



Full Length Article

Contribution of PPAR γ in Modulation of LPS-Induced Reduction of Milk Lipid Synthesis in Bovine Mammary Epithelial Cells

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Abstract

Lipid content of milk is recognized as an indicator of milk quality. Lipopolysaccharides (LPS)-induced milk fat depression has also been observed in lactating dairy cows. However, it is not completely clear how the LPS regulate the milk lipid synthesis? Our objective was to examine the molecular mechanism in bovine mammary epithelial cells (bMEC). The bMEC were treated with oleic acid to induce milk lipid synthesis. The intracellular triglyceride in bMEC layer and the secreted triglyceride in culture medium were detected by enzymatic colorimetric assay. The expression and activity of the peroxisome proliferator-activated receptor gamma (PPAR γ), the expression of the *FASN* (fatty acid synthetase), *ACACA* (acetyl-CoA carboxylase-1), *ACBP* (acyl-CoA-binding protein), and *LPL* (lipoprotein lipase) were investigated. The results showed that LPS decreased the level of lipid synthesis via down-regulating the transcription, translation, and nuclear translocation level of the PPAR γ . The results also indicated that the transcription level of the PPAR γ target genes, *FASN*, *ACACA*, *ACBP*, and *LPL* were significantly down-regulated in bMEC after LPS treatment. These results indicate that PPAR γ participate in LPS-induced reduction of milk lipid synthesis in bMEC. Our data may provide new insight into the mechanisms of milk fat depression caused by LPS. © 2019 Friends Science Publishers

Keywords: Dairy cow; Milk lipid synthesis; Lipopolysaccharides; Peroxisome proliferator-activated receptor gamma; Mammary epithelial cells

Introduction

Peroxisome proliferator-activated receptor gamma (PPAR γ) plays an important role in lipid homeostasis, insulin sensitivity, and inflammation (Kawai and Rosen, 2010). Expression of PPAR γ and the PPAR γ coactivator 1, increases 2.5- and 3-fold in bovine mammary gland of lactating animals (Bionaz and Loores, 2008). PPAR γ is putative transcription factor controlling the network of lipogenic genes. Kadegowda *et al.* (2009) reported that PPAR γ in bovine mammary cells up regulate the mRNA expression of PPAR γ lipogenic target genes, such as *FASN* (fatty acid synthetase), *ACACA* (acetyl-CoA carboxylase-1), and *SCD* (stearoylcoenzyme A desaturase). Kadegowda *et al.* (2009) also reported that PPAR is activated by palmitate and stearate in bovine MacT cells. Palmitic acid and acetic acid could induce milk lipid synthesis and markedly upregulate the transcription of PPAR γ , *FASN*, *ACACA*, and *ACD* in bovine mammary epithelial cells (bMEC) (Liu *et al.*, 2016). These evidence support PPAR γ likely being the central regulatory point for milk fat synthesis.

Milk fat depression (MDF) is indicated by a decrease in milk fat by 0.2% or more (McCarthy *et al.*, 2018). Lipopolysaccharides (LPS) are the major component of the outer membrane of Gram-negative bacteria. The concentrations of rumen lipopolysaccharides showed a strong negative relationship with milk fat content (Zebeli and Ametaj, 2009). LPS could induce milk fat depression by decreasing the plasma non esterified fatty acid (NEFA) and lipoprotein lipase (LPL) expression and activity (Yoon, 2014). Elevated interleukin 1 beta (IL-1 β) level in mammary gland was observed in LPS-induced mastitis (Miao *et al.*, 2012). Matsunaga *et al.* (2018) found that IL-1 β could inhibit milk lipid synthesis in bMEC via activation of signal transducer and activator of transcription (STAT) 3 and inactivation of STAT5. Besides above pathways, it is not completely clear how the LPS regulate the milk lipid synthesis in bMEC? We hypothesize that PPAR γ may be a key factor in LPS-induced the decrease of milk lipid synthesis in bMEC. In the current study, we analyzed the change of PPAR γ pathway after LPS challenge to elucidate the mechanisms of LPS regulates the milk lipid synthesis in bMEC.

