

## Original Article

# PPAR- $\gamma$ agonists inhibit TGF- $\beta$ 1-induced chemokine expression in human tubular epithelial cells

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**Aim:** Peroxisome proliferator-activated receptor- $\gamma$  (PPAR- $\gamma$ ) has a wide range of biological functions, including anti-inflammation. In this study, we investigated the inhibitory effects of PPAR- $\gamma$  on transforming growth factor  $\beta$ 1 (TGF- $\beta$ 1)-induced interleukin-8 (IL-8) and monocyte chemoattractant protein-1 (MCP-1) expression in renal tubular epithelial cells (HK-2).

**Methods:** HK-2 cells were pretreated with 15d-PGJ2 or troglitazone (TGL) and then treated with TGF- $\beta$ 1. Expression of MCP-1 and IL-8 was measured using real-time PCR and ELISA.

**Results:** Treatment with 5 ng/mL TGF- $\beta$ 1 for 24 h increased both MCP-1 and IL-8 mRNA and protein levels in HK-2 cells. Both 15d-PGJ2 at 2.5 and 5  $\mu$ mol/L and TGL at 2.5  $\mu$ mol/L exhibited inhibitory effects on TGF- $\beta$ 1-induced MCP-1 expression. Additionally, 15d-PGJ2 at 2.5 and 5  $\mu$ mol/L and TGL at 2.5  $\mu$ mol/L inhibited TGF- $\beta$ 1-induced expression of IL-8.

**Conclusion:** PPAR- $\gamma$  agonists (15d-PGJ2 and TGL) could inhibit the TGF- $\beta$ 1-induced expression of chemokines in HK-2 cells. Our results suggest that PPAR- $\gamma$  agonists have the potential to be used as a treatment regimen to reduce inflammation in renal tubulointerstitial disease.

**Keywords:** peroxisome proliferator-activated receptor- $\gamma$ ; 15d-PGJ2; troglitazone; transforming growth factor  $\beta$ 1; tubular epithelial cell; chemokine; monocyte chemoattractant protein-1; interleukin-8

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## Introduction

Tubulointerstitial inflammation and fibrosis play important roles in the progression of chronic kidney disease (CKD) and are closely associated with the prognosis of kidney diseases<sup>[1–3]</sup>. Transforming growth factor- $\beta$ 1 (TGF- $\beta$ 1) is one of the most important cytokines that participate in tubulointerstitial inflammation and fibrosis. It has been demonstrated that chemokines, including monocyte chemoattractant protein-1 (MCP-1) and interleukin-8 (IL-8), are closely related to tubulointerstitial lesions<sup>[4–7]</sup>.

Peroxisome proliferator-activated receptor- $\gamma$  (PPAR- $\gamma$ ), a member of the ligand-activated transcription factor superfamily, is expressed in many organs, including the kidney<sup>[8,9]</sup>. In our previous study, we demonstrated that PPAR- $\gamma$  could counteract the profibrogenic effects of TGF- $\beta$ 1 in the kidney<sup>[10,11]</sup>. Furthermore, it has been found that activation of PPAR- $\gamma$  has anti-inflammatory effects in inflammatory

bowel disease, arthritis and multiple sclerosis<sup>[12–16]</sup>. However, the anti-inflammatory effects of PPAR- $\gamma$  in kidney diseases remain unclear. In the current study, we aimed to investigate the anti-inflammatory effects of PPAR- $\gamma$  in kidney diseases by examining the effects of 15d-PGJ2 (a natural ligand of PPAR- $\gamma$ ) and troglitazone (TGL) on TGF- $\beta$ 1-induced chemokine expression in renal tubular epithelial cells.

## Materials and methods

**Cell culture** Human proximal tubular cells (HK-2, CRL-2190) were purchased from ATCC and grown in keratinocyte serum-free media (KSFM, Invitrogen) supplemented with bovine pituitary extract (BPE, Invitrogen) and epidermal growth factor (EGF, Invitrogen). The cells were cultured in a 37 °C incubator with 5% CO<sub>2</sub> and passaged at 80% confluence using 0.05% trypsin-0.02% EDTA (Invitrogen).

