

Research Article

Lianhua-Qingwen Displays Antiviral and Anti-Inflammatory Activity and Synergistic Effects with Oseltamivir against Influenza B Virus Infection in the Mouse Model

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Influenza B virus (IBV) is one of the main pathogens of the annual influenza epidemic, and the disease burden is significant, especially among children and young teenagers. In this study, the antiviral and anti-inflammatory effects of a traditional Chinese medicine prescription, the Lianhua-Qingwen capsule, were evaluated. Our results showed that Lianhua-Qingwen capsule can inhibit both Victoria and Yamagata lineages, and the 50% inhibitive concentrations ranged from 0.228 ± 0.150 to 0.754 ± 0.161 mg/mL. The time course results demonstrated that IBV yields were reduced with treatment at 0–4 h after infection, and the mechanistic research verified that Lianhua-Qingwen capsule has hemagglutination inhibition activity against B/Guangzhou/0215/2012 but not A/California/04/2009. In addition to antiviral activity, Lianhua-Qingwen capsule can also inhibit excessive expression of RANTES, IL-6, IL-8, IP-10, TNF- α , MCP-1, MIP-1 β , and IFN- λ at the mRNA level and prevent a severe inflammatory response. The in vivo results confirmed that orally administered Lianhua-Qingwen capsule (100–400 mg/kg/day) does not reduce IBV-induced lung viral load and mortality in mice. However, the pathological change in lungs was alleviated, and there were fewer inflammatory cells in the lungs of Lianhua-Qingwen capsule treated mice than those in controls. Further research confirmed that the combination treatment of 200 mg/kg/day of Lianhua-Qingwen capsule with 2 mg/kg/day of oseltamivir significantly reduced IBV infection over the individual administration of either alone in vivo. Our findings prove that Lianhua-Qingwen capsule could be used as an assistant medicine to enhance the effect of oseltamivir against influenza B virus infection.

1. Introduction

Influenza B virus (IBV), one of the main pathogens of annual influenza epidemics, is divided into two genetically and antigenically distinct lineages, B/Victoria/2/1987-like (Victoria) and B/Yamagata/16/1988-like (Yamagata). Both lineages of IBVs circulate or cocirculate globally with the H1N1 or H3N2 subtype of influenza A viruses (IAVs) in annual seasonal epidemics. The proportion of IBV infection cases

out of total influenza-positive cases varies from approximately 1% to 40% in a single epidemic.

The pathogenicity and severity of IBV are weaker than those of IAV, but the disease burden of IBV is significant, especially among children and young teenagers [1]. In a report on mortality related to influenza between 1976 and 1999 in the USA, the highest mortality was associated with H3N2, followed by IBV and then H1N1 [2]. During 2003–2008, the mortality attributable to IBV was estimated

to be higher than that to H3N2 or H1N1 in China [3]. Furthermore, influenza B virus caused more complications, including neurological, muscular manifestations [4, 5] and cardiologic complications [6, 7].

Antiviral drugs play an important role in the prevention and treatment of IBV. The neuraminidase inhibitors (NAI) include oseltamivir, intravenously injected peramivir, and inhalational zanamivir. However, recent clinical studies suggest that oseltamivir is less effective in treating IBV than IAV [8, 9]. Additionally, in clinical studies in Japan, when more than 100 children with influenza B or influenza A (H3N2) were administered oseltamivir, the results showed that oseltamivir was less effective for influenza B than influenza A in reducing the time the virus lasted or duration of fever [10–12].

In 2009, the Chinese government recommended traditional Chinese medicine (TCM) prescriptions of Lianhua-Qingwen capsule (LQ) as a candidate formula to treat and control the H1N1 pandemic. This new formula is a natural herbal medicine developed from two classical TCM formulae, *Yinqiao San* and *Maxing Shigan Tang*, which have been used historically for treatment of influenza-like illness in China [13]. When a randomized, double-blind, positive-controlled clinical trial of LQ anti-influenza A (H1N1) virus treatment was performed in China, the results confirmed that it was able to alleviate the symptoms significantly and achieve the same effect as oseltamivir [14]. LQ was approved for clinical trials as treatment for influenza infection by the FDA in 2016. In addition, our previous results also demonstrated that LQ could inhibit different strains of influenza A viruses and that it also suppressed virus-induced NF- κ B activation and alleviated virus-induced cytokine expression [15].

There are several studies on the prospective antiviral drugs against influenza A virus, but very little have focused on IBV. The damage caused by IBV has become prohibitive. Based on the previously established LQ clinical curative effect and experimental data on influenza A virus, in this study, the effects of LQ against influenza B virus *in vitro* and *in vivo* have been evaluated.

2. Materials and Methods

2.1. Drugs. The Lianhua-Qingwen capsule material (Lot No. B1602001) was provided by Shijiazhuang Yiling Pharmaceutical Co., Ltd (Shijiazhuang city, China). The drug was dissolved by DMSO into 500 mg/mL and diluted using MEM to operational concentration before experiment (*in vitro*). Oseltamivir was obtained from Roche Co., Ltd. (Basel, Switzerland). Ribavirin was purchased from Star Lake Bioscience Co., Ltd. (Zhaoqing city, China).

2.2. Viruses and Cells. Influenza B virus (B/Lee/40) was purchased from American Type Culture Collection (ATCC; Manassas, VA, USA). B/Guangzhou/GIRD08/2009 (Victoria-like), B/Guangzhou/GIRD01/2016 (Victoria-like), and B/Guangzhou/0215/2012 (Victoria-like) were isolated from clinical samples. Influenza B virus B/Guangzhou/19/2016 (Yamagata-like) was gifted by Dr. Feng Ye (the First

Affiliated Hospital of Guangzhou Medical University). Influenza A virus A/California/04/2009 was gifted by professor Malik J. S. Peilis (WHO Collaborating Centre for Infectious Disease Epidemiology and Control, School of Public Health, Li Ka Shing Faculty of Medicine, the University of Hong Kong, Hong Kong Special Administrative Region). All the viruses were cultured in MDCK (Madin-Darby canine kidney, ATCC), and all the cells were grown in Dulbecco's modified Eagle's medium (DMEM, Gibco) with 10% heat-inactivated fetal calf serum (FCS, Gibco).

2.3. Cytotoxicity. The cytotoxicity of LQ to MDCK cells was assessed via MTT assay, and 1×10^4 cells were seeded into 96-well plate. After incubation for 18 h, the culture medium was removed, and the cells were washed once with PBS. A series of 2-fold dilutions of concentrations of LQ (maximum concentration of 10 mg/mL) were then added to the wells, and the cells were incubated at 37°C, 5% CO₂, for 48 h. The medium was replaced with 1 mg/mL of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT)-PBS solution (100 μL/well). The plate was incubated at 37°C for 4 h, the solution was then replaced with DMSO, and the ODs value was measured in 570 nm of wave after a gentle shaking. Three independent MTT assays were performed. The 50% toxicity concentration (TC₅₀) was obtained via linear regression, and the result is shown as the mean ± standard deviation (SD).