Materials and Methods

Cell Culture

Several immortalized bovine mammary epithelial cell lines have been established, such as hormone-adapted bovine mammary epithelial cell line (BMEC+H), immortalized bovine mammary cell line with both epithelial and myoepithelial characteristics (ET-C), and immortalized bovine mammary alveolar cells (Mac-T) (Hosseini *et al.*, 2013). However, these cell lines cannot synthesize milk lipids efficiently. In the present study, fibroblasts-free bMEC culture was obtained by differential trypsinization according to previous study (Xu *et al.*, 2017). The percentage of cytokeratin 18 (CK 18)-positive cells was calculated using flow cytometry according to previous study (Smalley, 2010). Primary antibody used in this study was mouse anti-CK 18 monoclonal antibody (1:1000; Abcam, Cambridge, C.A., U.S.A.). Secondary antibody used in this study was fluorescein isothiocyanate (FITC)-conjugated goat anti-mouse IgG (1:500; Abcam, Cambridge, C.A., U.S.A.). The bMEC were treated with oleic acid to induce milk lipid synthesis. BODIPY (493/503, Invitrogen, Carlsbad, C.A., U.S.A.) was used to visualize milk fat in bMEC according to previous study (Spangenburg *et al.*, 2011).

Cell Treatment

LPS (Sigma-Aldrich, St. Louis, M.O., U.S.A.) was added to the medium in 6-well culture plate at the 10 μ g/ml concentration during 0–48 h. The culture medium and cell layer were collected to analyze the level of milk lipid and the activity of PPAR γ pathway after LPS challenge.

Measurement of Triglyceride (TG)

The intracellular TG in bMEC layer and the secreted TG in culture medium were detected by enzymatic colorimetric assay using the TG assay kit (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) according to the manufacturer's protocol.

RT-PCR

FASN, *ACACA*, *ACBP* (acyl-CoA-binding protein), and *LPL* (lipoprotein lipase) are PPAR γ target genes. These genes play vital role in regulating milk lipid synthesis. Therefore, the mRNA level of *FASN*, *ACACA*, *ACBP*, *LPL* and *PPARG* genes were evaluated by quantitative RT-PCR. Total RNA from bMEC layer was extracted with TRIzol reagent (Sigma-Aldrich). High-quality RNA samples were reverse-transcribed to cDNA using a reverse-transcription kit (TaKaRa, Kyoto, Japan). The mRNA expression level was evaluated using a SYBR Green PCR Kit (TaKaRa). Quantitative RT-PCR was conducted on a real-time PCR analyzer (Bio-Rad, Hercules, CA, USA). The relative

expression level of genes was calculated by normalizing to *GAPDH* (Glyceraldehyde 3-phosphate dehydrogenase) using the $2^{-\Delta\Delta CT}$ method (Taylor *et al.*, 2010). Primer sequences used in the study were listed in Table 1.

Western Blotting

The translation level of PPAR γ in bMEC was performed as Western blotting protocol. Cells were lysed with a lysis buffer. Then, the protein concentration was determined by the method of Bradford (Biyotime, Shanghai, China). The protein samples were mixed in 1:1 ratio with the SDS-polyacrylamide gel standard loading buffer. Samples were run on 12% Tris-Glycine precast gel (BeyoGel™ SDS-PAGE Precast Gel) in SDS-PAGE running buffer. After protein transfer, PVDF membranes were blocked by incubation with blocking buffer. The rabbit anti-PPAR γ polyclonal antibody (1:1000; Abcam) and rabbit anti- β -actin polyclonal antibody (1:2000, Bioss, Beijing, China) were used as primary antibodies. HRP-labeled goat anti-rabbit IgG (1:500; Abcam) were used as secondary antibody. The immunoreactive bands were detected using ECL Western Blotting Substrate (Solarbio, Beijing, China). The images of the protein bands were obtained with a Bio-Rad ChemiDoc™ XRS+ (Bio-Rad).

Immunostaining

Nuclear translocation for PPAR γ in bMEC was performed as immunofluorescence staining protocol. Briefly, coverslips were incubated for 1 h with rabbit anti-PPAR γ polyclonal antibody (1:1000; Abcam), followed by 1h with alexa fluor 488-labeled goat anti-rabbit IgG (1:500; Abcam). Nuclei were stained with DAPI (Sigma-Aldrich) for 1 min after removal of secondary antibodies. Finally, the coverslips were observed and photographed using a confocal laser-scanning microscope (Leica, Mannheim, Germany).

Statistical Analysis

The results were expressed as the mean $\pm$ standard deviation and were analyzed using S.P.S.S. 19.0 software (S.P.S.S., IBM, Armonk, NY, USA). The differences were considered significant at *P*-values of < 0.05 and highly significant at *P*-values of < 0.01.

