Thymosin β4 Protect Against LPS Induced Lung Injury and Inflammation and Subsequent Fibrosis in Mice

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Research

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Abstract

Background:

Inflammation plays a critical role in the progress ion of pulmonary fibrosis. Thymosin β4 (Tβ4) has antioxidant, anti-inflammatory and antifibrotic effects. Although the potent protective role of Tβ4 in bleomycin-induced pulmonary fibrosis has been validated, the mechanism is not clear, and its impact on LPS-induced lung injury/fibrosis has not been reported.

Method:

Expression of Tβ4 in fibrotic lung tissues was assessed by real-time quantitative reverse transcriptase PCR (RQ-PCR), immunohistochemistry (IHC) and Western Blotting. The effects of intraperitoneal adeno-associated virus-Tβ4 (AAV-Tβ4) on LPS-induced lung injury and fibrosis were observed through the evaluation of collagen deposition and α-SMA expression. In vitro tests with HPAEpiC and HLF-1 cells were performed to confirm the effects of Tβ4.

Results:

In this study, we evaluated the role of Tβ4 on pulmonary fibrosis and explored the possible underlying mechanisms. We found that Tβ4 was markedly upregulated in human or mouse fibrotic lung tissues. Adeno-associated virus-Tβ4 (AAV-Tβ4) markedly alleviated LPS-induced oxidative damage, lung injury, inflammation and fibrosis in mice. Our in vitro experiments also showed that LPS inhibited mitophagy and promoted inflammation via oxidative stress in HPAEpiC, and usage of Tβ4 significantly attenuated LPS-induced mitophagy inhibition, inflammasome activation and TGF-β1 induced epithelial-mesenchymal transition (EMT) in HPAEpiC. Moreover, we found that Tβ4 suppressed the proliferation and attenuated the TGF-β1-induced activation of HLF-1 cells.

Conclusions:

In conclusion, Tβ4 alleviated LPS-induced lung injury, inflammation, and subsequent fibrosis in mice, suggesting a protective role of Tβ4 in disease pathogenesis of pulmonary fibrosis (PF). Tβ4 may involve attenuating oxidative injury, promoting mitophagy, and then alleviating inflammation and fibrosis. Modulating of Tβ4 may be novel strategies for treating PF.

1. Introduction

Pulmonary fibrosis (PF) is a chronic, progressive irreversible and fatal lung disease marked by progressive dyspnea and, ultimately, respiratory failure[1]. Although it is a rare disease, its poor prognosis made it a considerable challenge for clinicians, with a median survival of 2–5 years[2]. Cigarette smoking, exposure to organic and inorganic dust, and genetic factors have been shown to play important roles in disease pathogenesis, and 30% of PF are caused by connective tissue disease (CTD)[3].

Oxidative/antioxidative imbalance and the excessive production of pro-inflammatory and pro-fibrotic cytokines are critically involved in the pathogenesis of PF. These stimulations then lead to alveolar epithelial injury, followed by proliferation of type alveolar epithelial cells and myofibroblasts, and expression of deposition of extracellular matrix (ECM) proteins,such as collagen, and then parenchymal remodeling[4]. Anti-oxidative, anti-inflammatory and anti-fibrotic therapies are often used in the treatment of PF, unfortunately, none of these treatments has been proven available, and lung transplantation is now the only way to a small minority of PF patients[5, 6].

Thymosin β4 consists of 43 amino acids and belongs to a highly conserved β-thymosins family[7]. It spreads in nearly all cells and exits in body fluids, including tears, saliva, blood and plasma[8, 9]. Tβ4 has been reported participating in wound healing, inflammation, fibrosis and tissue regeneration, and recent studies show that Tβ4 prevents inflammation and fibrosis in the eye, skin, heart, liver and bleomycin-induced pulmonary fibrosis[8, 10, 11]. However, the underlaying mechanism of Tβ4 in regulating these fibrotic processes is not fully understood.

Autophagy is a conserved process by which cytoplasmic components, including damaged proteins and organelles, are degraded by lysosomes[12]. An increasing amount of evidence have shown that autophagy limits NLRP3 inflammasome activating by targeting ROS-producing mitochondria, and the process by which mitochondria are degraded by autophagy is called mitophagy[13, 14]. Some recent studies have shown that Tβ4 limits inflammation via contributing to autophagosome formation and membrane remodeling during autophagy[15], and Tβ4 could also prevent oxidative stress[16]. However, to date, no studies have examined whether mitophagy regulates inflammation via Tβ4 during PF.

In the present study, we constructed a recombinant adeno-associated virus (rAAV) to achieve persistent expression of Tβ4 in LPS-induced PF models, and we explored the possible role of Tβ4 in regulating mitophagy and inflammation in vitro.

2. Materials And Methods

2.1 Histological sampling

We collected surgical resected paraffin-embedded human fibrotic lung tissues specimens (10 cases) and pathologically normal para-tumor lung tissue specimens (10 cases) from the Department of Pathology, the First Affiliated Hospital of Xi’an Jiaotong University, with the approval of the Institutional Review Board. Immunoreactions were performed on selected lung sections.

2.2 Preparation of recombinant AAV

Self-complementary recombinant adeno-associated virus were constructed by applying an AAV Helper-Free System (Cell Biolabs, SanDiego, CA, United States). The coding DNA of human Tβ4 (GenBank NM_021109.3) was inserted into pscAAV-MCS to yield the pscAAV- Tβ4 plasmid. Recombinant AAV containing Tβ4 (AAV-Tβ4) was generated via co-transfection of pscAAV-Tβ4, pHelper and pAAVRC5 into

AAV-293 cells using polyethylenimine (PEI). Recombinant AAV carrying LacZ (AAV-LacZ) was constructed as a control virus. 72 hours after transfection, cells were collected for viral particle isolation, purification and quantitative analysis.

TaqMan Universal PCR Master Mix (Applied Biosystems, Foster City, CA, United States) was employed to determine the recombinant AAV (rAAV) titters and the abundance of the rAAV in the lung. The primers against the cytomegalovirus promoter region were as follows: 5'-AGACTTGGAAATCCCCGTGAGT-3' (forward) and 5'-CGTATTAGTCATCGCTATTACCATGGT-3' (reverse). The sequence of the probe was 5'-6FAM-AACCGCTATCCACGCCCATTGATG-TAMRA-3'. The collected data were analyzed by the standard curve method.

2.3 Animals

Specific pathogen free, 6-week-old male ICR mice, weighing 25–30 g were obtained from the Experimental Animal Center, School of Medicine, Xi'an Jiaotong University. The mice were housed under pathogen free conditions under a 12 hours light/dark cycle at constant temperature (22 ± 2 °C) and humidity, with free access to water and standard laboratory chow. All mice were acclimatized to the abovementioned conditions for one week before initiating experiments. All efforts were undertaken to minimize the suffering of the mice.

