Research Article

Antihepatitis B Virus Activity of a Protein-Enriched Fraction from Housefly (Musca domestica) in a Stable HBV-Producing Cell Line

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Hepatitis B virus (HBV) infection remains a major public health problem. Although several vaccines and therapeutic strategies are currently being implemented to combat HBV virus, effective antiviral therapy against HBV infection has not been fully developed. Alternative strategies and new drugs to combat this disease are urged. Insects and insect derivatives are a large and unexploited source of potentially useful compounds for modern medicine. In the present study, we investigated the first anti-HBV activity of a protein-enriched fraction (PE) from the larvae of the housefly (Musca domestica) in a stable HBV-producing cell line. HBsAg and HBeAg in the culture medium were measured by enzyme-linked immunosorbent assay. HBV-DNA was quantified by fluorescent quantification PCR. HBV core protein was assayed by immunofluorescent staining. Results indicate PE treatment inhibited both HBsAg, HBeAg secretion, and HBV-DNA replication. Furthermore, PE could also suppress HBV core protein expression. PE could be a potential candidate for the development of a novel and effective drug for the treatment of HBV infection.

1. Introduction

Hepatitis B virus (HBV) infection remains a major public health problem and causes transient and chronic hepatitis [1]. Approximately 3.5 hundred million individuals are infected with HBV worldwide, and approximately 1 million people die of HBV infection or related diseases each year [2]. Although several vaccines and therapeutic strategies are currently being implemented to combat HBV virus, no effective antiviral therapy against HBV infection has yet been fully developed [3]. The side effects of current pharmacological agents and development of drug-resistance in HBV are emerging clinical problems [4, 5]. Thus, alternative strategies and new drugs to combat this disease are urged.

Insects and insect derivatives are a large and unexploited source of potentially useful compounds for modern medicine [6]. Housefly (Musca domestica) can thrive without causing infection in the most unfavorable surroundings, largely due to its antimicrobial and immunoactive substances in the immune system [7]. Musca domestica larvae are traditionally used as therapeutic agents for decubital necrosis, malnutritional stagnation, and eczema since the Ming/Qing Dynasty (1368 Anno Domini) up to now in China [8]. Recently, the effects of antioxidant [9], antibacterial [10], antitumor activities [11], and immunomodulatory functions [12] of the protein-enriched extracts of housefly larvae have been reported. Additionally, the protein-enriched extracts of housefly larvae have been reported to possess potential hepatoprotective effect [13] and antiviral activity against pseudorabies virus [14] and influenza virus [7]. However, it is unclear whether the protein-enriched extracts of housefly larvae have potent antiviral activity against hepatitis B virus.

In the present study, HepG2.2.15 cell, which has been stably transformed with two copies of the HBV genome into human hepatoblastoma cell line HepG2, was used as in vitro model to evaluate the anti-HBV effect of protein-enriched
fraction (PE) from *Musca domestica* larvae. HBsAg and HBeAg in the culture medium were measured by enzyme-linked immunosorbent assay. HBV-DNA was quantified by using fluorescent quantification PCR. HBV core protein in HepG2.2.15 cell was assayed by immunofluorescent staining and scanned by confocal microscope.

2. Methods

2.1. Preparation of Protein-Enriched Fraction from *Musca domestica* Larvae. *Musca domestica* was supplied by Guangdong Provincial Center for Disease Control and Prevention (CDC), China. The protein-enriched fraction of *Musca domestica* larva was prepared from *Musca domestica* larva as described before [12]. First, the third-instar larvae were collected, washed with distilled water, and frozen at −20°C. Then, the larvae were weighted and homogenized with a homogenizer (4 pulses, 5 sec at 3500 rpm) on ice. The homogenate was filtered with a layer of 64 mm nylon mesh and then incubated at 4°C for 60 min. After removing the insoluble material, the solution was centrifuged at 1300 g for 10 min at 4°C. The supernatant was concentrated and lyophilized. The protein concentration was determined using the bicinchoninic acid (BCA) protein assay kit according to the manufacturer’s instructions. The mass of lyophilized powder was weighed and the content of protein was calculated. The protein fractions were stored at −80°C.

2.2. Cell Culture. HepG2.2.15 cells were grown in complete DMEM (Gibco-BRL, CA) containing 10% FBS (HyClone, Thermo Fisher, PA), 100 units/mL penicillin, 100 mg/mL streptomycin, and 380 micro-g/mL G418 antibiotic (Sigma, MO) in a humidified incubator with 5% CO₂ at 37°C.