2.4. Virus Yield Reduction Assay. Anti-IBV activity was evaluated by cytopathogenic effect (CPE) and MTT assays. Confluent monolayers of MDCK cells in 96-well plates were inoculated with virus (0.01 MOI). After 2 h, the inoculum was replaced with test medium containing a series of concentrations of LQ or DMSO (less than 1%) with 1 μg/ml tosyl-phenylalanine chloromethyl-ketone (TPCK) treated trypsin (Sigma), 100 U/ml penicillin, and 100 μg/ml streptomycin (Gibco). The plate was incubated at 34°C, 5% CO₂, for 72 h. The inhibition rates were measured via MTT assay. Three independent tests were conducted, and the 50% inhibition concentration (IC₅₀) was obtained via the Reed-Muench method [16].

2.5. Time Course Assay. The most effective concentration of the LQ in IBVs was tested by cytopathic effect (CPE). Three infection models were constructed. Before infection, 10⁶ TCID₅₀ of virus was mixed with LQ and incubated at 37°C for 1 h (*pretreatment of virus, Pre-V*); before infection, cells were treated with LQ for 1 h at 37°C (*pretreatment of cells, Pre-C*). LQ was used to treat cells at 2 h after infection (*posttreatment of virus, Post-V*). The supernatant was collected at 24 h postinfection, and the virus titers were determined in MDCK cells.

In *Post-V* model, MDCK cells were inoculated with B/Guangzhou/0215/2012 (MOI = 0.1) at 4°C for 2 h, and the viral solution was removed after washing twice with cold PBS. The medium containing 1 μg/mL TPCK treated trypsin was added, and the cell plate was transferred and incubated

at 37°C, 5% CO₂, which was defined as 0 h at this time. Then, 0.6 mg/mL LQ was added at 0 h, 2 h, 4 h, 6 h, and 8 h; the supernatant was collected at 12 h, and the virus titer was detected subsequently in MDCK cells.

2.6. The Synthesis of Nucleoprotein. MDCK cells on treated coverslips were inoculated with B/Guangzhou/0215/2012 (1 MOI) at 4°C for 2 h; then, the supernatant was removed, and the cells were washed twice with cold PBS. Next, 0.6 mg/mL LQ or the same concentration of DMSO was added to cells at 0 h after infection. The supernatant was removed at 8 h after infection, and the coverslips were prepared for use in the immunofluorescence assay by washing twice.

2.7. Hemagglutination Inhibition Assay. Then, 25 μL of series concentrations of LQ was mixed with an equivalent of eight hemagglutination units of virus solution. The plate was incubated at 37°C for 1 h, and then 50 μL of 0.5% chicken erythrocyte suspension was added. The hemagglutination inhibition activity of LQ was defined in complete inhibition of influenza virus hemagglutination activity after incubation for 40 min at room temperature.

2.8. Viral Binding Assay. Next, 1 × 10³ cells were seeded in 24-well culture plate with coverslips. The medium was removed after incubation for 18 h; cells were washed with cold PBS. The mixture containing a selected concentration of LQ and virus (10 MOI), which were incubated at 37°C for 1 h, was added to cells, and the cells were incubated at 4°C for 90 min. The mixture was removed; the cells were washed with cold PBS three times. The viral binding was measured using an immunofluorescence assay.

2.9. Immunofluorescence Assay. The cells were fixed with 4% paraformaldehyde (v/v) at room temperature for 30 min; the membrane was permeabilized with 0.5% (v/v) of Triton X-100 and then blocked with 50 mg/mL of goat serum (Sigma) for 30 min. Next, 1 μg/mL of mouse monoclonal antibody (Abcam) against influenza virus nucleoprotein was added to the cells and incubated at 4°C overnight. After three washes, 10 μg/mL of FITC-conjugated goat anti-mouse IgG antibody (Abcam) was added, and the cells were then incubated at 37°C for 90 min. After washing, the nucleus was stained with 5 ng/mL of DAPI for 5 min. The slips were mounted, and the results were obtained under fluorescence confocal microscopy (Nikon, D-ECLIPSE C1-S1).

2.10. Real-Time PCR Assay. A549 cells growing in 96-well plates at 37°C, 5% CO₂, were prepared and then infected with influenza B virus (B/Guangzhou/0215/2012, 0.1 MOI) for 2 h. The inoculums were removed, and the cells were treated with 0.15, 0.3, and 0.6 mg/mL of LQ. The cells were collected at 24 h after infection, the total RNA was extracted using the TRIZOL reagent (Invitrogen), and cDNA was synthesized using PrimeScript™ RT Master Mix (perfect real time) (TAKARA). The expression of IFN-α/β1, CCL5/RANTES,

IL-6, CXCL8/IL-8, CXCL10/IP-10, TNF-α, CCL2/MCP-1, CCL3/MIP-1α, CCL4/MIP-1β, IL-10, and IL-13 genes and reference GAPDH gene was detected using TB Green™ Premix Ex Taq™ II (TAKARA) by the ABI 7500 Real-Time PCR System [17].

2.11. Animal Experiment. Five-week-old, special-pathogen-free, female BALB/c mice were purchased from Guangdong Medical Laboratory Animal Center (Foshan city, Guangdong province, China, SCXK(G) 2008-0002). The animals were fed a standard laboratory diet and provided water ad libitum. The animal experiments were performed in accordance with the Guidelines of Guangdong Regulation for the Administration of Laboratory Animals. The experiment was performed after two days of feeding. The animal experiments in this study have been allowed by the ethics committee. Before animal experiment, the 50% lethal dose (LD₅₀) of B0215 virus was measured by survival, and 10 mice/dose were inoculated with 6 doses of 10-fold dilution of virus and observed for 15 days.

To assess the survival rate of LQ treated virally infected mice, 60 mice were divided into 6 groups (placebo, ribavirin 75 mg/kg/day, LQ 100/200/400 mg/kg/day, uninfected control, n = 10); 5 groups (placebo, ribavirin 75 mg/kg/day, LQ 100/200/400 mg/kg/day) were inoculated with 5-fold 50% lethal dose (LD₅₀) of B0215; control group was inoculated with equivalent solution without virus. The drugs were administered at 4 h before infection and continued for 5 days once per day, with equivalent PBS given as placebo and control (Ctrl). Survival was evaluated 15 days after infection.