To test the transduction efficiency of repeated intraperitoneal (i.p.) rAAV injection, twenty four mice were divided into 3 groups: PBS, AAV-LacZ and AAV-Tβ4. Mice in PBS group were injected with PBS, mice in AAV groups were injected were given AAV-LacZ [4×10^{10}viral genome (vg)] or AAV-Tβ4 (4×10^{10}vg) on day 0. Two mice from each group were randomly euthanized on day 14 and day 28. The remaining mice were injected again with AAV-LacZ and AAV-Tβ4 on day 28 and were sacrificed on day 42. The lungs of euthanized mice were harvested for further examination.

2.4 AAV-mediated Tβ4 expression upon LPS-induced lung injury and fibrosis

To verify the expression of Tβ4 in mouse lung after LPS treatment, thirty five mice were divided into normal saline (NS, n = 5) and LPS (n = 30) groups. Septic lung injury model was established by i.p. injection of 5 mg/kg LPS for five consecutive days[17]. Five mice from the LPS group were euthanized on days 7, 14, 21, 28, 35 and 42, while all the mice in the NS group were euthanized on day 7. Mouse lungs were collected for HE and picrosirius red staining, western blotting, and other experiments.

To investigate the effects of Tβ4 on acute lung injury and fibrosis, forty mice were equally assigned into four groups: NS, NS + LPS, LPS + AAV-LacZ and LPS + AAV-Tβ4. Mice in AAV groups were i.p. injected with AAV (AAV-LacZ or AAV-Tβ4, 4×10^{10} vg) for the first time, while mice in the other two groups were injected with an equal volume of NS. Two days later (Day 0), the mice were i.p. instilled with NS or LPS. Five mice in each group were sacrificed on day 7. The remaining mice received the second i.p. administration of AAV or NS on day 26 (four weeks after the first adenovirus administration) and were sacrificed on day 42, when the lungs and serum were harvested for subsequent experiments. The mice

were weighed during LPS modeling, and their lung coefficient was calculated (lung coefficient = lung wet weight/body weight × 100).

2.5 Bronchoalveolar lavage (BAL)

BAL was carried out on day 7 following LPS injection. After the mice were sacrificed, their lungs and trachea were extracted immediately, and a 20G intravenous catheter was inserted into their trachea. 1 mL PBS was instilled into the lungs and withdrawn three times via the catheter. More than 85% of the fluid was recovered as bronchoalveolar lavage fluid (BALF), which was then centrifuged at 1000 rpm for 10minutes at 4 °C. The supernatants were collected and stored at -80℃, and the precipitate was washed with red blood cell lysis buffer and resuspended in 500 μL PBS for further tests.

2.6 Measurement of malondialdehyde (MDA) and myeloperoxidase (MPO)

MDA content and MPO activity in mouse lung tissue were detected with commercially available kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) according to the manufacturer's protocols.

2.7 Measurement of hydroxyproline content

Pulmonary hydroxyproline content was detected with commercially available kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) according to the manufacturer's protocols.

2.8 Measurement of IL-1β

IL-1β level was detected by enzyme-linked immunosorbent assay (ELISA) using commercially available kits (eBioscience, San Diego, CA, USA) according to the manufacturer's protocols.

2.9 Cell culture, proliferation assay and reagents treatment

The HPAEpiC were cultured in DMEM, while HIF-1 cells were cultured in F-12K medium supplemented with 10% foetal bovine plasma and 2 mM L-glutamine at 37 °C in a 95% air, 5% CO_2-humidified atmosphere.

Cells were trypsinized, and 500 cells were seeded onto 96-well plates and allowed to adhere for 24hours. Cells were then treated with Tβ4 at different concentrations (0, 75, and 150 nM) and incubated for another 72hours. Cell viability was assessed using CCK-8 (Dojindo, Kyushu, Japan) assay at 24, 48, and 72hours according to the manufacturer's protocols.

Cells were trypsinized, and 5×10^5 cells were seeded onto plastic dishes and then treated with H_2O_2 (0, 100, 200 and 400 μM), LPS (1 μg/mL), NAC (10 mM), FCCP (10 μM), Oligomycin (10 μM) or TGF-β1 (5 ng/mL).

2.10 Western Bloting

Protein extracts were prepared from cells and mouse lung tissues by RIPA Lysis Buffer supplemented with Complete EDTA-free protease inhibitor cocktail tablets (Roche Applied Science, Basel, Switzerland)

and phosphatase inhibitor cocktails (Sigma-Aldrich). Protein samples (50 μg) were loaded onto SDS-PAGE gels and transferred onto PVDF membranes. After blocking in 5% evaporated milk at room temperature for 2hours, the membranes were then incubated with the indicated primary antibodies in 5% evaporated milk in TBS plus 0.1% Tween 20 overnight at 4 °C. The following primary antibodies were used: anti-Thymosin β4 (ab167650, Abcam, Cambridge, UK), anti-α-SMA (#56856, Cell Signaling Technology, Danvers, MA, USA), IL-1β (#12703, Cell Signaling), PINK1 (#6946, Cell Signaling), anti-Tom40 (H-300, Santa Cruz Biotechnology, Santa Cruz, CA), and β-actin as a loading control (no. 4970; Cell Signaling). and β-Actin as a loading control (#4970, Cell Signaling). Signals were developed using a chemiluminescent substrate and visualized through X-ray films.

2.11 Immunohistochemistry

Immunoreactions were performed on selected liver sections. Antigens were detected by the following primary antibody, followed by appropriate secondary antibodies: anti-Thymosin β4 (ab167650, Abcam, Cambridge, UK) and anti-α-SMA (#56856, Cell Signaling Technology, Danvers, MA, USA). The slides were then observed under a Nikon Eclipse microscope (Tokyo, Japan) coupled to a digital camera.

2.12 Statistical analysis

The results are expressed as the means ± standard deviation. Statistical analysis was performed using SPSS software 13.0 (SPSS, Inc., Chicago, IL, USA). The Shapiro-Wilk test and Levene statistic were used to evaluate the normality and homogeneity, respectively, of the variance. According to the situation, t-tests or Mann-Whitney U tests were used to evaluate differences between two groups; correlations between two quantitative groups were analysed with Pearson or Spearman correlation tests. The $\chi 2$ test was used for comparisons between two groups. The reported P-values are two-sided, and P-values < 0.05 were considered statistically significant.

3. Results

3.1 Tβ4 expression was elevated in human and mouse fibrotic lung tissues

Immunohistochemical staining showed a marked increase in Tβ4 expression in fibrotic human lung tissues, especially in hyperplastic alveolar epithelial cells, resulted in a significant increase in the average IOD compared with that in normal tissues (Fig. 1A). In LPS-treated mice, qRT-PCR and western blot showed markedly elevated expression of Tβ4 (Fig. 1B, C). The expression of Tβ4 was also confirmed by immunohistochemistry, which demonstrated that type II alveolar epithelial cells were weakly immunostained with anti-Tβ4 antibody in normal, while strongly immunostained in hyperplastic epithelial cells in fibrotic mouse lung tissues (Fig. 1D).