2.3. Cytotoxicity Measurement. Cytotoxicity was assessed by the MTT assay as previously described [15]. Briefly, HepG2.2.15 cells were cultured in 96-well plates (2 × 10⁴/well) for 9 days with various concentrations of PE. The cells with media alone were used as controls. The culture medium was replaced every 3 days. At the end of the culture, MTT solution (5 g/L) was added, and incubated another 4 h at 37°C. Finally, DMSO was added to solubilize the formazan, and the optical density (OD) values were read at 450 nm. The survival ratio (%) was calculated using

\[
\text{Survival rate} (\%) = \left( \frac{\text{OD}_{450} \text{ of negative control}}{\text{OD}_{450} \text{ of experimental group}} \right) \times 100\%.
\]  

(1)

2.4. Antiviral Assays. Antiviral assays were conducted as previously described [15, 16]. Briefly, the HepG2.2.15 cells were seeded in 24-well plates (2 × 10⁴/well) and incubated to reach confluence. Then the culture medium was replaced by fresh medium with different concentrations of PE or ADV (adefovir, positive control) for 3, 6, and 9 days. The cells with media alone were used as controls. The culture medium was replaced every 3 days. The supernatants were collected for HBV antigens and extracellular HBV-DNA assays, respectively. The cells were collected for the intracellular HBV-DNA assays on the 9th day.

2.5. Measurement of Secreted HBsAg and HBeAg. HBsAg and HBeAg in the culture medium were measured by enzyme-linked immunosorbent assay (ELISA) using HBsAg and HBeAg diagnostic kit (Shanghai Kehua Biotech Co., Ltd., China) according to the manufacturer’s recommendations. The OD values at 450/630 nm were read. The inhibitory rates were calculated using

\[
\text{Inhibitory rate} (\%) = \left[ \frac{(\text{OD}_{	ext{control}} - \text{OD}_{	ext{PE}})}{\text{OD}_{	ext{control}}} \right] \times 100\%.
\]  

(2)

2.6. HBV-DNA Quantification by Fluorescent Quantification PCR. HBV-DNA was quantified using fluorescent quantification PCR [17]. Viral DNA was extracted from the culture medium and cells, and then proper aliquots were used for the fluorescent quantification PCR. HBV fluorescent quantitative PCR diagnostic kit (Da-An Gene Co., Ltd., China) was used to determine the load of HBV viral according to the manufacturer’s protocol. The PCR reaction was carried out as follows: initially denaturation at 93°C for 2 min followed by 10 cycles of 93°C for 45 s and 55°C for 60 s and 30 cycles of 93°C for 30 s and 55°C for 45 s. HBV-DNA was quantified using a standard curve. The inhibition ratio (%) was calculated using

\[
\text{Inhibitory rate} (\%) = \left[ \frac{(\text{HBV-DNA concentration}_{\text{control}} - \text{HBV-DNA concentration}_{\text{PE}})}{\text{HBV-DNA concentration}_{\text{control}}} \right] \times 100\%.
\]  

(3)

2.7. Immunofluorescent Staining and Confocal Microscope Analysis for HBV Core Protein. A single HepG2.2.15 cell suspension was seeded on coverslip in six-well plate (2 × 10⁴/well) overnight. Cells were treated with different concentrations of PE or ADV (adefovir, positive control) for 9 days and fixed with 4% paraformaldehyde and permeabilized with 0.1% (vol/vol) Triton X-100 for 30 min. The primary antibody is rabbit polyclonal IgG anti-human HBcAg (1:200; Abcam, England) and the secondary antibody is Alexa 488 conjugated goat anti-rabbit IgG (1:200; Jackson ImmunoResearch, USA). The chromosome was stained with 4',6-diamidino-2-phenylindole (DAPI, Vector, CA) for nuclear indication. Images were captured using a confocal laser scanning microscope (TCS-NT, Leica Microsystems, Heidelberg, Germany).

2.8. Statistical Analysis. All data were expressed as the mean ± standard error of the mean (SEM). Differences
between mean values were analyzed using one-way ANOVA. All statistical analyses were performed by SPSS (version 13.0 for Windows) statistical software. Each measurement was performed at least in triplicate.

3. Results

3.1. The Protein Content and Cytotoxicity Measurement. The protein content of PE was about 99.18 ± 0.27%. The cell survival rate of the HepG2.2.15 cell in the presence of various concentrations of PE was tested. As shown in Figure 1, no obvious cytotoxicity was observed for PE, even at concentration of 100 micro-g/mL for 9 days.