To evaluate the effect of LQ on viral yield in vivo, 30 mice (6 mice each in 5 groups) were infected with 10-fold LD₅₀ of B/Guangzhou/0215/2012 (B0215) via nose. Oral medicines or PBS (placebo) was administered to infected mice (n = 6) for five days. Then, the mice were sacrificed, and the lungs were obtained on the 6th day of titer and pathological examination.

The effects of combinations of LQ and oseltamivir in the influenza B virus mouse model were also studied. 60 mice were divided into 10 groups (control, placebo, 200 mg/kg/day of LQ, 2/10/50 mg/kg/day of oseltamivir, 200 mg/kg/day of LQ combined with 2/10/50 mg/kg/day of oseltamivir respectively, n = 6). Mice except control group were infected with 10-fold LD₅₀ B0215, and control group were inoculated with equivalent solution without virus. Mice were treated with oseltamivir alone or combined with LQ from 4 h before infection to 4 days after infection with the day of infection defined as 0 day, and equivalent amounts of PBS were given as placebo and control. Six days after infection, the mice lungs were collected for titer and pathological examination. Mice were anaesthetized by isoflurane, and at the end of the experiment, mice were euthanized by carbon dioxide inhalation.

2.12. Statistical Analysis. The data obtained were analyzed using SPSS (version 13.0). The data were expressed as the mean ± SD. Significant differences were obtained by single-

tailed Student's *t*-test when comparing two groups. Multiple group comparisons were performed via one-way ANOVA test based on variance homogeneity. All results in which $P < 0.05$ were considered significant.

3. Results

3.1. LQ Displays Efficacy against Influenza B Viruses In Vitro. First, a cell proliferation and viability assay based on three independent MTT assays was performed to determine the nonspecific cytotoxicity of LQ for MDCK cells. The 50% toxic concentration (TC_{50}) of LQ was 4.0221 ± 0.0471 mg/mL (Table 1). There is no significant cellular toxic effect within the concentration range of 0.075–1.0 mg/mL of LQ in MDCK cells when the medicine and cells were incubated together at 37°C for 48 h in a humidified atmosphere of 5% CO₂. Furthermore, we tested the antiviral activity of LQ against five stains of influenza B viruses: B/Lee/40, three of Victoria-like virus (isolated in 2009, 2012, and 2016), and one of Yamagata-like virus (isolated in 2016). The results (Table 1) showed that LQ exhibited an inhibitory effect on five IBV strains with 50% inhibitory concentrations (IC_{50}) ranging from 0.228 ± 0.150 to 0.754 ± 0.161 mg/mL, and the selective index (SI) [18] ranged from 5.3 to 17.6. The inhibitory effect of LQ against the strains isolated in 2016 was more potent than that on the strains isolated before 2012. Interestingly, LQ showed the same inhibitory effect on the two lineages of strains isolated in 2016.

3.2. LQ Inhibits the Early Phase of Influenza B Virus Replication. According to three treatment models representing prevention (pretreatment of cells, Pre-C), direct action (pretreatment of virus, Pre-V), and therapy (post-treatment, Post-V), the IBV was inhibited by more than 0.15 mg/mL of LQ with dose dependence in the pretreatment of virus model and the posttreatment model (Figure 1(a)), indicating that LQ may play an inhibitory role in both direct and therapeutic models, but not a preventive one. Furthermore in posttreatment model, the time course results (Figure 1(b)) showed that IBV yield was reduced with treatment with 0.6 mg/mL of LQ at 0–4 h after infection, but treatment was not effective in reducing yield at more than 6 h. This demonstrated that LQ inhibits the early stages of viral cycle of IBV.

3.3. LQ Inhibits NP Replication of Influenza B Virus. To identify the effect of LQ on IBV replication, the synthesis of viral nucleoprotein of infected cells was examined by immunofluorescence. The cells were infected with B/Guangzhou/0215/2012 and then treated with 0.6 mg/mL of LQ for 8 h. Compared to nontreatment or treatment with the same concentration of medicine solvent (0.12% DMSO), 0.6 mg/mL of LQ distinctly decreased the synthesis of nucleoprotein (Figure 1(c)).

3.4. LQ Inhibits Influenza B Virus Binding to Cell Surface.

TABLE 1: Anti-influenza B virus activity of Lianhua-Qingwen capsule.

Viruses	TC_{50} (mg/mL)	IC_{50} (mg/mL)	SI
B/Lee/40		0.625 ± 0.131	6.4
B/Guangzhou/GIRD08/ 2009 ^v		0.754 ± 0.161	5.3
B/Guangzhou/GIRD01/ 2016 ^v	4.0221 ± 0.0471	0.228 ± 0.150	17.6
B/Guangzhou/0215/2012 ^v		0.487 ± 0.187	14.0
B/Guangzhou/19/2016 ^v		0.298 ± 0.078	13.5

^vVictoria-like virus, ^yYamagata-like virus.

To study the antiviral mechanism of LQ in pretreatment of virus, inhibition of HA was evaluated. The HA inhibition assay results (Figure 2) showed that ≥ 0.313 mg/mL of LQ has HA inhibition activity against B/Guangzhou/0215/2012 but not A/California/04/2009. To confirm this result, indirect immunofluorescence microscopy of viral binding was performed, and there was a similar result (Figure 2(b)); that is, 0.6 mg/mL of LQ could inhibit viral binding to MDCK cells for B/Guangzhou/0215/2012 but not for A/California/04/2009.

3.5. LQ Displays Inhibition of Inflammatory Cytokines and Chemokines after Influenza B Virus Infection in mRNA Levels. Inflammatory cytokine and chemokine expression imbalance will cause tissue damage. Therefore, the effects of LQ on cytokines and chemokines were determined. The results (Figure 3) showed a significantly increased mRNA level of RANTES (62-fold), IL-6 (99-fold), IL-8 (46-fold), IP-10 (150-fold), TNF- α (53-fold), MCP-1 (8.8-fold), MIP-1 β (58-fold), and IFN- λ 1 (113-fold) in the A549 cells at 12 h after IBV infection compared to GAPDH gene. Also, a reduction of all inflammatory factors mRNA level was observed in cells treated with ≥ 0.15 mg/mL of LQ compared to dissolvent treated infected cells. Queerly, a dose-dependent reduction was observed in most of the inflammatory factor mRNA levels except CCL5/RANTES with inverse reduction.