Results

Cell Culture Results

As shown in Fig. 1, purified bMEC with epithelial-like shape were typically observed (Fig. 1A). The flow cytometry data showed that the ratio of CK18-positive cells is 99.04% (Fig. 1B). In addition, intracellular lipid droplets fluorescence staining result (yellow; Fig. 1C) showed that oleic acid could induce high lipid production ability of

Table1: Primer sequences used in the study

Gene name	Sequence	GenBank Accession No.	Length (bp)
<i>FASN</i>	F: GTGGGCTTGGTGAAGTGTCT R: AGGACTTCGGGTCTGTCTCA	NM_001012669.1	112
<i>ACACA</i>	F: AACGCAGGCATCAGAAGATT R: CGCACTCACATAACCAACCA	NM_174224.2	119
<i>ACBP</i>	F: AAGACCAAGCCAGCAGATGA R: GTCCCTTTCAGTTCATTCCA	NM_001113321.1	146
<i>LPL</i>	F: ACATTGCCCACCTCATTCCT R: TACATTCTGTACCGTCCA	NM_001075120.1	109
<i>PPARG</i>	F: GCATTTCCACTCCGCACTAT R: ACAGGCTCCACTTTGATTGC	NM_181024.2	118
<i>GAPDH</i>	F: GGCATCGTGGAGGGACTTATG R: GCCAGTGAGCTTCCCGTTGAG	NM_001034034.2	171

bMEC. These results suggest that the bMEC culture model is suitable for investigating the milk lipid synthesis function.

TG Synthesis and Secretion

As shown in Fig. 2, LPS could decrease milk lipid synthesis and secretion in bMEC. Total TG content at 1, 3, 6, 12, 24, and 48 h after LPS treatment was 0.90-, 0.72-, 0.57-, 0.38-, 0.49-, and 0.52-fold lower than the control, respectively.

PPAR γ Expression and Activity

The transcription, translation, and translocation of PPAR γ were detected in this study. As shown in Fig. 3, the transcription level (Fig. 3A) and translation level (Fig. 3B and 3C) of PPAR γ were down-regulated in bMEC treated with LPS. The transcription level of PPAR γ at 6 h after LPS treatment was 6.3-fold lower than the control ($P < 0.01$). The translation level of PPAR γ at 48 h after LPS treatment was 4.6-fold lower than the control ($P < 0.01$). Consistent with the above results, LPS could inhibit the translocation of PPAR γ from the cytoplasm to the nucleus (Fig. 3D). These results suggest that LPS could inhibit the expression level and activity of PPAR γ in bMEC.

PPAR γ Target Genes Transcription Level

ACBP, *LPL*, *FASN*, and *ACACA* gene are PPAR γ target genes. These genes play vital role in regulating milk fat synthesis in bovine mammary gland. Therefore, the mRNA level of *ACBP*, *LPL*, *FASN*, and *ACACA* genes were evaluated by quantitative RT-PCR. As shown in Fig. 4, LPS could inhibit the transcription of *ACBP*, *LPL*, *FASN*, and *ACACA* genes in a time-dependent manner. The transcription level of *ACBP* at 24 h after LPS treatment was 3.0-fold lower than the control ($P < 0.01$). The transcription level of *LPL* at 48 h after LPS treatment was 5.3-fold lower than the control ($P < 0.01$). The transcription level of *FASN* at 24 h after LPS treatment was 4.1-fold lower than the control ($P < 0.01$). The transcription level of *ACACA* at 12 h after LPS treatment was 2.9-fold lower than the control ($P < 0.01$). These results

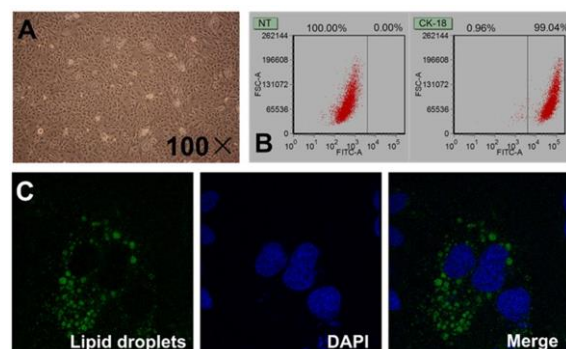


Fig. 1: Characterization of the bMECs. **A:** Morphology of the purified bMECs (100 $\times$). **B:** Flow cytometry analysis of CK-18 positive cells. **C:** The result of BODIPY staining of lipid droplets (yellow) in the bMECs (400 $\times$)