3.2 Intraperitoneal administration of adeno-associated virus efficiently transduced mouse lung tissue

To verify the transduction efficiency of recombinant adeno-associated viruses in mouse lung, we used qRT-PCR to determine the abundance of vector DNA in mouse lung. As shown in Fig. 2A, qRT-PCR revealed the presence of vector DNA in mouse lung after the administration of recombinant adeno-associated viruses. Moreover, western blot showed that expression levels of Tβ4 following the second injection of recombinant adeno-associated viruses were comparable to those observed following first injection, which indicated that realizing prolonged ectopic expression by repeated injection of recombinant adeno-associated viruses was feasible (Fig. 2B).

3.3 Tβ4 protected mice form LPS-induced lung injury and inflammation

Body weight continuously decreased, while lung coefficient markedly increased after LPS treatment, AAV-Tβ4 significantly attenuated these changes (Fig. 3A, B). We found lower tissue MDA content in AAV-Tβ4 group than in NS + LPS or LPS + AAV-LacZ groups, both in day 7 and day 42 (Table 1). Histological examination showed lung injury and inflammation by interstitial edema, infiltration of inflammatory cells, and hyaline membrane formation, and all these changes were alleviated by AAV-Tβ4 (Fig. 3C). Moreover, LPS increases in BALF protein content (Fig. 3D), and total cell number (Fig. 3E) were significantly attenuated by AAV-Tβ4.

Table 1
AAV-Tβ4 alleviates increases in MDA content and MPO activity in lung tissues

		NS	NS + LPS	LPS + AAV-LacZ	LPS + AAV- Tβ4
	Time	(n = 5)	(n = 5)	(n = 5)	(n = 5)
MDA	Day 7	0.64 ± 0.68	1.42 ± 0.12	1.46 ± 0.32	0.95 ± 0.17*
(nmol/mg prot.)	Day 42	0.78 ± 0.35	1.71 ± 0.45	1.69 ± 0.29	1.16 ± 0.29*
MPO	Day 7	0.45 ± 0.43	0.89 ± 0.23	0.99 ± 0.34	0.53 ± 0.17*
(U/g)	Day 42	0.62 ± 0.23	1.07 ± 0.26	1.02 ± 0.19	0.79 ± 0.17*
* $P < 0.05$ vs the NS + LPS or LPS + AAV-LacZ group					

We found tissues MPO activity, an indicator of oxidative injury as well as neutrophil infiltration, was elevated by LPS treatment, and this increase was also attenuated by AAV-Tβ4 (Table 1). To further explore the anti-inflammatory function of Tβ4 in LPS-treated mice, the BALF level of inflammatory mediators, such as TNF-α, IL-1β and IL-6 in fibrotic mouse lungs were tested, and we found AAV-Tβ4 significantly mitigated the increase (Table 2).

Table 2
AAV-Tβ4 alleviates LPS-induced upregulation of inflammatory factors in lung tissue

Concentration in BALF (pg/mL)	NS	NS + LPS	LPS + AAV-LacZ	LPS + AAV- Tβ4
	(n = 5)	(n = 5)	(n = 5)	(n = 5)
IL-1β	63.15 ± 2.11	84.43 ± 1.67#	85.13 ± 1.76#	70.18 ± 2.55*
IL-6	76.87 ± 1.91	90.12 ± 3.33#	92.23 ± 3.21#	79.38 ± 2.11*
TNF-α	6.76 ± 1.89	15.56 ± 7.23#	16.15 ± 7.15#	9.05 ± 1.97*
#P< 0.01 vs the NS group				
* P< 0.01 vs the NS + LPS or LPS + AAV-LacZ group				

3.4 Tβ4 attenuated LPS-induced lung fibrosis in mice

42 days after LPS treatment, pulmonary hydroxyproline content was markedly increased (Fig. 4A). HE and picro-shaped red staining followed showed that lots of spindle-shaped fibrotic cells clumped together, and collagen fibers accumulated (Fig. 4C, D), with increased fibrosis score in LPS-treated mice (Fig. 4B). All these above fibrotic changes were significantly alleviated by AAV-Tβ4, while usage of AAV-LacZ showed no significant effect (Fig. 4A-D).

The expression of α-SMA was significantly lower in LPS + AAV-Tβ4 group than in NS + LPS and LPS + AAV-LacZ group (Fig. 4E), and this result was also verified by western blot (Fig. 4F) and immunohistochemistry (Fig. 4G).

3.5 LPS promoted inflammation and inhibited mitophagy in HPAEpiC

We next investigated the effect of LPS in HPAEpiC. We first confirmed that the ROS donor H_2O_2 led to decreased mitochondria membrane potential (MMP) and promoted ROS accumulation and inflammation in a dose-dependent manner. Moreover, the antioxidant NAC decreased the LPS/H_2O_2-induced inflammation in HPAEpiC, suggesting that ROS plays a central role in LPS-induced inflammation in HPAEpiC (Fig. 5A-F).

Recently mitophagy has been shown to alleviate inflammation via inhibiting the NLRP3 inflammasome, we then tested whether ROS induce inflammation through mitophagy. Usage of oligomycin, an ATP synthase inhibitor, promoted LPS-induced IL-1β secretion; moreover, usage of FCCP, a drug dissipates MMP and induces mitophagy by activating PINK1, rescued HPAEpiC from LPS-induced inflammation (Fig. 5G, H). Because ROS-induced inflammation in HPAEpiC was modulated by mitophagic inhibitor and inducer, we thus wondered whether ROS regulated mitophagy in HPAEpiC.

As the initiator of mitophagy, PINK1 phosphorylates ubiquitin to active Parkin, which builds ubiquitin chains on mitochondrial outer membrane proteins. We found that incubation with H_2O_2 led to decreased expression of PINK1 in a dose-dependent manner. Mitophagy inhibition leads to an increase in Tom40 protein level. We found here that usage of H_2O_2 promoted Tom40 accumulation in a dose-dependent manner (Fig. 5I).

3.6 Tβ4 attenuated LPS-induced mitophagy inhibition, inflammasome activation and TGF-β1 induced EMT in HPAEpiC

We firstly tested whether Tβ4 affects mitophagy and inflammation in HPAEpiC, and found that Tβ4 alleviated LPS/H_2O_2-induced decreased expression of PINK1, and Tom40 accumulation (Fig. 6A), we also revealed that Tβ4 successfully suppressed LPS/H_2O_2-induced NLRP3 activation and IL-1β secretion in HPAEpiC (Fig. 6B, C). qRT-PCR showed that although Tβ4 did not affect the basal expression levels of vimentin and α-SMA, it markedly opposed the TGF-β1-induced upregulation of vimentin and α-SMA in HPAEpiC (Fig. 6D, E).