3.6. LQ Reduces the Inflammation of Lungs in Mice Infection Model. To verify the treatment effect of LQ in vivo, the survival rate was tested at 15 days postinfection; the lung virus yield and lung inflammation (pathological state) were tested at 6 days postinfection in influenza B virus-infected mice. The results (Figure 4) showed that orally administered LQ (100–400 mg/kg/day) does not reduce IBV-induced lung viral load and mortality in mice. However, the pathological change in the lungs (Figure 5) was alleviated to a certain extent. Compared to uninfected mice (Figure 5(a)), untreated mice showed severe interstitial pneumonia at 6 days after IBV infection (Figure 5(b)). In the positive control, ribavirin treated mice (Figure 5(c)), there were a few inflammatory cells around the terminal bronchus. Although interstitial pneumonia was observed in 100–400 mg/kg/day of LQ treated mice (Figures 5(d)–5(f)), depreciation of

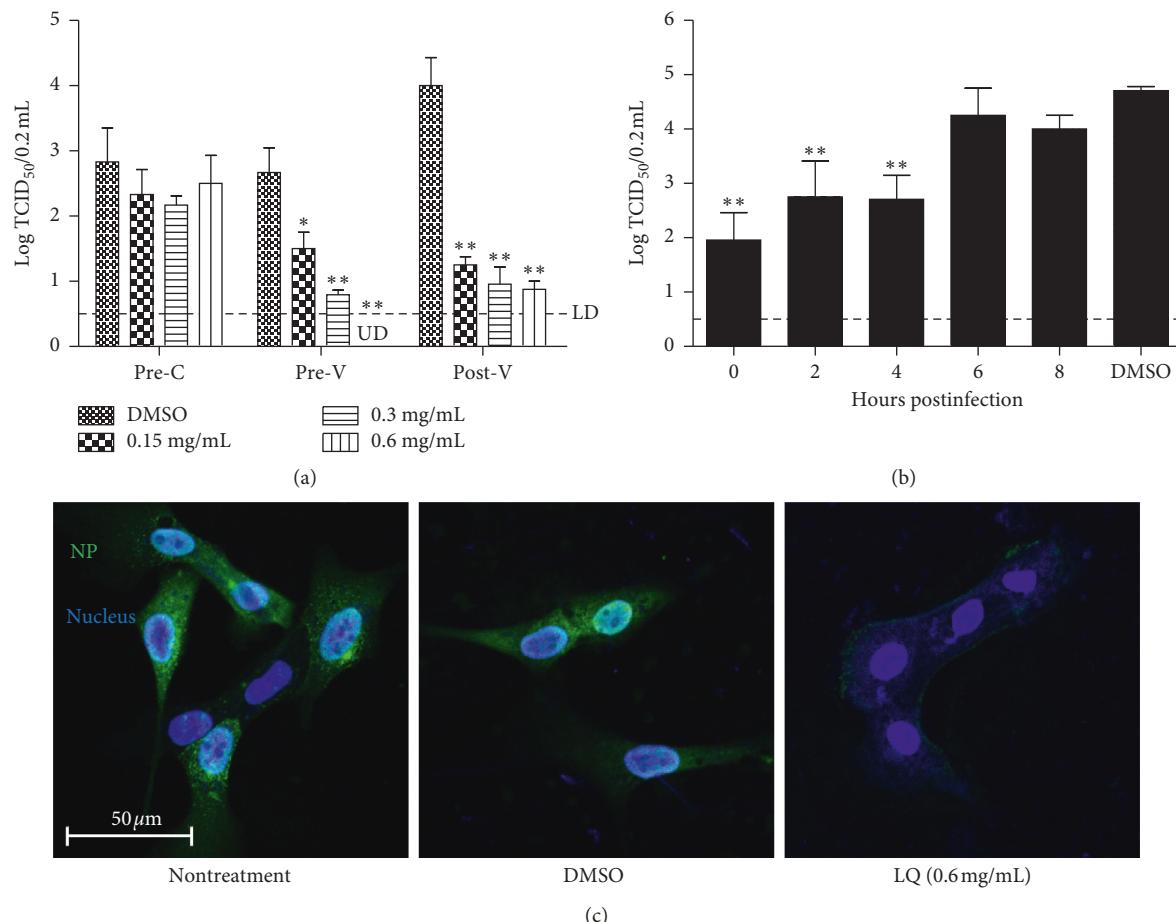


FIGURE 1: Influenza B virus yield after treatment with LQ. (a) The effect of treatment with LQ against influenza B virus in different models: Pre-C, pretreatment of cells with LQ; Pre-V, pretreatment of virus with LQ; Post-V, posttreatment after infection. UD: under detection. (b) The time course assay: cells were treated with 0.6 mg/mL of LQ after infection with B0215 (MOI = 0.01); the supernatant was collected and titrated after two days. The dotted line is the value which detected limitation. * $P < 0.05$, ** $P < 0.01$ compared to treatment with 0.12% DMSO (the concentration of 0.6 mg/mL of LQ). (c) Immunofluorescence assay for nucleoprotein expression of influenza B virus. Cells were infected with B0215 at 0.1 MOI for 90 min at 4°C; the viral solution was replaced with medium containing 1 μ g/mL of TPCK treated trypsin, LQ (0.6 mg/mL), or 0.12% DMSO. The cells were fixed and immunofluorescence assay was performed at 8 h after infection.

inflammatory cells was observed in LQ treated mice lungs compared to the placebo group.

3.7. LQ Combined with Oseltamivir in Infected Mice Model Displays Beneficial Effects. Because LQ has a weak potency against IBV in individual administration, the effect of the combination of LQ and oseltamivir in IBV-infected mice was tested. The viral titer in lungs (Figure 6) of infected mice treated with LQ (200 mg/kg/day) and oseltamivir (2 mg/kg/day) (average value = log 3.67 TCID₅₀/g) was lower than the viral titer for mice treated with only LQ at dose of 200 mg/kg/day (average value = log 4.5 TCID₅₀/g) or mice treated with only oseltamivir at dose of 2 mg/kg/day (average value = log 4.5 TCID₅₀/g). Interestingly, viral load of 75 mg/kg/day of ribavirin treated mice (average value = log 3.17 TCID₅₀/g) was lower than that of 50 mg/kg/day of oseltamivir (average value = log 3.67 TCID₅₀/g).

