (3x10 min) at RT, the sections were first incubated with a biotinylated secondary antibody (rabbit IgG-Vectastain Elite ABC kit, Vector Laboratories, Burlingame, CA), diluted at 1:200 in blocking serum for 1 h at RT, rinsed again with TBST (3x10 min), and then treated with a horseradish peroxidase (HRP) labelled avidin-biotin complex (diluted in TBST) for 50 min at RT. After incubation, sections were thoroughly washed with TBST (3x10 min) and with 0.05 M Tris-HCl, pH 7.5 (1x10 min). The peroxidase activity was finally revealed by using hydrogen peroxide (0.005%) and 3,3'-diaminobenzidine tetrahydrochloride (DAB, 0.25mM in 0.05 M Tris-HCl, pH 5.5) as a chromogen. Stained sections were dehydrated, mounted in a Biolet mounting medium (Kouken Rika, Osaka, Japan).

The stained sections were all examined under a DX50 microscope (Olympus, Melville, NY) equipped with Nomarski (differential interference contrast), and photographed with a charge-coupled device camera (Olympus).

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      10      20      30      40      50      60
atttcaagggcgagtgatggtgctagaagagcgaacacacggacatggaaggaggtt
  F  Q  G  A  V  D  G  A  R  K  A  N  S  T  R  T  W  K  E  V

      70      80      90      100     110     120
tgotttgcgtggtggacagcgaagaggttcogtctggcccaaatgtgtgaccttcacatt
  C  F  A  C  V  D  S  E  E  F  R  L  A  Q  M  C  G  L  H  I

      130     140     150     160     170     180
gtagtacacgcagatgaattagaagacctaatattattaycaggatcgaggatatttt
  V  V  H  A  D  E  L  E  D  L  I  N  Y  X  Q  D  R  G  Y  F

      190     200     210     220
gaagaactgatcaatttgttgaggcagcactaggttt
  E  E  L  I  N  L  L  E  A  A  L  G

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Fig. 1(B). Nucleotide sequence (lower case letters) and deduced amino acids (upper case letters) of *Pam CHC* PCR amplified fragment which used as probes for Northern blot analysis. Primers positions are underlined.

3. Results and Discussion

3.1 Sequence analysis and alignment

Analysis of the deduced amino acid of the partial sequence of *Pam CHC* (obtained from the GenBank database, accession no.: GQ887261.1) shows that this sequence is represented as multiple alpha helical repeats occurred in the arm region of the clathrin heavy chain. The deduced amino acid sequence of *Pam CHC* displayed a high level of identity and similarity to mosquitoes and *Drosophila melanogaster* *CHCs*. The *Pam CHC* was 93% identical to *Aedes aegypti* (*Aa*), 94% identical to *Culex quinquefasciatus*, and 92% identical to *Drosophila melanogaster* *CHCs*. Alignment of these sequences revealed that this region of the *Pam CHC* peptide is highly conserved in all analyzed species

(Fig. 1A). In all insect species, so far studied, the level of conservation in the middle portion of *CHC* was found to be higher than that of the sequence as a whole. This evolutionary conservation possibly reflects the importance of this region in forming the three-dimensional triskelion (19). These obtained results enabled us to confidently amplify the probe for *Pam CHC* expression analysis from this region (Fig. 1B).