3.7 Tβ4 suppressed the proliferation and attenuated the TGF-β1-induced activation of HLF-1 cells

The CCK-8 assay showed that Tβ4 significantly inhibited the growth of HLF-1 cells (Fig. 7A). qRT-PCR revealed that Tβ4 did not affect basal expression of α-SMA and vimentin, but markedly attenuated the TGF-β1 induced elevation of α-SMA and vimentin in HLF-1 cells (Fig. 7B, C).

4. Discussion

Pulmonary fibrosis is a heterogeneous disease with significant global morbidity and mortality. PF is the most common form of pulmonary fibrosis, and the mechanism of disease pathogenesis of PF is now poorly understood. Recent studies have shown that PF mainly results from inflammation and consequently fibroblast proliferation, which leads to abnormal deposition of extracellular collagen[3]. In the present study, we firstly found increased expression of Tβ4 in human and mouse fibrotic lung tissues. The role of Tβ4 in alleviating hepatic, renal and cardiac fibrosis has been confirmed by some recent researches[9, 18, 19]. The increased production of local Tβ4 in mice serves as an adaptive response to lung injury, and this increased expression of endogenous Tβ4 might not be sufficient enough to alleviate lung injury and fibrosis. Our data revealed protective effect of Tβ4 in pulmonary fibrosis, AAV-mediated dramatic overexpression of in mouse lung successfully alleviated LPS-induced lung injury and fibrosis in mice. Our subsequent results indicated that the protective role of Tβ4 may involve suppressing oxidant damage and inflammasome activity, and then alleviating fibrosis.

The lung is susceptible to high oxygen tension, exogenous oxidants and pollutants can increase oxidant production in the lung[20]. Previous studies have revealed that ROS play a role in the pathogenesis of

lung inflammation, the generation of mitochondrial ROS is crucial for NLRP3 inflammasome activation, leading to the release of IL-1β[21]. Here, our in vitro data demonstrated that ROS promotes inflammation in alveolar epithelial cells, alveolar epithelial injury leads to the impairment of air exchange function and, more importantly, the secretion of IL-1β[22]. We also found that treatment of LPS induced ROS generation in HPAEpiC, leading to activation of NLRP3 inflammasome, and this effect was alleviated by NAC, an antioxidant.

Chronic inflammation participates in the pathogenesis of many human diseases, including PF. These diseases are characterized by excessive ROS production, and dysfunctional mitochondria have also been shown implicated in these disorders, act as both a source and a target of ROS[23]. Mitophagy is a special type of autophagy which degrades damaged mitochondrial. In the present study, we found mitophagy was decreased in HPAEpiC, and this phenomenon was alleviated by NAC. Moreover, we found that FCCP, a mitophagy inducer, alleviated LPS/H_2O_2 induced IL-1β secretion,whereas oligomycin, an mitophagy inhibitor, promoted LPS/H_2O_2 induced IL-1β secretion in HPAEpiC. Defective mitophagy leads to accumulation of damaged ROS-generating mitochondria and then activation of NLRP3 inflammasome, our data revealed for the first time that ROS promotes inflammation via mitophagy inhibition in HPAEpiC.

The anti-oxidative effect of Tβ4 has been conformed in many previous studies[11, 16], in the present study, we observed that Tβ4 significantly attenuated LPS-induced elevation of mouse pulmonary MPO activity, MDA content and pro-inflammatory cytokines in vivo and LPS/ H_2O_2 induced mitophagy inhibition and inflammasome activation in vitro. Inflammation is thought participates in the initial period of pathogenesis of lung fibrosis, dysfunction of alveolar epithelial cells and subsequent inflammation trigger fibrogenic process, resulting in the deposition of matrix and remodeling of lung[24]. Our data demonstrated that Tβ4 alleviated LPS-induced lung inflammation and fibrosis in mice, and suppressed fibrogenic process in HPAEpiC and HLF-1 cells.

In conclusion, the present study demonstrates that Tβ4 alleviates LPS-induced lung injury, inflammation, and subsequent fibrosis in mice, suggesting the protective role of Tβ4 in disease pathogenesis of PF. In addition, this study also indicates that the protective effect of Tβ4 may involve attenuating oxidative injury, promoting mitophagy, and then alleviating inflammation and fibrosis. Modulating of Tβ4 may be novel strategies for treating PF.

Abbreviations

Tβ4
Thymosin β4
RQ-PCR
Quantitative reverse transcriptase PCR
IHC
Immunohistochemistry
AAV

Adeno-associated virus
LPS
Lipopolysaccharide
PF
Pulmonary fibrosis
CTD
Connective tissue disease
ECM
Extracellular matrix
i.p.
intraperitoneal
BALF
Bronchoalveolar lavage fluid
MDA
Malondialdehyde
MPO
myeloperoxidase
MMP
mitochondria membrane potential

Declarations

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Contributions

Zhen Tian contributed to the study conception and design. Experiments were performed by Zhen Tian, Naijuan Yao. Data analysis were performed by Yuchao Wu, Fei Wang. The first draft of the manuscript was written by Zhen Tian and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Ethics declarations:

Ethics approval and consent to participate

This study followed the national guidelines and protocols of the National Institutes of Health and was approved by the Local Ethics Committee for the Care and Use of Laboratory Animals of Xi'an Jiaotong University.