The results of the pathological changes in the lungs (Figure 7) showed that treatment with oseltamivir at doses of 2 and 10 mg/kg/day in conjunction with 200 mg/kg/day of LQ is better than oseltamivir alone. Severe interstitial pneumonia was observed in untreated mice (Figure 7(c)), 200 mg/kg/day of LQ treated mice (data not showed), and 2 mg/kg/day of oseltamivir treated mice (Figure 7(i)) at 6 days after IBV infection. The lungs of 50 mg/kg/day of oseltamivir treated mice (Figure 7(g)) were similar to those of normal mice (Figure 7(a)), as well as the mice treated simultaneously with 50 mg/kg/day of oseltamivir and 200 mg/kg/day of LQ (Figure 7(d)). Moderate pneumonia was observed in 10 mg/kg/day of oseltamivir treated mice (Figure 7(h)) and 75 mg/kg/day of ribavirin treated mice (Figure 7(b)), and mild pneumonia was observed in mice treated simultaneously with 10 mg/kg/day of oseltamivir and 200 mg/kg/day of LQ (Figure 7(e)). Even though severe pneumonia occurs in mice treated simultaneously with 2 mg/kg/day of oseltamivir and 200 mg/kg/day of LQ

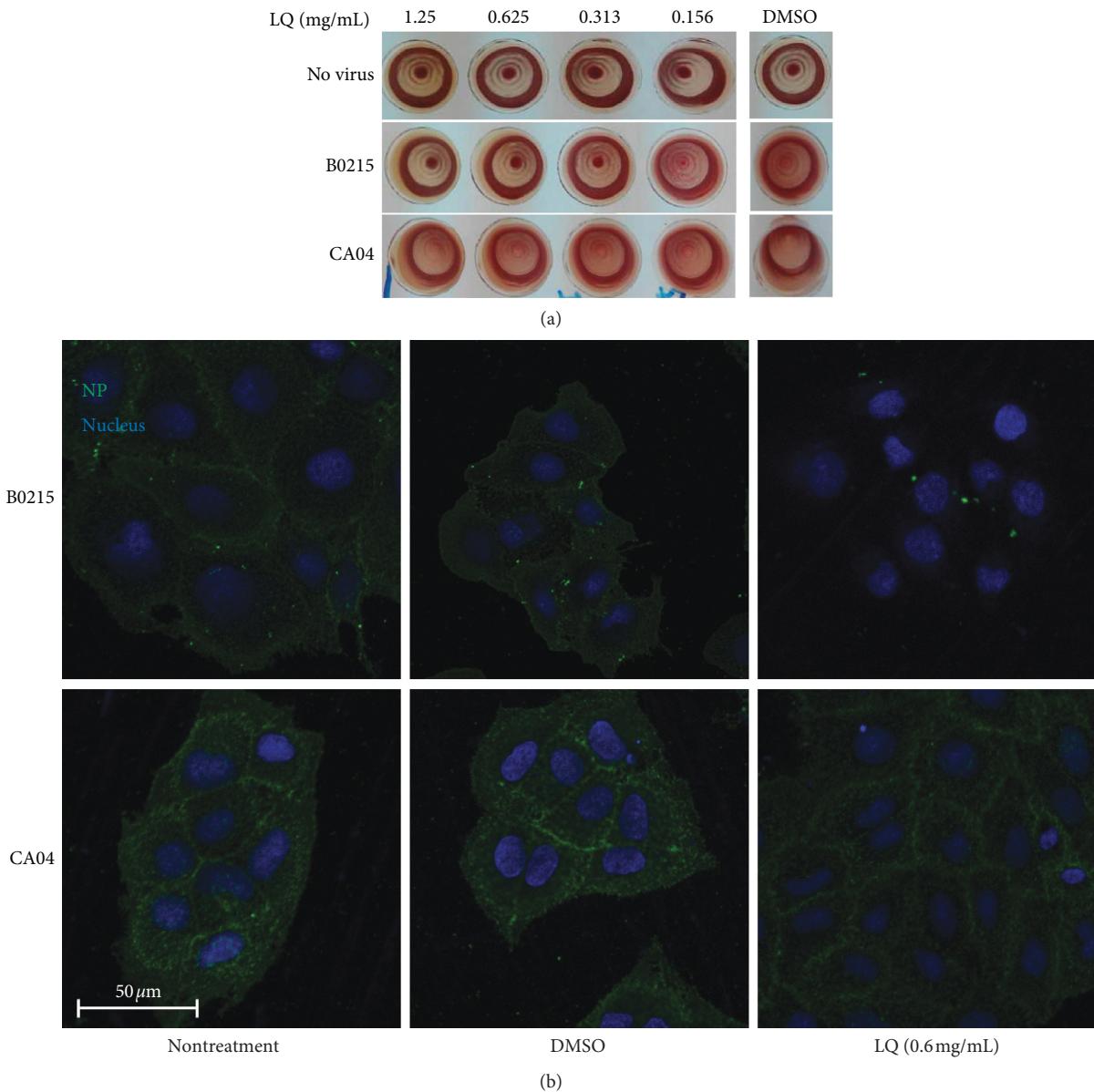


FIGURE 2: LQ might target viral binding activity of influenza B virus B0215. (a) Influenza virus hemagglutination inhibition assay after treatment with LQ. (b) Immunofluorescence assay for influenza B virus and influenza A virus viral binding after treatment with 0.6 mg/mL of LQ or the same concentration of DMSO for 1 h.

(Figure 7(f)), the inflammatory cells were fewer than those in mice treated with 2 mg/kg/day of oseltamivir alone.

4. Discussion

Although influenza B and influenza A are similar, there are many differences between them, particularly the efficiency of antivirus medicines, such as M2 inhibitors and NA inhibitors. This paper describes the effect of LQ against influenza B virus in vitro in a mouse model. We found that LQ has a wide spectrum of antiviral activity against different strains of influenza B virus, including Victoria and Yamagata lineages. Base on the results in vitro, three probable pathways might be deduced for anti-influenza B virus activity of LQ: (a) blockage of viral binding to host

receptors; (b) reduction of viral replication; (c) reduction of inflammatory cytokines and chemokines storm reduced by infection.

First, three antiviral effect models with pretreatment of cells, pretreatment of virus, and posttreatment were performed, the results showed significant inhibitory activity with the pretreatment of virus and posttreatment. A time course also indicated that IBV yield was reduced with LQ treatment at 0–4 h after infection. It demonstrated that LQ may act as a potent anti-influenza B virus agent at an early stage during the infection, typically the synthesis of NP and assembly into vRNP in nucleus. In this study, NP was localized by immunofluorescence staining. The results showed potent inhibitory effect of LQ against NP synthesis of influenza B virus.