3.2. Anti-HBV Antigens Secretion Activity of PE. Based on the results of cytotoxicity, we selected three treatment concentrations of PE with the highest dose at 40 micro-g/mL to evaluate its antiviral effect. The levels of HBsAg and HBeAg in the supernatant of HepG2.2.15 cell culture system were measured by ELISA using HBsAg and HBeAg diagnostic kit. Treatment of HepG2.2.15 cells with different concentrations of PE at different times resulted in a significant reduction of HBsAg and HBeAg secretion (Figure 2) in a dose-dependent manner.

3.3. Effect of PE on HBV-DNA Replication. The results of fluorescent quantification PCR revealed that treatment with various concentrations of PE for 9 days result in the reduction of intracellular and extracellular HBV-DNA levels, as compared with a control group (P < 0.05). As the figure shows (Figure 3), the mean inhibition percentage of viral DNA levels with PE at the dosages of 10 micro-g/mL, 20 micro-g/mL, and 40 micro-g/mL were 19.48%, 28.39%, and 39.02% extracellularly and 13.15%, 20.39%, and 31.24% intracellularly, respectively.

3.4. Inhibit the Expression of HBV Core Protein in HepG2.2.15 Cells by PE Treatment. HepG2.2.15 cells were treated with PE at the concentrations of 10 micro-g/mL, 20 micro-g/mL, and 40 micro-g/mL for 9 days. HBV core protein was assayed by immunofluorescent staining and scanned by confocal microscope. The results (Figure 4) showed that the signal of core protein is obviously decreased in the cytoplasm of HepG2.2.15 cells treated with PE in a dose-dependent manner when compared with the control cells.

4. Discussion

There are two arms of therapy to manage HBV infection, either by direct antiviral therapy to inhibit replication of HBV or by indirect immunomodulatory therapy to enhance cellular immunity to combat this disease [18]. Direct antiviral therapy with nucleoside analogues (e.g., lamivudine entecavir, dipivoxil, adefovir, and tenofovir) could efficiently control hepatitis B, but drug resistant mutant could be developed progressively after initiation of therapy [19]. Indirect immunomodulatory therapy with interferon alpha (IFN α) had low efficiency with many limitations [20]. Moreover, major side effects and high costs of these agents strengthened the need for new anti-HBV agents.

Hundreds of traditional Chinese medicines (TCMs) have been used for hepatitis B treatment [21–23]. For example, typical strategies of TCM treatment in hepatitis B are (1) to decrease the load of HBV viral; (2) to improve liver function; (3) to ameliorate liver inflammation; (4) to improve immune function; (5) to regulate lipid metabolism; and (6) to ameliorate hepatic fibrosis [21, 22]. The protein-enriched fraction extract from traditional Chinese medicines, housefly larvae, has been found to possess potential hepatoprotective effect [13], immunomodulatory function [12], inflammation regulation effect [24], and antiviral activity against pseudorabies virus [14] and influenza virus [7]. However, the anti-HBV active of the protein-enriched extracts of housefly larvae, until now, has not been studied. In the present study, our results, for the first time, clearly demonstrated that the protein-enriched extracts of housefly larvae could inhibit HBV replication in an HBV-producing cell line. We speculate that PE treatment may benefit the liver by protecting the liver, inhibiting inflammation, inhibiting HBV replication, and enhancing cellular immunity. So the protein-enriched extracts of housefly larvae could be an excellent candidate for the development of potential HBV therapeutic agent.

Before identifying the effective dose which interfered with HBV replication and viral protein production, it is critical to use concentrations that are not overtly cytotoxic, since any impairment to cell functions would affect virus replication. Our results showed that the administration of even 100 micro-g/mL of PE for 9 days did not induce cell death, indicating PE achieved the virus inhibiting effect without cytotoxicity on HepG2.2.15 cell lines. The HepG2.2.15 cell line was obtained by stable transfection of the human HepG2 hepatoma cell line with a plasmid containing two copies of the HBV genome (subtype ayw) [25]. The cell line could support the full replication cycle HBV and incomplete double- and single-stranded forms of the HBV genome. Therefore, the cell line is an appropriate in vitro model for identifying the secretion of HBV particles as well as
In conclusion, we demonstrated for the first time that protein-enriched extracts of housefly larvae efficiently inhibited the expression of HBV virus proteins and the HBV-DNA replication in HepG2.2.15 cell line in vitro. PE has potential anti-HBV activities, which support its use in traditional Chinese medicines, and it can be further studied for the drugs development to treat HBV infection patients.