Competing interests

All authors declare that they have no competing interests

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Figures

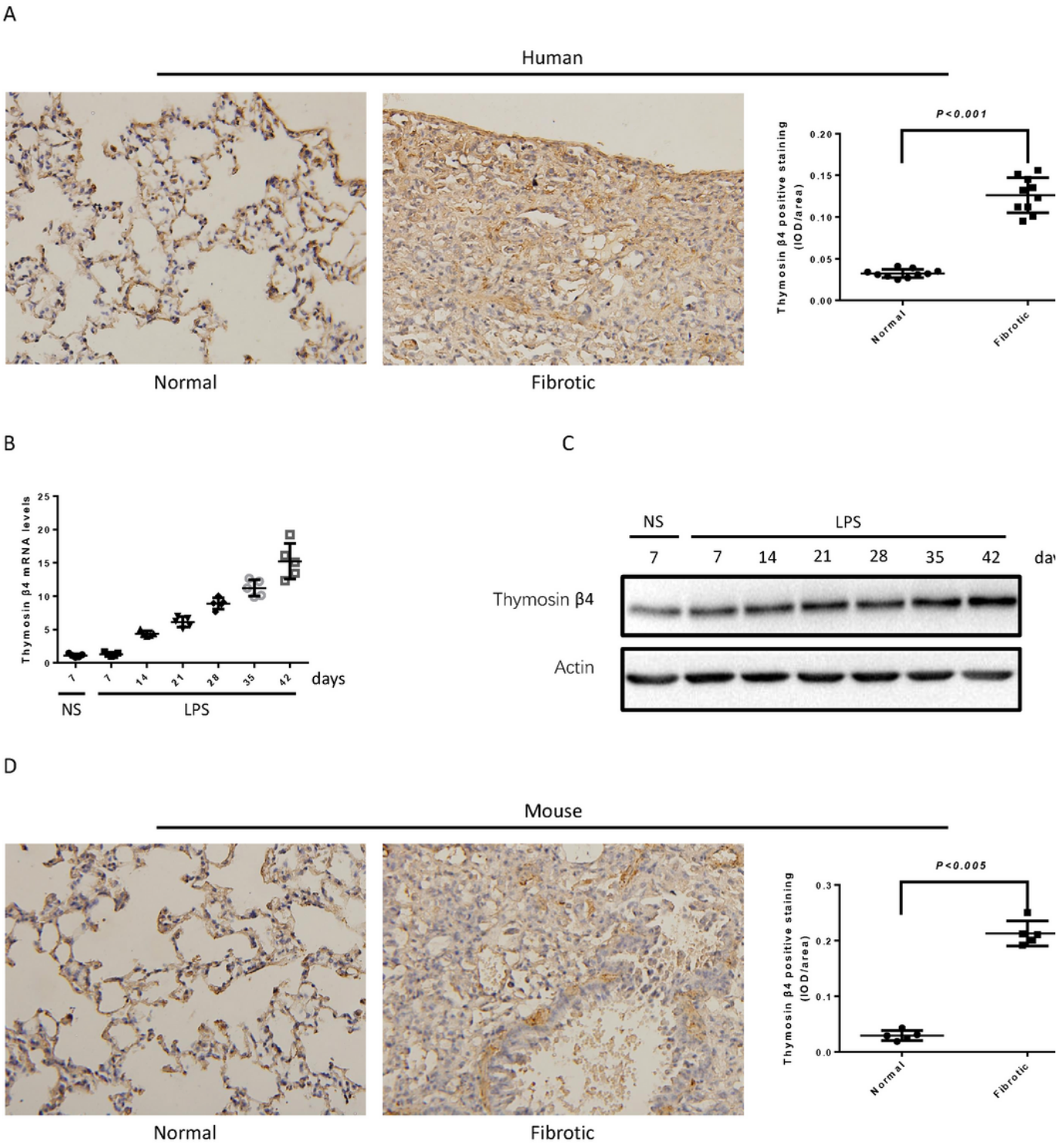

Figure 1

Tβ4 expression is elevated in human and mouse fibrotic lung tissues Immunohistochemistry showed that type II alveolar epithelial cells were positively stained with anti-Tβ4 antibody in normal human lung tissue, and Tβ4 expression was drastically elevated in fibrotic human lung tissues (A). Expression of Tβ4 in mouse lung tissues was upregulated at both the mRNA (B) and protein (C) levels. Immunohischemical

staining showed that the expression of Tβ4 in normal and fibrotic mouse lung tissues are similar to those in the normal and fibrotic human lung tissues (D).

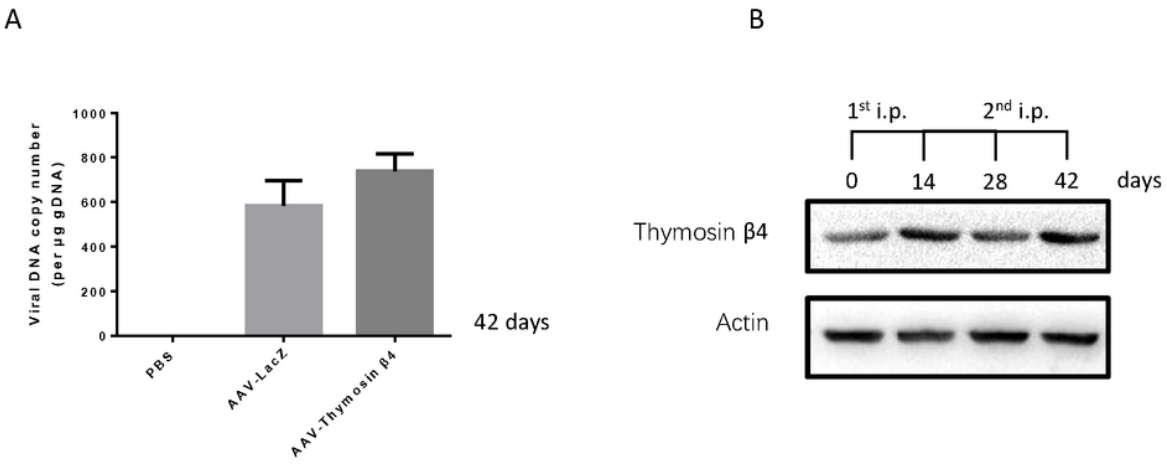

Figure 2

I.p. administration of adeno-associated virus carrying Thymosin β4 mediated expression of Tβ4 in mouse lung rt-PCR showed the presence of viral DNA in lung tissues of AAV-treated mice 2 weeks after i.p. administration of AAV-Tβ4 (A). Western blot showed that the expression of Tβ4 following the second injection of the adeno-associated virus were comparable to those after the first injection in mouse lung (B).