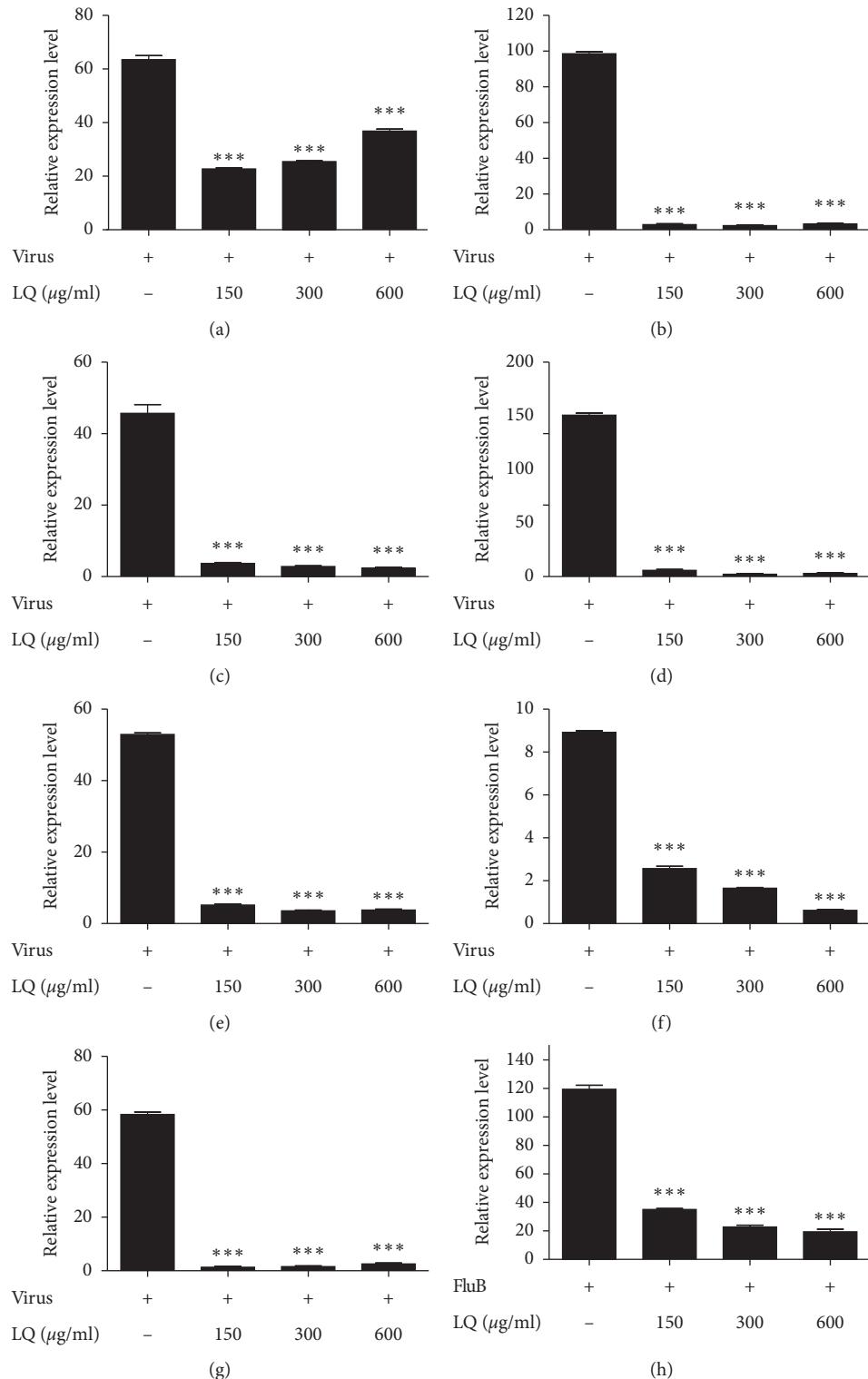


FIGURE 3: The effect of cytokine mRNA expression level in influenza B virus-infected A549 cells after treatment with Lianhua-Qingwen. ***P < 0.001 compared to control via t-test. (a) CCL-5/RANTES. (b) IL6. (c) CXCL8/IL8. (d) CXCL10/IP-10. (e) TNF- α . (f) CCL2/MCP-1. (g) CCL4/MIP-1 β . (h) IFN- λ 1.

Virus entry is the first step of infection, and this process is essential and is mediated by surface glycoprotein hemagglutinin (HA) of influenza virus [19]. There is inhibitory effect of LQ with pretreatment of virus, and it may affect

virus HA, blocking virus binding to cell surface. Therefore, we tested whether LQ can inhibit the virus binding. The results clarified that LQ plays a role in the hemagglutination inhibition (HI) activity of influenza B virus (B/Guangzhou/