To investigate the fibrogenic effect of TGF- $\beta$ 1 on the HK-2 cells, the cells were seeded into 6-well culture dishes and incubated with KSFM without BPE and EGF for 24 h to

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arrest and synchronize cell growth. After the 24 h, cells were treated with TGF- $\beta$ 1 (R&D Systems, Minneapolis, MN) at different concentrations (0, 0.5, 1, 2, 5, and 10 ng/mL) for 24 h or treated with 5 ng/mL TGF- $\beta$ 1 for different time intervals (0, 2, 6, 12, 24, 36, and 48 h). Cells were then harvested for further experimentation.

**RT-PCR and real-time RT-PCR** Total RNA was isolated from HK-2 cells using the TRIzol reagent (Invitrogen) according to the manufacturer's protocol. The RNA was eluted with RNase-free water. Reverse transcription was performed using a standard reagent (Promega) according to the manufacturer's protocols. Real-time PCR amplification was performed using the SYBR Green master mix (Toyobo, Japan) and the Opticon 3 Real-time PCR Detection System (Bio-rad). Cycling conditions were 94 °C for 5 min followed by 44 cycles of 94 °C for 15 s and 60 °C for 1 min. A final extension at 72 °C for 10 min was performed after the cycles were completed. Primers for amplifying GAPDH, MCP-1 and IL-8 were designed using Primer software and validated for specificity. Primer sequences are summarized in Table 1. Relative amounts of mRNA were normalized to GAPDH levels and calculated using the delta-delta method from the threshold cycle numbers. Levels in the control experiments were set to 1, and all the other values are expressed as multiples thereof.

**Enzyme-linked immunosorbent assay** Commercial ELISA kits (Biosource, USA) were used to detect the level of MCP-1 and IL-8 in the supernatant of HK-2 cells according to the manufacturer's protocol.

**Statistical analysis** All values are expressed as the means $\pm$ SD. Statistical analyses were performed using SPSS for Windows 11.0 (SPSS, Inc, Chicago, IL, USA). Statistical analyses between two groups were assessed by *t*-test. Statistical analyses among groups were assessed by ANOVA. *P*-values <0.05 were considered to be statistically significant.

## Results

### Dose- and time-dependent effects of TGF- $\beta$ 1 on

**MCP-1 and IL-8 mRNA in HK-2 cells** Untreated HK-2 cells expressed a basal level of both MCP-1 and IL-8 mRNA. When HK-2 cells were treated with different concentrations of TGF- $\beta$ 1 for 24 h, the level of MCP-1 mRNA increased above basal levels with 2 ng/mL, peaked with 5 ng/mL and decreased with 10 ng/mL of TGF- $\beta$ 1, which corresponded to 1.64-, 2.65-, and 1.95-fold increases in MCP-1 mRNA levels, respectively (Figure 1A). When HK-2 cells were treated with 5 ng/mL of TGF- $\beta$ 1 for different time periods, MCP-1 mRNA expression increased at 6 h, peaked at 12 h and decreased after 24 h. No significant difference in MCP-1 expression was found at 36 h between the TGF- $\beta$ 1-treated and control groups (*P*>0.05, Figure 1B).

When HK-2 cells were treated with different concentrations of TGF- $\beta$ 1 for 24 h, IL-8 mRNA levels increased with 1 ng/mL, peaked with 5 ng/mL and decreased with 10 ng/mL of TGF- $\beta$ 1 (Figure 2A). Treatment of the HK-2 cells with 5 ng/mL of TGF- $\beta$ 1 increased IL-8 mRNA levels by 2.64 fold at 12 h (*P*<0.01) and by 2.19 fold at 48 h (*P*<0.01) (Figure 2B).