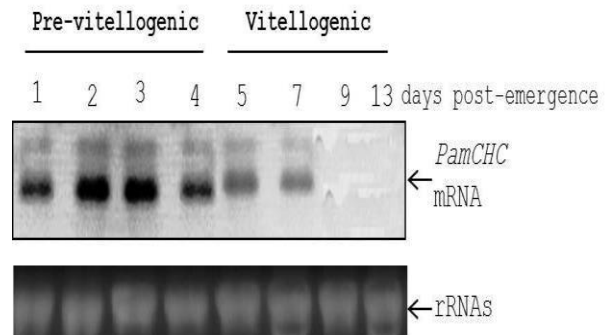


Fig. 2. Developmental expression patterns of *Pam CHC* in the ovary of adult female *P. Americana* during vitellogenic period. Northern blot analyses were performed on total RNA extracted from above-mentioned developmental periods. The transcript signals were probed with fluorescein-labeled cDNA fragments of *Pam CHC* (see Materials and Methods). Ovarian *Pam CHC* transcript (~6.3 kb) is marked by an arrow; the upper band (~7.3 kb) might represent another isoform of *CHC*. Ribosomal RNAs (rRNAs, bottom panel) are shown as internal controls after staining with ethidium bromide. This result is a representative of two to three replicates.

3.2 Developmental expression pattern of *Pam CHC* gene transcript

In order to determine the developmental profile of *Pam CHC* transcript, Northern blot analysis was performed with total RNA extracted from the ovaries during different periods of egg development. The Northern blotting analysis, using a 218bp PCR amplified fragment (Fig. 1A) as a probe demonstrated two transcripts in the current preparations, 6.3 kb and 7.3 kb (Fig. 2). However, the 7.3 kb transcript is much lower than that of 6.3 kb transcript but it follows the same kinetics. Accordingly, the detected 6.3 kb transcript is considered as an (abundant) ovarian-specific *Pam CHC* transcript. Similarly, two *CHC* transcripts were detected in mosquito: 6.5 kb of the mosquito *Aa CHC* transcript was determined to be an ovarian specific transcript, expressed only in oocytes and nurse cells, whereas 7.5 kb *Aa CHC* transcript expressed in the somatic tissues of both sexes (10). The *Pam CHC* ovarian specific transcript was pronounced in the previtellogenic period (days 1-4) but dropped during the vitellogenic period (days 5-7) and ultimately no transcript was detected in fully vitellogenic ovaries (days 9-13). This is in contrast to *Aa CHC* where the transcript level started to increase dramatically from 1 day to 3 days after eclosion and increased further after the onset of vitellogenic periods, reaching its peak by

12h post blood meal (PBM), then decreased considerably by 24h PBM when the endocytotic activity is at its peak (20,11). Recently, (15) reported that the transcription level of *P. americana* *VgR* gene was pronounced in immature female ovaries of final instar nymphs and in the early previtellogenic period (day 1-2). Thus, it appears that genes coding for receptor-mediated endocytosis are specifically expressed at high levels in the early stages of the ovarian development.

3.3 Developmental profile and cellular distribution of *Pam CHC* protein

In order to analyze the developmental profile of *Pam CHC* protein synthesis, extracts prepared from female ovaries during different stages of development were separated by 10% SDS-PAGE and assayed using an immunoblot analysis (Fig. 3). Consistent with our obtained results from Northern blot analysis, *Pam CHC* protein was detected with an apparent molecular weight of ~175 kDa in ovarian tissues. The *Pam CHC* protein was detected throughout the ovarian developmental periods. However, its level was dramatically higher on days 2 of previtellogenic period and then days 4, 5 of late previtellogenic and early vitellogenic periods. Similarly, *P. americana* *VgR* protein was also observed early, on the day of adult female emergence. However, *Vg* uptake occurred on day 5, one day after *Vg* first appeared in the haemolymph (15). Together, both *VgR* and *CHC* proteins are produced in the ovary of *P. americana* long before vitellogenesis begins.

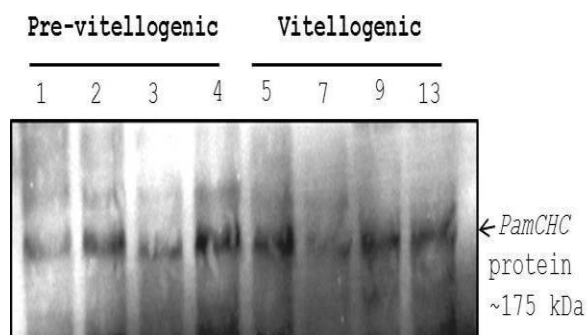


Fig. 3. Developmental expression profile of *Pam CHC* protein in *P. americana* ovaries as revealed by immunoblot analysis. Protein extracts (10µg/ lane) from female adult ovaries at indicated times were separated by 10% SDS-PAGE, electroblotted to Immobilon-P membranes and probed with anti-*CHC* antibody. Arrow on the right indicates the molecular weight (kDa) of the identified *Pam CHC*.