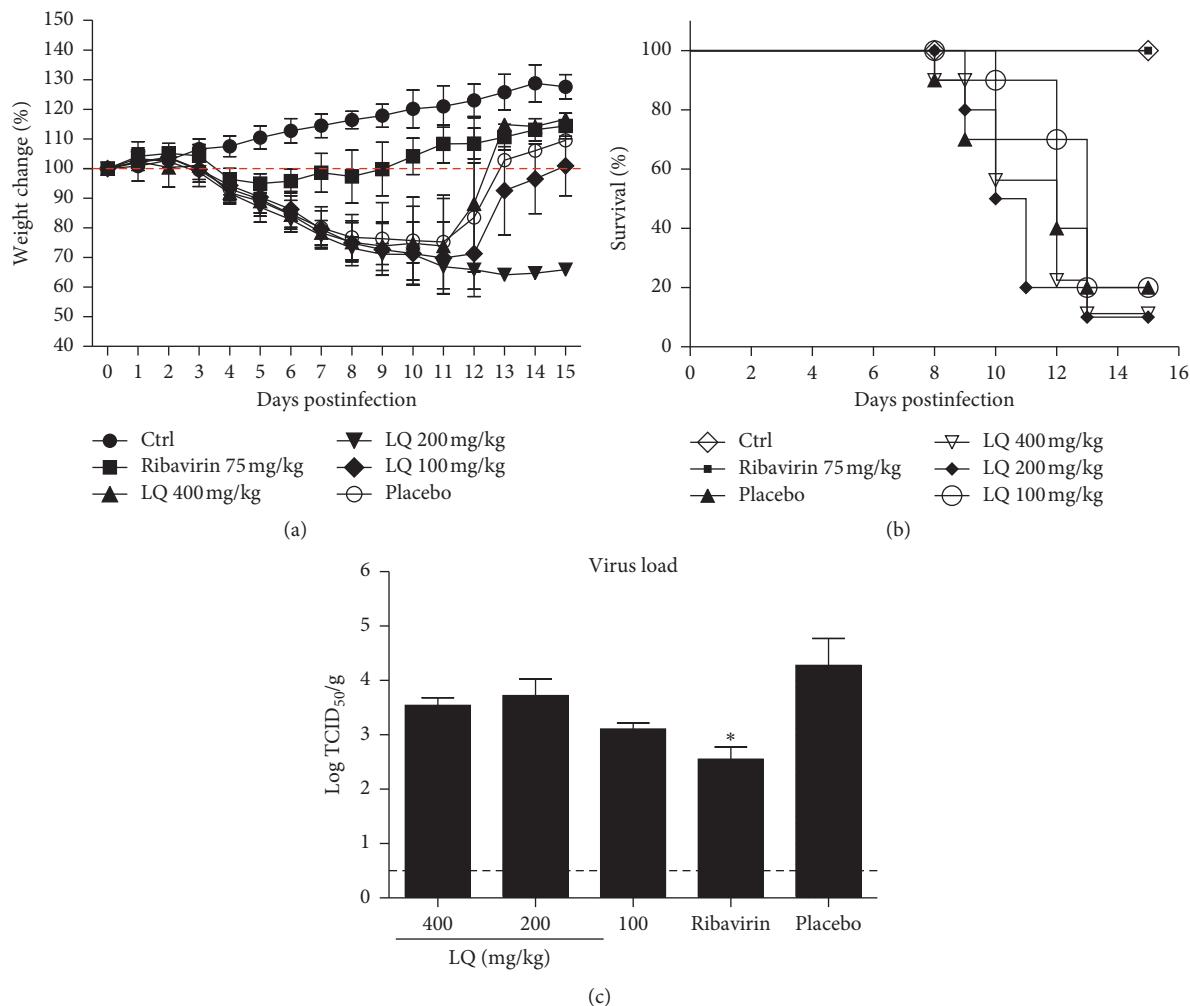


FIGURE 4: The survival and viral titer in lungs of B0215-infected mice after treatment with LQ. (a) Weight change after treatment. (b) Survival after treatment. (c) Viral titer in lungs after treatment. The dotted line is limited detection (LD). * $P < 0.05$ compared to placebo via *t*-test.

0215/2012) but not influenza A virus (A/California/04/2009). To confirm this result, an immunofluorescence assay for viral binding was performed, and the viral binding of B/Guangzhou/0215/2012 to the MDCK cells surface was reduced by treatment with the LQ, but the same result did not occur in influenza A. The receptor binding site of influenza B virus HA has some significant differences from that of influenza A virus HA [20]. Also, influenza B virus HA binds to sialic acids with lower affinity than influenza A virus [21]. We assumed that the reason for this result is whether LQ affects the domain of influenza B HA, which is different from influenza A HA, or the weaker dynamics of influenza B HA. It needs more studies to investigate the mechanisms in the future.

The cytokines and chemokines evoked by the infection have been shown to contribute to the pathology associated with influenza virus infection [22]. LQ is a combination of traditional Chinese medicines. In addition to antiviral activity, it may also have anti-inflammatory activity. Influenza virus infection causes cell necrosis/apoptosis, which induces an immune reaction and the production of cytokines.

However, the cytokine storm, including the deregulated and exaggerated production of cytokines, usually aggravates the degree of disease [22]. Our results showed that LQ can inhibit the excessive expression of RANTES, IL-6, IL-8, IP-10, TNF- α , MCP-1, MIP-1 β , and IFN- λ at the mRNA level and prevent severe inflammation response.

Animal models are essential in the preclinical evaluation of potential antiviral compounds to investigate safety and efficacy. In contrast to influenza A virus, animal models for the study of influenza B infection are lacking. This lack of studies is due to the limitation of the influenza B host range [23], which is related to the NS1 protein [24] and M1 protein [21]. To evaluate the efficacy of LQ in vivo, we screened the clinical influenza B virus strains and obtained a stable mouse lethal strain, B/Guangzhou/0215/2012 (B0215). In this study, the data of viral load in lungs and survival rates showed that orally administered LQ in the concentration of 400 mg/kg/d has no significant protective effect against 5-fold LD₅₀ B0215-infected mice. However, the pathological change in the lungs was alleviated to a certain extent, and there were fewer inflammatory cells in lungs of LQ treated mice

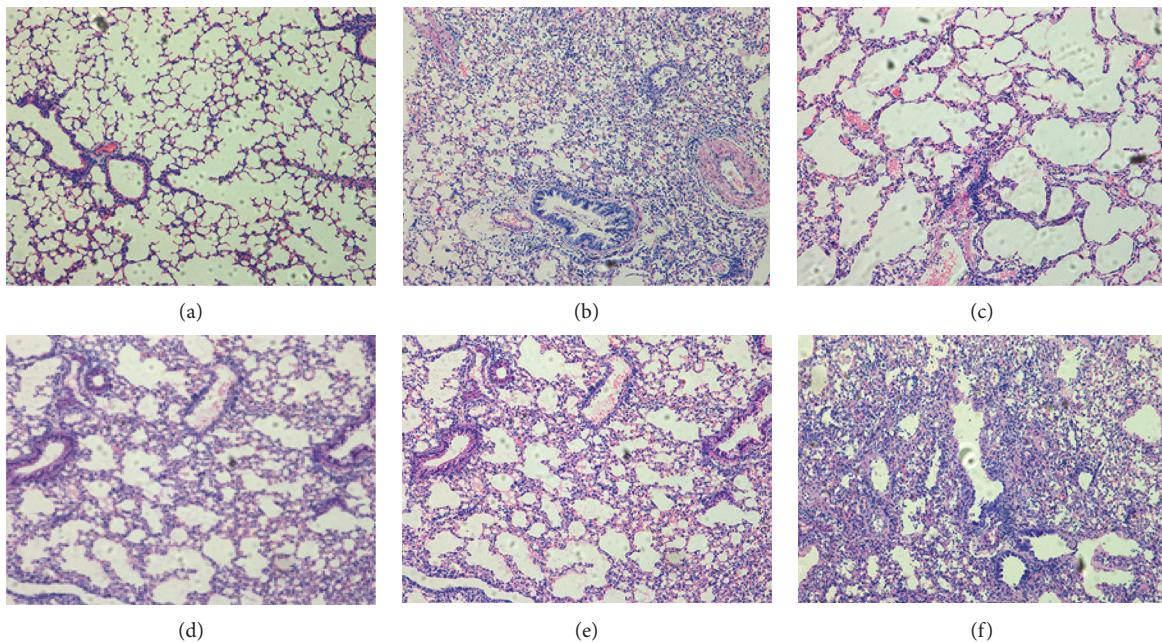


FIGURE 5: The pathological change of B0215-infected mice lungs after treatment with LQ. (a) Uninfected. (b) Placebo. (c) Treated with 75 mg/kg/day of ribavirin. (d–f) Treated with 100, 200, and 400 mg/kg/day of LQ, respectively (100x).