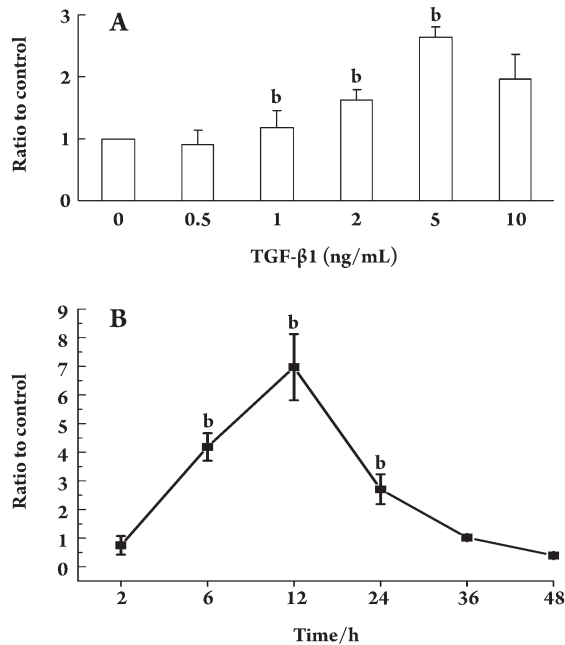
**Effects of TGF- $\beta$ 1 on MCP-1 and IL-8 protein levels in HK-2 supernatants** After 12 h of treatment with TGF- $\beta$ 1 (5 ng/mL), the levels of MCP-1 in cell supernatants increased from 10.68 pg/mL to 43.39 pg/mL at 12 h, to 185.91 pg/mL at 36 h, and decreased to 148.31 pg/mL at 48 h (Figure 3A). TGF- $\beta$ 1 (5 ng/mL) also upregulated the level of IL-8 protein in supernatants at 12 h (Figure 3B).

**Inhibitory effects of TGL and 15d-PGJ2 on TGF- $\beta$ 1-induced MCP-1 and IL-8 mRNA expression in HK-2 cells** Treatment of HK-2 cells with 5 ng/mL of TGF- $\beta$ 1 for 24 h significantly increased the MCP-1 and IL-8 mRNA levels. Treatment of HK-2 cells with 1  $\mu$ mol/L or 2.5  $\mu$ mol/L TGL for 24 h significantly decreased the TGF- $\beta$ 1-induced MCP-1 mRNA level (*P*<0.05, Figure 4A). Treatment of HK-2 cells with 2.5  $\mu$ mol/L of TGL for 24 h decreased TGF- $\beta$ 1-induced IL-8 mRNA levels from 2.55-fold to 1.49-fold (*P*<0.05, Figure 4B).

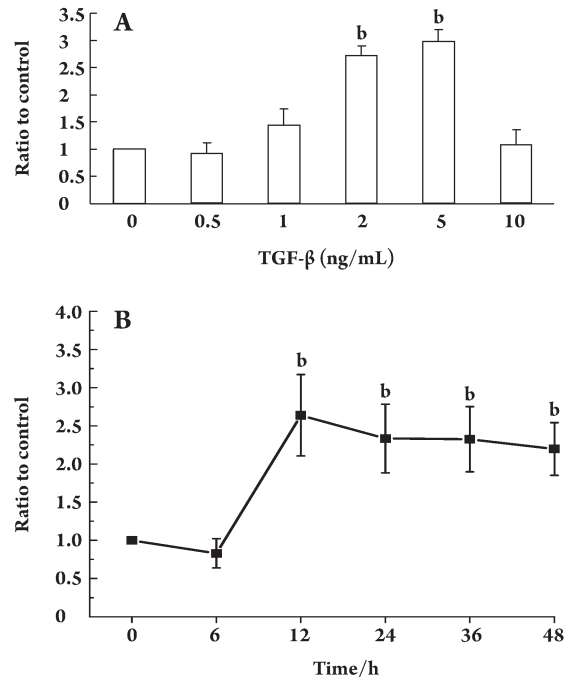
Treatment of HK-2 cells with 2.5  $\mu$ mol/L or 5  $\mu$ mol/L of 15d-PGJ2 for 24 h decreased the TGF- $\beta$ 1-induced MCP-1

**Table 1.** The primers for the real-time PCR.

| Gene  |         | Primer sequence                 | Product length (bp) | Tm (°C) |
|-------|---------|---------------------------------|---------------------|---------|
| GAPDH | Forward | 5'- CAGGGCTGCTTTAACTCTGGTAA -3' | 101                 | 60      |
|       | Reverse | 5'- GGGTGGAAATCATATGGAACATGT-3' |                     |         |
| MCP-1 | Forward | 5'-CAGCCAGATGCAATCAATGC-3'      | 198                 | 60      |
|       | Reverse | 5'-GTGGTCCATGGAATCCTGAA-3'      |                     |         |
| IL-8  | Forward | 5'-GAATGAATGGGTTTGCTAGA-3'      | 229                 | 60      |
|       | Reverse | 5'-CACTGTGAGGTAAGATGGTGG-3'     |                     |         |



**Figure 1.** The effects of TGF-β1 on MCP-1 mRNA expression in HK-2 cells. (A) The effects of different dosages of TGF-β1 (0.5, 1, 2, 5, and 10 ng/mL) on MCP-1 mRNA expression. (B) The effects of different durations of treatment with TGF-β1 (2, 6, 12, 24, 36, 48 h) on MCP-1 mRNA expression. <sup>b</sup>*P*<0.05 vs TGF-β1 control group.