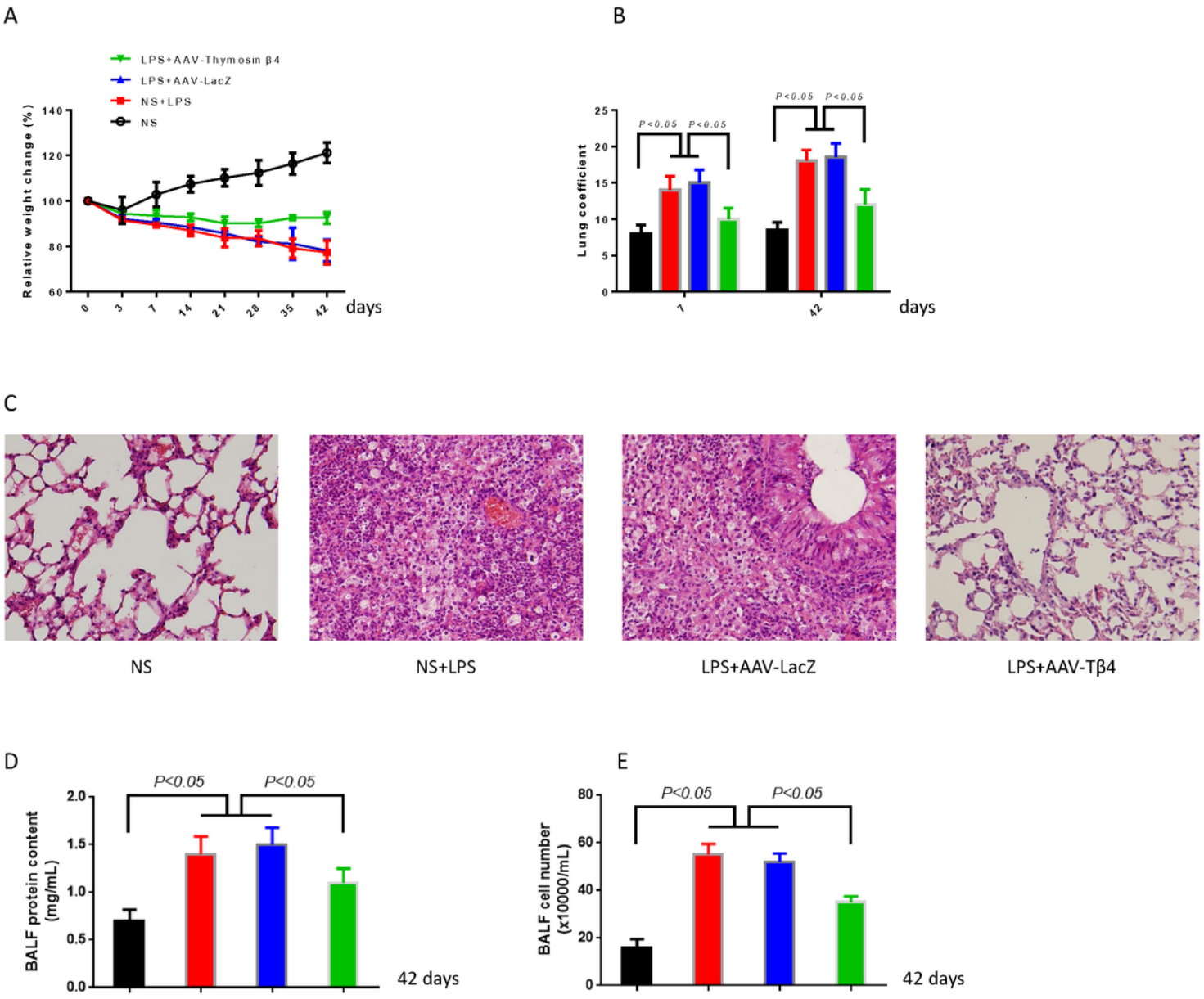

Figure 3

Tβ4 alleviates LPS-induced lung injury and inflammation in mice Mice in the AAV-Tβ4 group lost less bodyweight than those in the other two LPS groups (A). Similarly, AAV-Tβ4 alleviated increase in the mouse lung coefficient on both day 7 and day 42 after LPS installation (B). AAV-Tβ4 significantly mitigated lung injury and inflammation, as showed by HE staining of mouse lung (C), BALF protein concentration (D), and cell counting (E) at day 42.

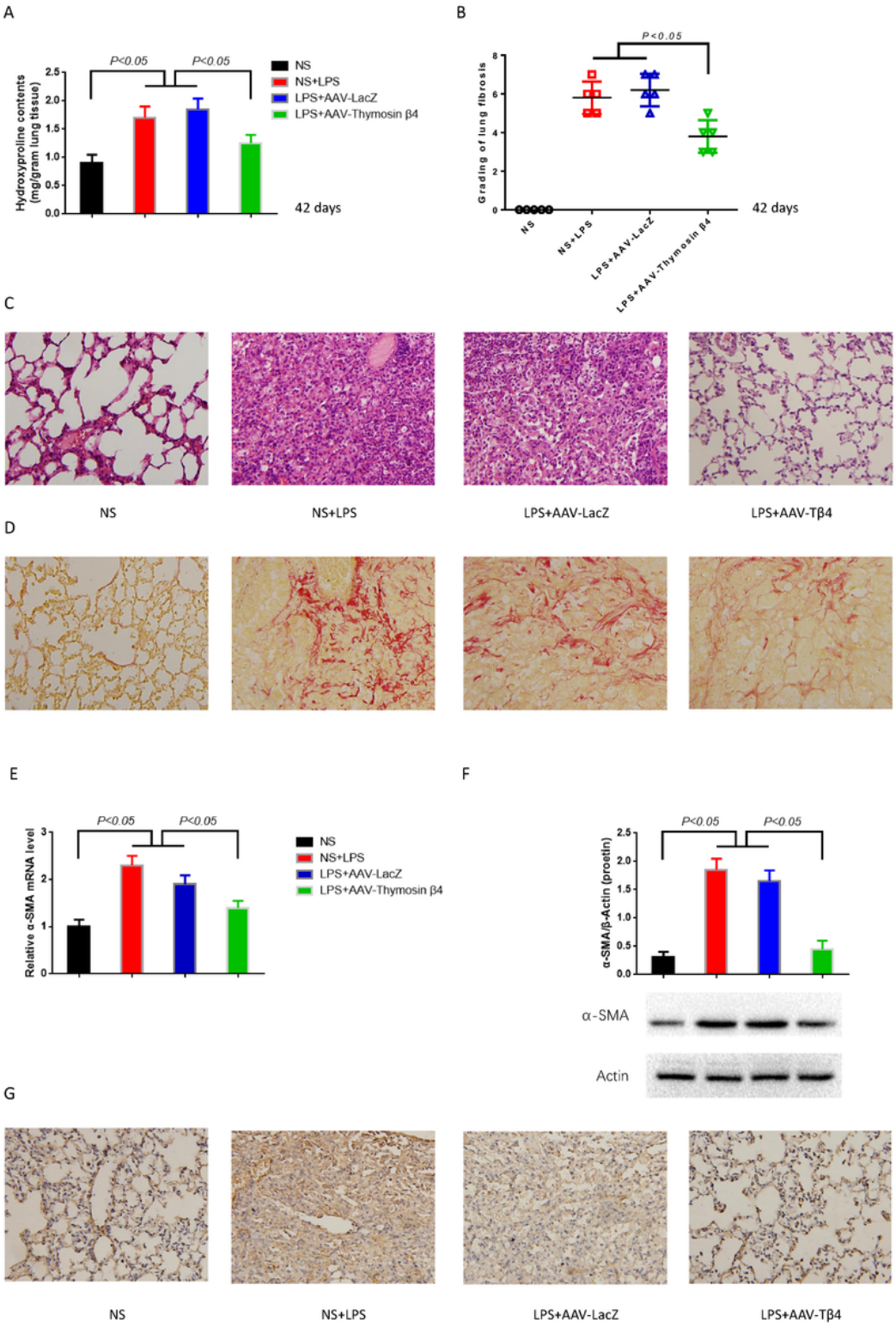

Figure 4

AAV-Tβ4 alleviates LPS-induced lung fibrosis in mice Tβ4 significantly attenuated LPS-induced lung fibrogenesis in mice, as indicated by lower pulmonary hydroxyproline content (A), milder lung structure destruction (C), less picro-sirius red-positive collagen deposition (D) and lower fibrosis score (B) compared with those in NS+LPS and AAV-LacZ+LPS groups. AAV-Tβ4 significantly alleviated LPS-

induced excess expression of α-SMA in mouse lung, as confirmed by rt-PCR (E), western blot (F) and immunohistochemistry (G), compared with those in NS+LPS and AAV-LacZ+LPS groups.