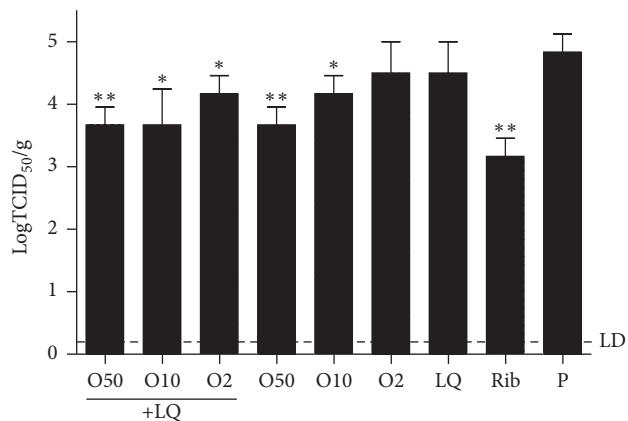


FIGURE 6: The viral load in lungs of B0215-infected mice treated with LQ combined with oseltamivir. The dotted line is the value which detected limitation. ** $P < 0.01$, * $P < 0.05$ compared to placebo via t -test.

compared to mice treated with PBS. Based on our experience of LQ, its effects are multifunctional and mild. According to our previous study of LQ anti-influenza A viruses [15], lung virus titer was reduced under a high dose (1300 mg/kg/d) of LQ in a mouse model of severe pneumonia. In order to investigate the true effects of LQ on influenza B virus, we had developed a ferret model and tree shrew model of influenza B virus [25]. We will evaluate the antiviral effects of LQ through more indicators, such as fever, activity, and viral load of upper respiratory in the future study.

In addition to effectiveness, resistance is another issue of concern of anti-influenza drugs. One approach to increasing antiviral potency and reducing resistance emergence is to use combinations of drugs that target different processes [26, 27]. Recently, many studies evaluating combinations of agents,

including amantadine, oseltamivir, and ribavirin [28–30] antiviral therapy with anti-inflammatory drugs or antioxidant [31–33], and antiviral therapy with immunomodulators [34–36], have been performed. Because LQ has an effect against IBV in individual administration, we speculated that LQ may have potent antiviral activity when combined with other chemical compounds, such as oseltamivir. Our results confirmed that the viral titer in lungs of mice treated with LQ at 200 mg/kg/day in combination with oseltamivir at 2 mg/kg/day was lower than that in mice treated with either LQ or oseltamivir alone. The viral load and inflammation in lungs of influenza B-infected mice were significantly reduced when 200 mg/kg/day of LQ was administered simultaneously with 2 mg/kg/day of oseltamivir for five days. However, we have not tested the combinations of the treatments *in vitro* yet.

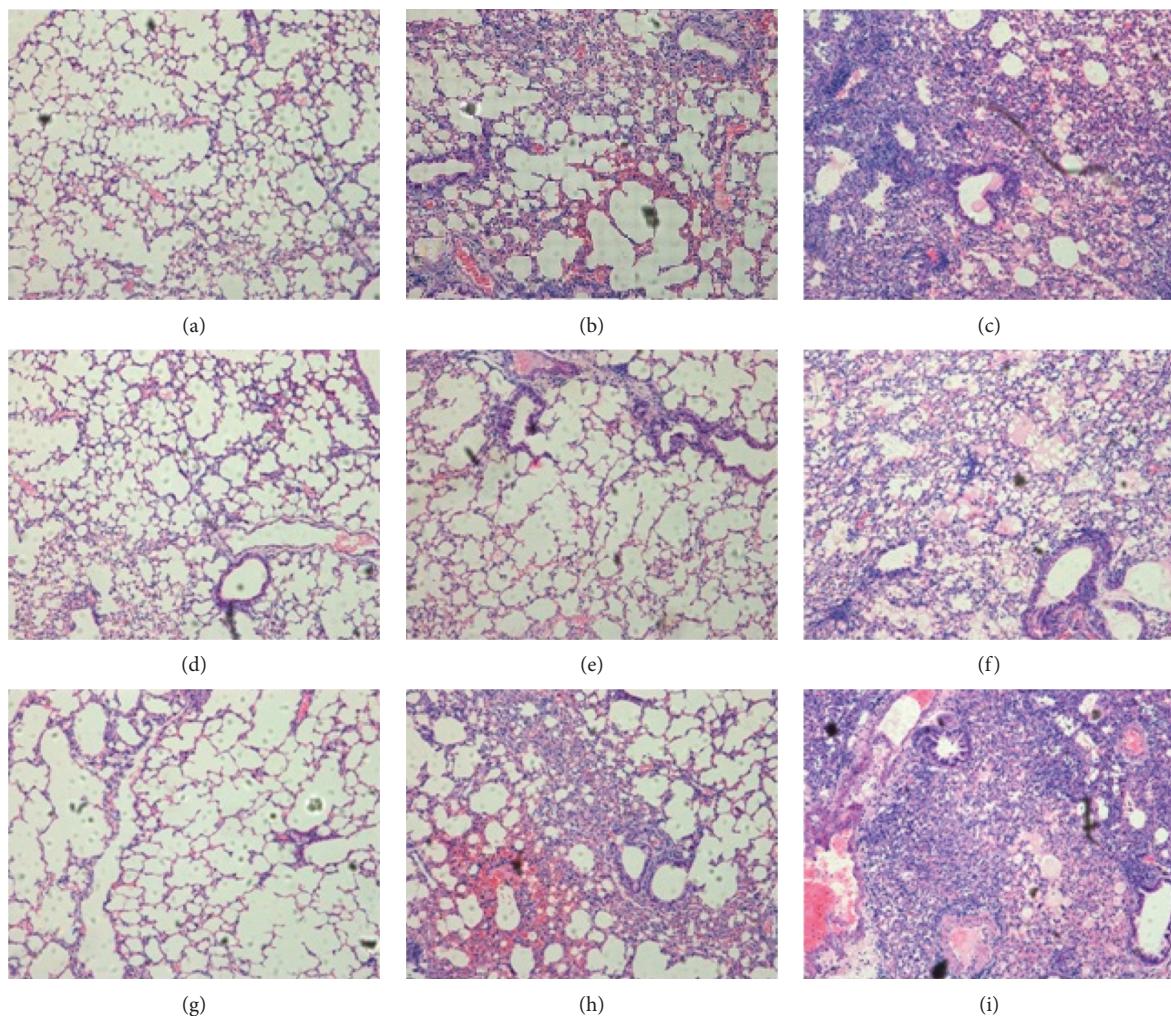


FIGURE 7: The pathological change of infected mice lungs treated with LQ combined with oseltamivir after infection with influenza B. (a) Uninfected. (b) Treated with 75 mg/kg/day of ribavirin. (c) Placebo. (d-f) Treated with 200 mg/kg/day of LQ combined with 50/10/2 mg/kg/day of oseltamivir. (g-i) Treated with 50/10/2 mg/kg/day of oseltamivir.

Data Availability

All the data supporting the results of this study are included within the article.

Disclosure

The funders have no direct involvement in study design or data collection, analysis, and interpretation. The study design and manuscript writing were conducted independently by the authors.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Chunguang Yang, Yutao Wang, and Jiayang He contributed equally to this work.

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