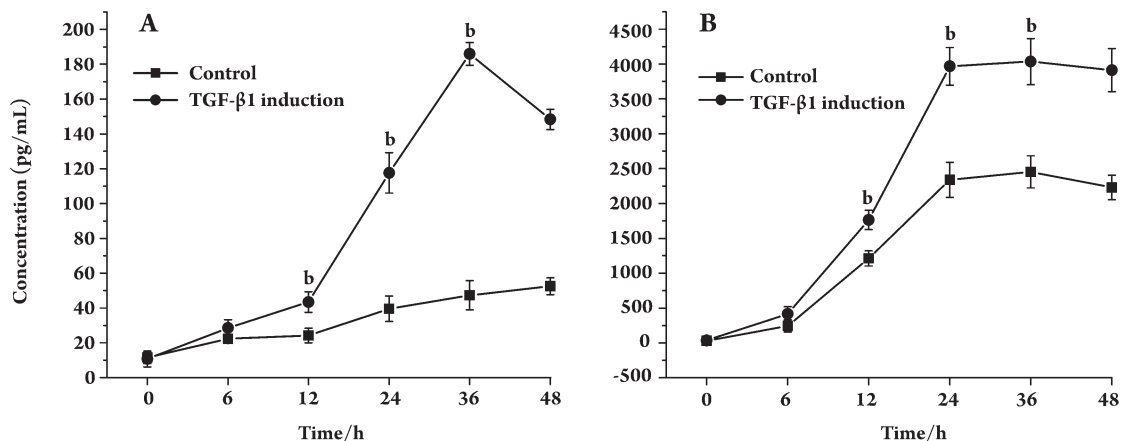


**Figure 2.** The effects of TGF-β1 on IL-8 mRNA expression in HK-2 cells. (A) The effects of different dosages of TGF-β1 (0.5, 1, 2, 5, and 10 ng/mL) on IL-8 mRNA expression. (B) The effects of different durations of treatment with TGF-β1 (6, 12, 24, 36, 48 h) on IL-8 mRNA expression. <sup>b</sup>*P*<0.05 vs TGF-β1 control group.