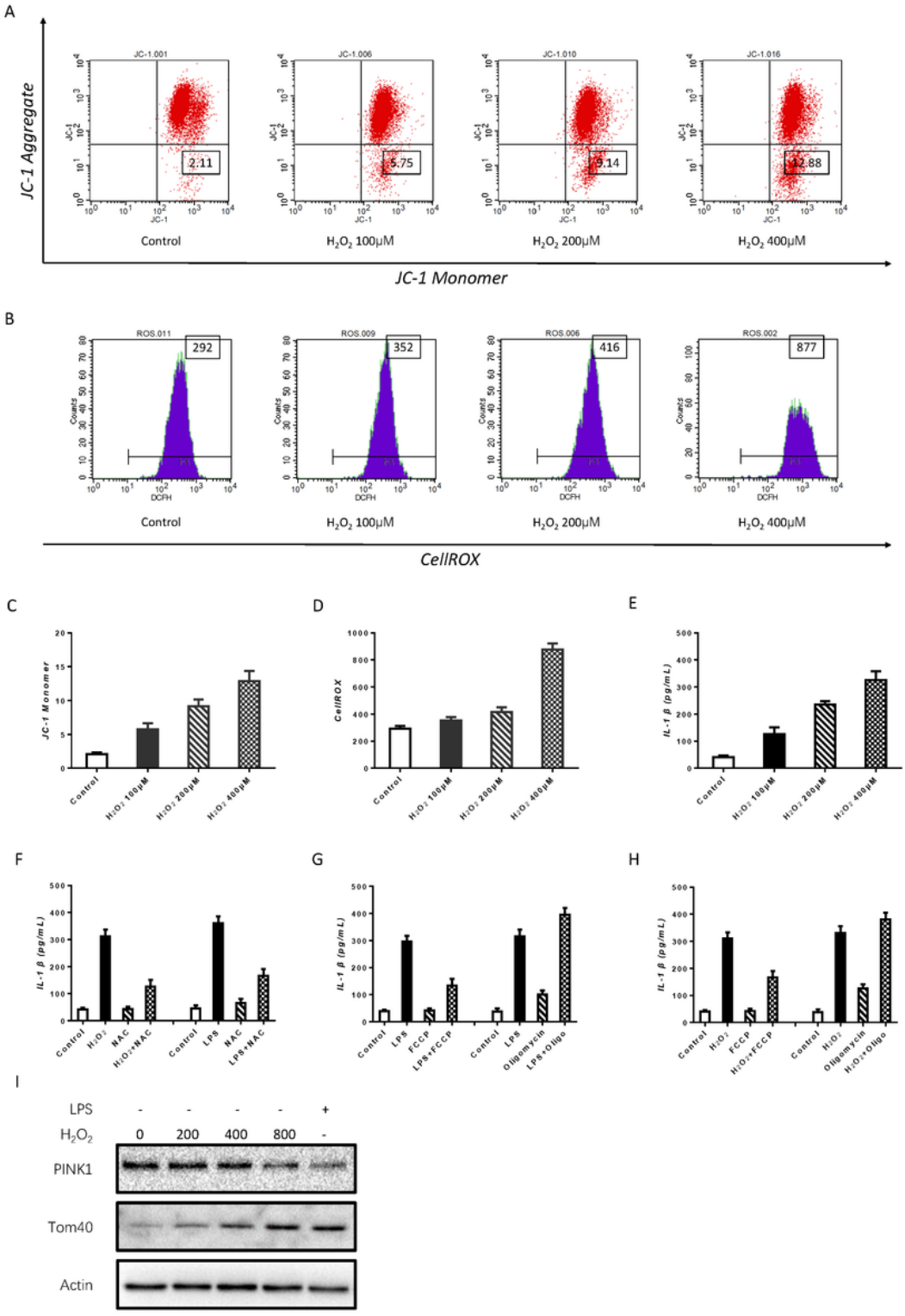

Figure 5

H2O2 influences MMP and ROS, and promotes inflammation in HPAEpiC H2O2 treatment influenced MMP (A, C) and accumulated ROS (B, D) in a concentration-dependent manner over the range of 0-400μM. H2O2 activated inflammation and promoted IL-1β secretion in a dose-dependent manner (E), and

usage of NAC successfully alleviated H2O2/LPS-induced IL-1β secretion (F). FCCP inhibited and oligomycin promoted H2O2/LPS-induced IL-1β secretion (G, H) in HPAEpiC. H2O2 inhibited mitopahgy in a dose-dependent manner (I).