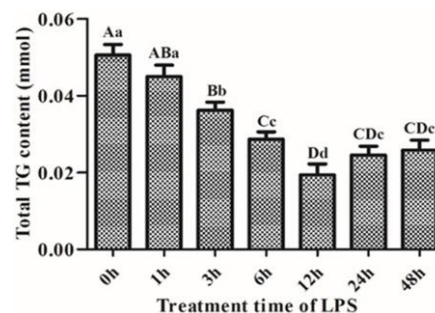


Fig. 2: LPS decreases TG content in the bMECs in a time-dependent manner. The data with different capital letters between two groups showed very significant differences ($P < 0.01$); data with different lower-case letters between two groups showed significant differences ($P < 0.05$); data with the same letters between two groups showed no significant differences ($P > 0.05$)

suggest that LPS could inhibit the uptake of long-chain (predominantly C₁₈) fatty acids and *de novo* synthesis (from C₄ to C₁₄) of fatty acids in bMEC.

Discussion

As a major component in milk, lipids in milk supply calories required for calves and infants (Rudolph *et al.*,

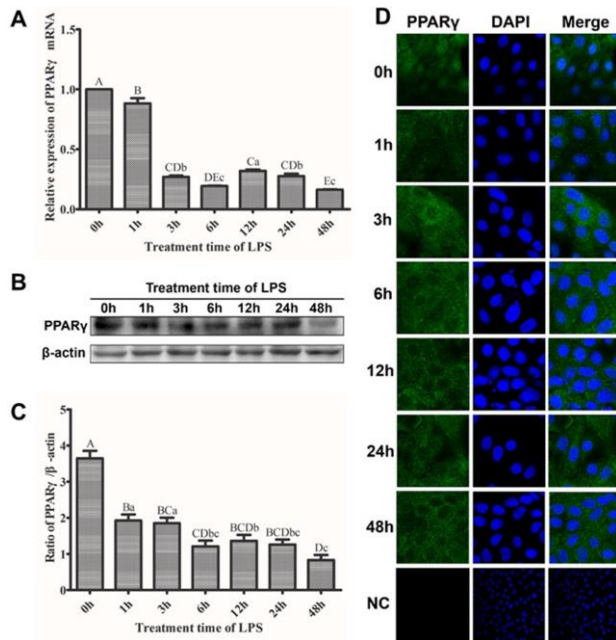


Fig. 3: LPS inhibits the transcription, translation and translocation of PPAR γ in the bMECs. **A:** The relative transcription level of PPAR γ gene. **B:** The western blotting result of PPAR γ . **C:** The relative expression level of PPAR γ . **D:** The nuclear translocation of PPAR γ (green) in bMECs (400 $\times$). The data with different capital letters between two groups showed very significant differences ($P < 0.01$); data with different lower-case letters between two groups showed significant differences ($P < 0.05$); data with the same letters between two groups showed no significant differences ($P > 0.05$).

2006). Milk fat depression have major economic impact in the dairy industry. Milk fat arise from two sources: the *de novo* fatty acids synthesis in mammary gland and the uptake of long-chain fatty acids from circulation (Rudolph *et al.*, 2007). Numerous lipogenic enzymes (*i.e.*, FASN, ACACA, LPL, ACBP, and CD36) are involved in the biosynthesis of milk lipids (Bionaz and Loor, 2008). Evidents suggests that PPAR γ is associated with milk fat synthesis (Bionaz and Loor, 2008; Kawaiand and Rosen, 2010; Ma, 2012). LPS could induce milk fat depression via regulating the body and blood fat metabolism. However, the specific roles and the mechanisms of PPAR γ in regulating LPS-induced reduction of milk lipid biosynthesis are still unknown.