**Conflict of Interests**

The authors declare that there is no conflict of interests regarding the publication of this paper.

the molecular events in intracellular viral replication cycle. PE has shown its inhibitory effect on HBV proliferation in vitro by decreasing the production of HBsAg and HBeAg, which are two predominant indications of HBV infection and can be detected in the supernatant. Consistent with the inhibitory effects on productions of HBsAg and HBeAg (Figure 2), significant depression in intracellular and extracellular HBV-DNA levels was observed (Figure 3). Moreover, the results of immunofluorescent staining showed that PE obviously decreased the level of cytoplasmic HBV core protein (Figure 4). These results suggested that the protein-enriched extracts of housefly larvae functioned to inhibit the HBV replication, viral protein production, and secretion.
control PE (10 μg/mL) PE (20 μg/mL) PE (40 μg/mL) ADV (5 μg/mL)

Alexa 488

(a1) (b1) (c1) (d1) (e1)

DAPI

(a2) (b2) (c2) (d2) (e2)

MERGE

(a3) (b3) (c3) (d3) (e3)

Figure 4: Analysis of HBV core protein in HepG2.2.15 cells treated with PE. Cells were treated with or without drug at the indicated doses for 9 days and stained by immunofluorescent staining. Cells were scanned for subcellular distribution of HBV core protein (Green) by confocal microscope. Blue nuclear stained with DAPI. Calibration bar = 30 μm for all images.

Authors’ Contribution

Xuemei Lu and Xiaobao Jin made an equal contribution to this work.

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References

[1] C. Z. W. Xu, Y. Wang, and L. Qiao, "Hepatitis B virus-induced hepatocellular carcinoma," Cancer Letters, vol. 345, no. 2, pp. 216–222, 2014.
[2] M. C. Kew, "Epidemiology of chronic hepatitis B virus infection, hepatocellular carcinoma, and hepatitis B virus-induced hepatocellular carcinoma," Pathologie Biologie, vol. 58, no. 4, pp. 273–277, 2010.
[3] C. Niu, H. Bao, T. Tolstykh et al., "Evaluation of the in vitro anti-HBV activity of clevudine in combination with other nucleoside/nucleotide inhibitors," Antiviral Therapy, vol. 15, no. 3, pp. 401–412, 2010.
[4] M. Buti, I. Oyagüez, V. Lozano, and M. A. Casado, "Cost effectiveness of first-line oral antiviral therapies for chronic hepatitis B: a systematic review," Pharmacoeconomics, vol. 31, no. 1, pp. 63–75, 2013.
[5] S. J. Hadziyannis, D. Vassilopoulos, and E. Hadziyannis, "The natural course of chronic hepatitis B virus infection and its management," Advances in Pharmacology, vol. 67, pp. 247–291, 2013.
[6] E. P. Cherniack, "Bugs as drugs, part 1: insects. The “new” alternative medicine for the 21st century?" Alternative Medicine Review, vol. 15, no. 2, pp. 124–135, 2010.
[7] F. Wang, H. Ai, and C. Lei, "In vitro anti-influenza activity of a protein-enriched fraction from larvae of the housefly (Musca domestica)," Pharmaceutical Biology, vol. 51, no. 3, pp. 405–410, 2013.
[8] X. M. Lu, J. Shen, X. B. Jin et al., "Bactericidal activity of Musca domestica cecropin (Mdc) on multidrug-resistant clinical isolate of Escherichia coli," Applied Microbiology and Biotechnology, vol. 95, no. 4, pp. 939–945, 2012.
[9] H. Ai, F. Wang, and C. Lei, "Antioxidant activities of protein-enriched fraction from the larvae of housefly, Musca domestica," Natural Product Research, vol. 22, no. 6, pp. 507–515, 2008.
[10] S. O. Park, J. H. Shin, W. K. Choi, B. S. Park, J. S. Oh, and A. Jang, "Antibacterial activity of house fly-maggot extracts against MRSA (Methicillin-resistant Staphylococcus aureus) and VRE (Vancomycin-resistant enterococci)," Journal of Environmental Biology, vol. 31, no. 5, pp. 865–871, 2010.
[11] L. Hou, Y. Shi, P. Zhai, and G. Le, "Antibacterial activity and in vitro anti-tumor activity of the extract of the larvae of the housefly (Musca domestica)," Journal of Ethnopharmacology, vol. 111, no. 2, pp. 227–231, 2007.
[12] F. J. Chu, X. B. Jin, and J. Y. Zhu, "Housefly maggots (Musca domestica) protein-enriched fraction/extracts (PE) inhibit lipopolysaccharide-induced atherosclerosis pro-inflammatory responses," Journal of Atherosclerosis and Thrombosis, vol. 18, no. 4, pp. 282–290, 2011.
[13] F. R. Wang, H. Ai, X. M. Chen, and C. L. Lei, "Hepatoprotective effect of a protein-enriched fraction from the maggots
(Musca domestica) against CCl4-induced hepatic damage in rats,” *Biotechnology Letters*, vol. 29, no. 6, pp. 853–858, 2007.