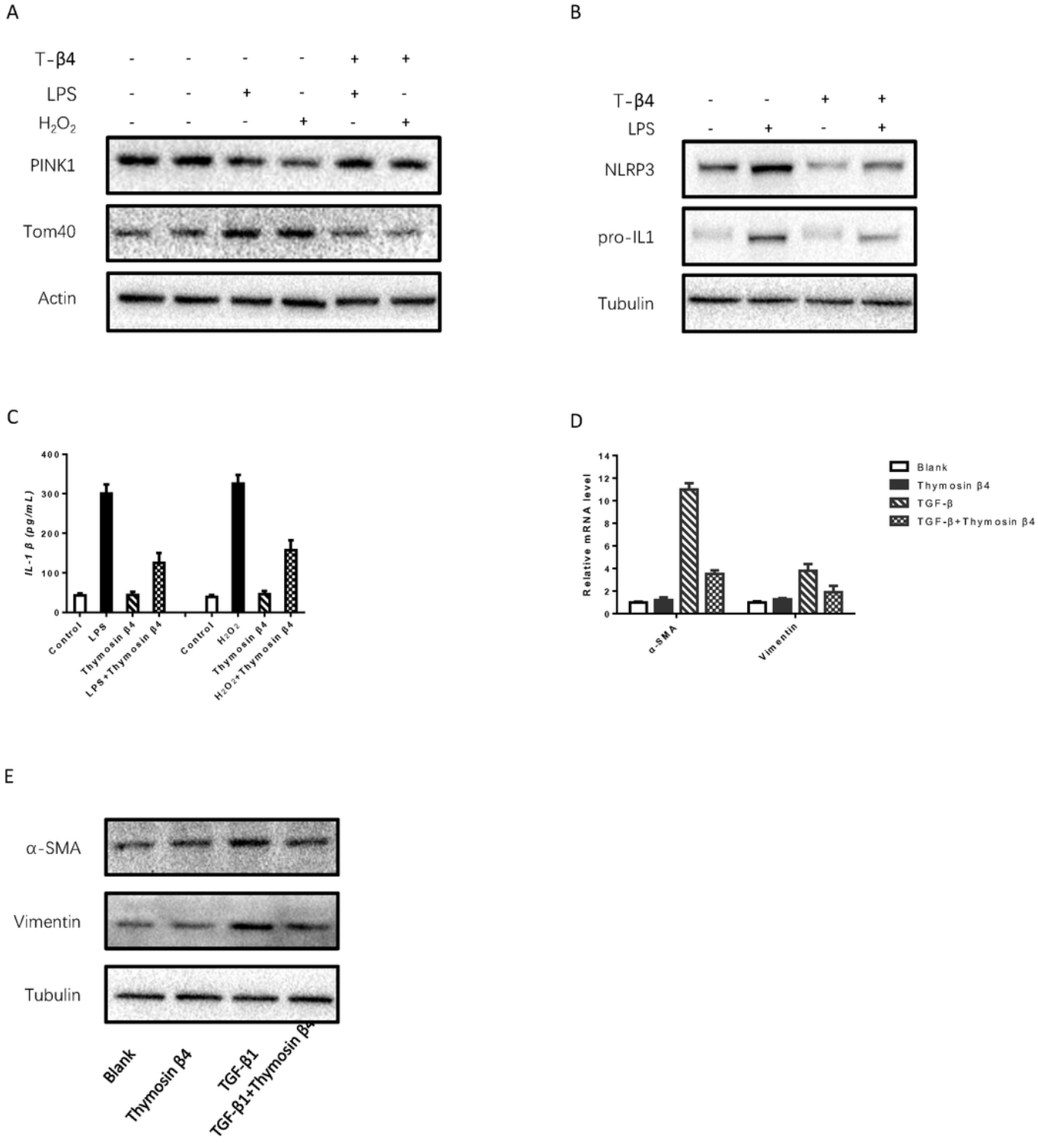

Figure 6

Tβ4 attenuates LPS-induced mitophagy inhibition, inflammasome activation and TGF-β1-induced EMT in HPAEpiC Tβ4 alleviated H2O2/LPS-induced decreased expression of PINK1 and accumulation of Tom40

(A). Tβ4 suppressed H2O2/LPS-induced NLRP3 inflammasome activation and IL-1β secretion (B, C). Tβ4 did not affect the basal expression of α-SMA, vimentin, but markedly attenuated the TGF-β1-induced upregulation of α-SMA and vimentin (D, E).

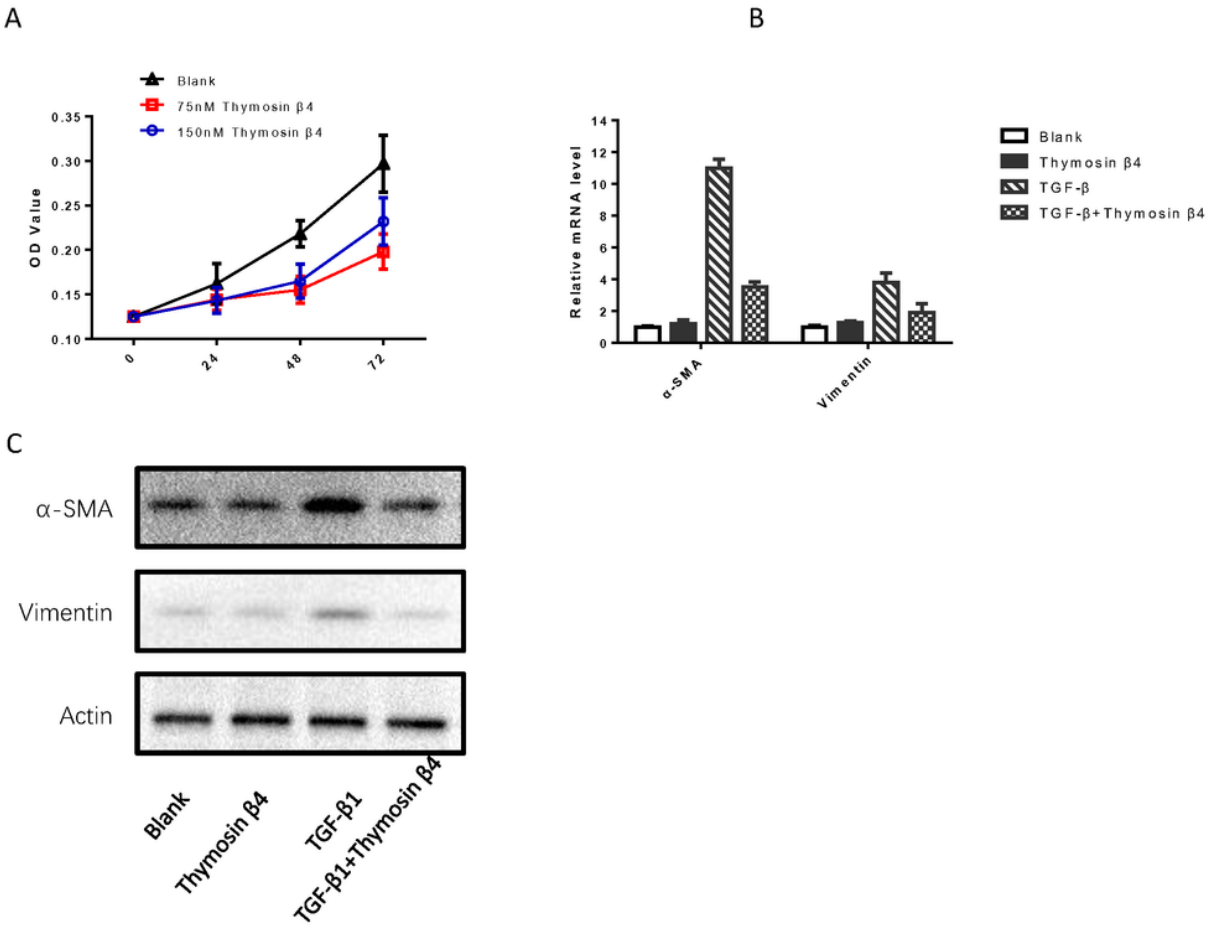

Figure 7

Tβ4 suppresses proliferation and TGF-β1-induced activation in HLF-1 cells Tβ4 suppressed HLF-1 cell growth in a dose-dependent manner (A). Tβ4 did not affect the basal expression of α-SMA, vimentin (B), but markedly attenuated the TGF-β1-induced upregulation of α-SMA and vimentin (C).