PPARs are ligand-activated transcription factors, including α , δ , and γ . The three subtypes of PPAR alter lipid metabolism in different ways. PPAR γ play vital role in adipocyte differentiation, and fatty acids synthesis (Kawaiand and Roser, 2010). Peroxisome proliferators (including herbicides, leukotriene antagonists, plasticizers, and hypolipidemic drugs) can activate PPAR (Ma, 2012). Furthermore, Bionaz *et al.* (2012) found that long-chain fatty acids activate PPAR and its target genes participate in regulating lipid metabolism in bovine kidney cells. Activated PPAR γ can coordinate up-regulation of lipogenic gene networks in bMEC (Bionaz and Loor, 2008). That

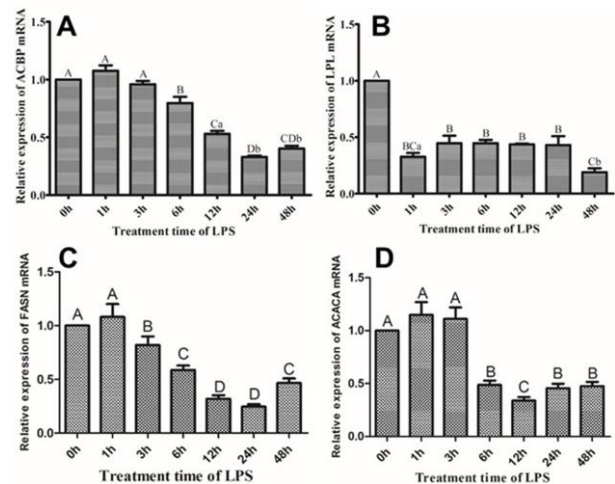


Fig. 4: LPS regulates the transcription of PPAR γ target genes in the bMECs. **A:** The transcription level of ACBP gene. **B:** The transcription level of LPL gene. **C:** The transcription level of FASN gene. **D:** The transcription level of ACACA gene. The data with different capital letters between two groups showed very significant differences ($P < 0.01$); data with different lower-case letters between two groups showed significant differences ($P < 0.05$); data with the same letters between two groups showed no significant differences ($P > 0.05$).

indicate the role of PPAR γ in regulating milk fat synthesis. PPAR γ in bMEC upregulates the expression of its target genes, such as FASN, ACACA, and SCD (Kadegowda *et al.*, 2009). Therefore, we hypothesize that PPAR γ may be a key factor in LPS-induced the decrease of milk lipid synthesis in bMEC.

Cell culture was a convenient tool for dissecting milk fat synthesis process. In the present study, near-fibroblast-free bMEC cultures were obtained by differential trypsinization. The flow cytometry data showed that the ratio of CK18-positive cells is 99.04%. The bMEC were treated with oleic acid to induce milk lipid synthesis. The results of BODIPY staining and TG detection showed that oleic acid could induce high lipid production ability of bMEC. Therefore, the lactating bMEC culture model is suitable for investigating the milk fat synthesis function. The TG content of the bMEC and culture medium were detected by enzymatic colorimetric assay. We found that LPS could decrease milk lipid synthesis and secretion. PPAR γ is a nuclear receptor and transcription factor that plays important role in milk fat synthesis and mastitis therapy in dairy cows (Kadegowda *et al.*, 2009). Therefore, the expression and activity of PPAR γ were detected in this study. We found that LPS could inhibit the expression and nuclear translocation of PPAR γ . The results suggest that PPAR γ participate in LPS-induced reduction of TG synthesis and secretion in bMEC.

ACBP, LPL, FASN, and ACACA gene are PPAR γ downstream target genes. As an intracellular carrier of acyl-CoA esters, ACBP can bind C₁₂-C₂₂ acyl-CoA

esters with very high affinity (Burton *et al.*, 2005). LPL is an enzyme playing an important role in milk lipid synthesis. It catalyzes the complete hydrolysis of TG yielding glycerol and fatty acids (Mead *et al.*, 2002). ACACA supplies malonyl-CoA to FAS and is committed to *de novo* lipogenesis in mammary gland tissue (Mao *et al.*, 2009; Ma, 2012). Therefore, the mRNA level of *ACBP*, *LPL*, *FASN*, and *ACACA* gene were evaluated by quantitative RT-PCR. Consistent with the PPAR γ , we found that LPS could inhibit the transcription of *ACBP*, *LPL*, *FASN*, and *ACACA* gene in a time-dependent manner. The results suggest that LPS could inhibit the long-chain fatty acids uptake and *de novo* synthesis of short- and medium-chain fatty acids in bMEC via inhibiting the expression and activity of the PPAR γ .

Conclusion

LPS can decrease the level of triglyceride synthesis in bMEC via down-regulating the expression and activity of the PPAR γ . Our data may provide new insight into the mechanisms of milk fat depression caused by LPS.

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