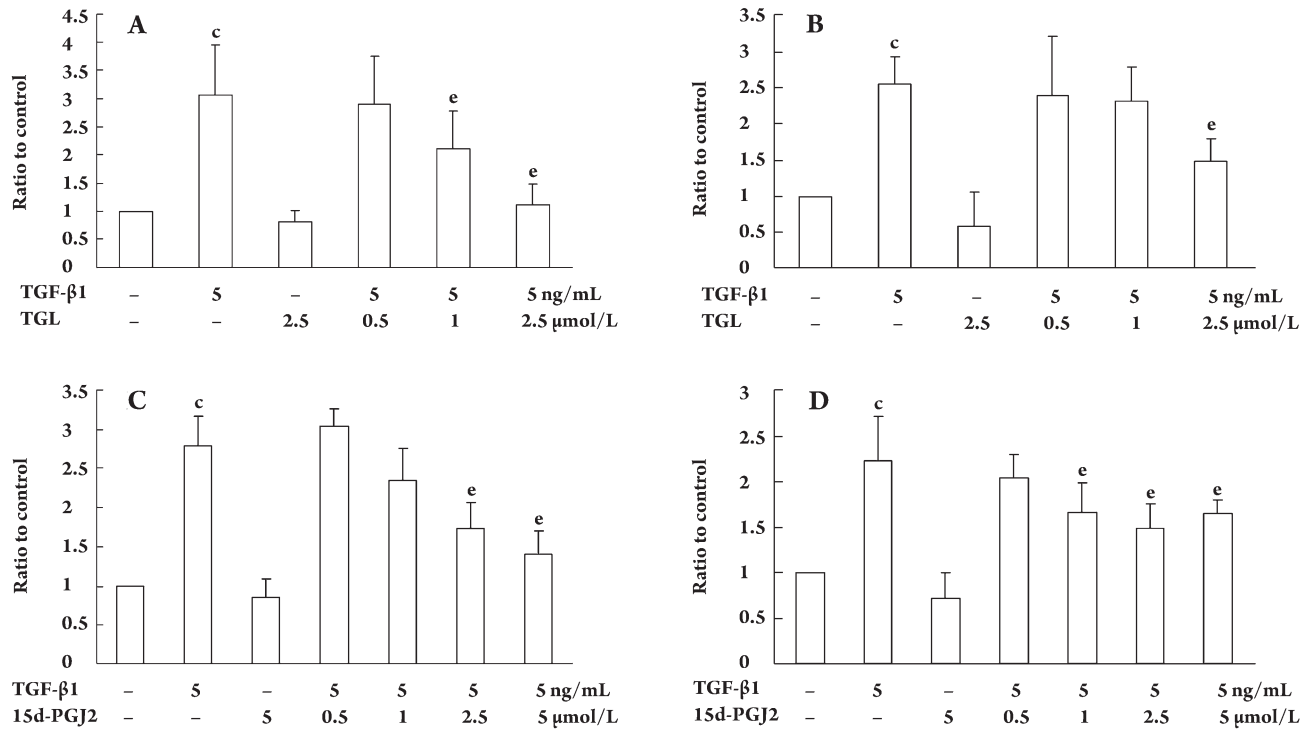
mRNA level (*P*<0.05, Figure 4C). Treatment of HK-2 cells with 1, 2.5, or 5 μmol/L of 15d-PGJ2 for 48 h decreased the TGF-β1-induced IL-8 mRNA level (*P*<0.05, Figure 4D).

**Inhibitory effects of TGL and 15d-PGJ2 on level of TGF-β1-induced MCP-1 and IL-8 in supernatant**  
 Treatment of HK-2 cells with 2.5 μmol/L of TGL or 2.5

or 5 μmol/L of 15d-PGJ2 for 24 h significantly decreased the levels of TGF-β1-induced MCP-1 in the supernatant (*P*<0.05). Furthermore, a significant difference in the level of inhibition was observed between the groups of HK-2 cells treated with the 5 and 2.5 μmol/L doses of 15d-



**Figure 3.** The level of MCP-1 and IL-8 after TGF-β1 treatment. (A) The level of MCP-1 in the supernatant after different durations of TGF-β1 (5 ng/mL) treatment. (B) The level of IL-8 in the supernatant after different durations of TGF-β1 (5 ng/mL) treatment. <sup>b</sup>*P*<0.05 vs TGF-β1 control group.



**Figure 4.** The effect of TGL and 15d-PGJ2 on TGF-β1-induced MCP-1 and IL-8 mRNA expression in HK-2 cells (24 h). The mRNA level of MCP-1 (A) and IL-8 (B) in HK-2 cells after different concentrations of TGL treatment. The mRNA level of MCP-1(C) and IL-8 (D) in HK-2 cells after different concentrations of 15d-PGJ2 treatment. *n*=3. Mean±SD. <sup>c</sup>*P*<0.01 vs control. <sup>e</sup>*P*<0.05 vs TGF-β1 induction group.

PGJ2 (*P*<0.05). Similarly, treatment of HK-2 cells with 2.5 μmol/L of TGL or with 5 μmol/L of 15d-PGJ2 for 24 h significantly decreased the levels of TGF-β1-induced IL-8 protein in the supernatant (*P*<0.01) (Table 2 and Table 3).