Next, the *Pam CHC* protein was detected by immunocytochemical techniques in the germline cells (oocytes) of the germarium (Fig. 4A). Surprisingly, in early and late previtellogenic ovaries, the *Pam CHC* protein was found to be accumulated primarily in the oocyte cortex adjacent to the follicular epithelium (Fig. 4B-D). No *Pam CHC* protein signal was observed in controls immunostained with preimmune rabbit serum

(Fig. 4E). In contrast, previous immune cytochemical study with *P. americana* *VgR* revealed that *VgR* protein was found to be distributed throughout the oocytes of early previtellogenic ovaries then accumulated in cortex adjacent to the follicular epithelium only in late previtellogenic ovaries (15). Together, our obtained immunocytochemical results suggest a possible role for clathrin in the early fluid phase endocytosis (pinocytosis) in addition to its role in receptor-mediated (*Vg/VgR* complex) endocytosis.

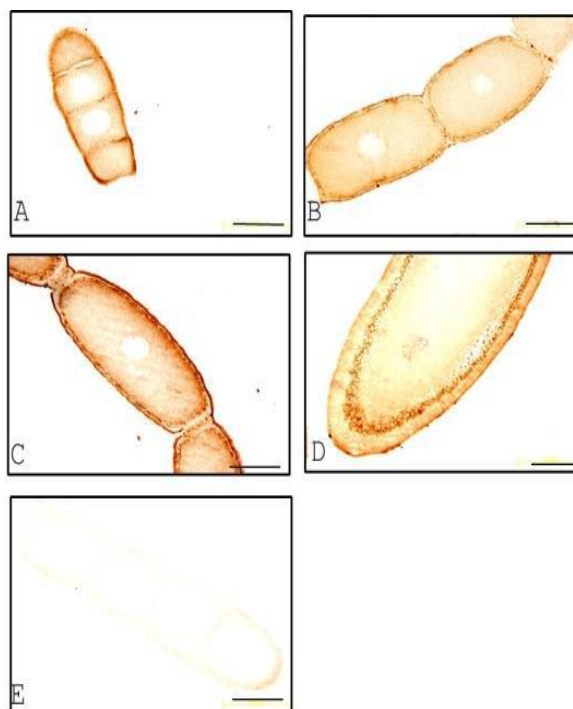


Fig. 4. Immunocytochemical localization of the *Pam CHC* protein in *P. americana* ovariole using 3, 3'-diaminobenzidine tetrahydrochloride (DAB) staining. Immunostaining with *CHC* antibody shows that the *Pam CHC* protein is expressed at high levels in germ-line cells and is also detected in the germarium (A). *Pam CHC* protein is accumulated primarily in the oocyte cortex of the primary oocytes (B-C) and in secondary oocytes (D) just before the start of vitellogenesis. The control immunostained with preimmune rabbit serum (E). Scale bars = 100µm.

4. Conclusion

Two *CHC* transcripts were detected in the American cockroach, *P. americana* during oogenesis, an ovarian specific transcript and the other might be of somatic one, suggesting that *CHC* gene might be represented by two isoforms in this cockroach. However, this suggestion will need further investigation to be confirmed. Both *Pam CHC* transcript and protein are expressed at high levels in the early stages of the ovarian development. Accordingly, a possible role for *Pam CHC* in the early fluid phase endocytosis (pinocytosis) in addition to its role in the receptor-mediated (*Vg/VgR* complex) endocytosis was suggested.

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