[14] Y. Wang, D. Lu, Y. Zhao, C. L. Lei, and F. Zhu, “Antiviral and antitumor activities of the protein fractions from the larvae of the housefly, Musca domestica,” *African Journal of Biotechnology*, vol. 11, no. 39, pp. 9468–9474, 2012.

[15] L. Zheng, Q. Wang, X. Yang et al., “Antiviral activity of FNC, 2'-deoxy-2'-β-fluoro-4'-azidocytidine, against human and duck HBV replication,” *Antiviral Therapy*, vol. 17, no. 4, pp. 679–687, 2012.

[16] L. Ma, J. Song, Y. Shi et al., “Anti-hepatitis B virus activity of chickweed [Stellaria media (L.) Vill.] extracts in HepG2.2.15 cells,” *Molecules*, vol. 17, no. 7, pp. 8633–8646, 2012.

[17] L. Belloni, L. Allweiss, F. Guerrieri et al., “IFN-α inhibits HBV transcription and replication in cell culture and in humanized mice by targeting the epigenetic regulation of the nuclear cccDNA minichromosome,” *The Journal of Clinical Investigation*, vol. 122, no. 2, pp. 529–537, 2012.

[18] A. Alberti and N. Caporaso, “HBV therapy: guidelines and open issues,” *Digestive and Liver Disease*, vol. 43, supplement 1, pp. S57–S63, 2011.

[19] C. H. Chen, J. H. Wang, S. N. Lu et al., “Treatment response and evolution of HBV resistance during lamivudine plus adefovir or entecavir therapy in patients with adefovir-resistant mutants,” *Antiviral Therapy*, vol. 17, no. 4, pp. 701–709, 2012.

[20] J. Pogorzelska and R. Flisiak, “Long-term effects of HBV treatment Peg-IFN α-2a alone or combined with lamivudine,” *Przegląd Epidemiologiczny*, vol. 61, no. 3, pp. 433–437, 2007.

[21] L. Zhang, G. Wang, W. Hou, P. Li, A. Dulin, and H. L. Bonkovsky, “Contemporary clinical research of traditional Chinese medicines for chronic hepatitis B in China: an analytical review,” *Hepatology*, vol. 51, no. 2, pp. 690–698, 2010.

[22] Y. F. Xiang, H. Q. Ju, S. Li, Y. J. Zhang, C. R. Yang, and Y. F. Wang, “Effects of 1,2,4,6-tetra-O-galloyl-β-D-glucose from P. emblica on HBsAg and HBeAg secretion in HepG2.2.15 cell culture,” *Virologica Sinica*, vol. 25, no. 5, pp. 375–380, 2010.

[23] M. S. Shin, E. H. Kang, and Y. I. Lee, “A flavonoid from medicinal plants blocks hepatitis B virus-e antigen secretion in HBV-infected hepatocytes,” *Antiviral Research*, vol. 67, no. 3, pp. 163–168, 2005.

[24] F. J. Chu, X. B. Jin, Y. Y. Xu et al., “Inflammatory regulation effect and action mechanism of anti-inflammatory effective parts of housefly (Musca domestica) larvae on atherosclerosis,” *Evidence-Based Complementary and Alternative Medicine*, vol. 2013, Article ID 340267, 10 pages, 2013.

[25] R. Zhao, T. Z. Wang, D. Kong et al., “Hepatoma cell line HepG2.2.15 demonstrates distinct biological features compared with parental HepG2,” *World Journal of Gastroenterology*, vol. 17, no. 9, pp. 1152–1159, 2011.