**Discussion**

Tubular epithelial cells play an important role in tubu-

**Table 2.** The effects of TGL and 15d-PGJ2 on MCP-1 level induced by TGF-β1. *n*=3 independent experiments. Mean±SD. <sup>c</sup>*P*<0.01 vs control; <sup>f</sup>*P*<0.01 vs TGF-β1 induction group.

| Groups                       | Concentration (pg/mL)    |
|------------------------------|--------------------------|
| Control                      | 21.36 ± 6.51             |
| TGF-β1                       | 56.17±14.31 <sup>c</sup> |
| TGF-β1+15d-PGJ2 (2.5 μmol/L) | 29.30±11.72 <sup>f</sup> |
| TGF-β1+15d-PGJ2 (5 μmol/L)   | 14.09±4.50 <sup>f</sup>  |
| TGF-β1+TGL (2.5 μmol/L)      | 22.82±12.39 <sup>f</sup> |
| 15d-PGJ2 (5 μmol/L)          | 15.08±4.38               |
| TGL (2.5 μmol/L)             | 12.57±4.60               |

All experiments were performed in triplicate, and each sample was tested by two ELISA wells.

**Table 3.** The effects of TGL and 15d-PGJ2 on IL-8 level induced by TGF-β1. *n*=3 independent experiments. Mean±SD. <sup>c</sup>*P*<0.01 vs control; <sup>f</sup>*P*<0.01 vs TGF-β1 induction group.

| Groups                       | Concentration (pg/mL)       |
|------------------------------|-----------------------------|
| Control                      | 2423.78±887.71              |
| TGF-β1                       | 3544.42±721.05 <sup>c</sup> |
| TGF-β1+15d-PGJ2 (2.5 μmol/L) | 2762.36±817.99              |
| TGF-β1+15d-PGJ2 (5 μmol/L)   | 1982.54±595.06 <sup>f</sup> |
| TGF-β1+TGL (2.5 μmol/L)      | 2042.97±827.34 <sup>f</sup> |
| 15d-PGJ2 (5 μmol/L)          | 1775.16±449.96              |
| TGL (2.5 μmol/L)             | 1847.69±604.33              |

All experiments were performed in triplicate, and each sample was tested by two ELISA wells.

lointerstitial fibrosis by secreting cytokines and extra-cellular matrix. TGF-β1, which has a wide spectrum of biological functions, is one of the most important cytokines in this process. Recent studies suggest that chemokines, such as MCP-1 and IL-8, are closely associated with kidney diseases, and tubular epithelial cells are the predominant secretors of these chemokines<sup>[17, 18]</sup>. MCP-1 and IL-8 cause tubu-

macrophages/monocytes, T cells, neutrophils, eosinophils and basophils, into the tubulointerstitium, where the target cells secrete cytokines, including TGF- $\beta$ 1 and TNF- $\alpha$ <sup>[19-22]</sup>. However, recent studies on TGF- $\beta$ 1-induced chemokine secretion by tubular epithelial cells had contradictory results. Gerritsma JS and colleagues demonstrated that TGF- $\beta$ 1 increased the level of IL-8, but decreased the level of MCP-1<sup>[23]</sup>. However, in a study published by Qi *et al*, IL-8 and MCP-1 expression was upregulated after TGF- $\beta$ 1 treatment<sup>[24]</sup>.

In our previous studies, we demonstrated that TGF- $\beta$ 1 increased ECM synthesis in renal interstitial fibroblasts<sup>[25]</sup>. However, it is not clear whether TGF- $\beta$ 1 recruits inflammatory cells and leads to their infiltration into the tubulointerstitium by upregulating cytokine secretion. In the current study, we investigated the expression of MCP-1 and IL-8 in HK-2 cells after stimulation with TGF- $\beta$ 1. Our results showed that HK-2 cells expressed basal levels of MCP-1 and IL-8, which agrees with results from previously published studies<sup>[26, 27]</sup>. In this study, we demonstrated that TGF- $\beta$ 1 upregulated the expression of MCP-1 and IL-8 in HK-2 cells. Our results from this study are consistent with our previous studies that demonstrated that TGF- $\beta$ 1 had proinflammatory and profibrogenic effects on HK-2 cells. Our results are also consistent with the study, for example, published by Qi and colleagues<sup>[24]</sup>. Recent studies suggest that increased expression of MCP-1 is found in several renal diseases<sup>[20, 21]</sup>, supporting the concept that TGF- $\beta$ 1 upregulates expression of MCP-1 in tubular epithelia. In the studies published by Gerritsma *et al* and Qi *et al*<sup>[23, 24]</sup>, the expression of IL-8 in tubular epithelial cells was upregulated after 48 h or 72 h of TGF- $\beta$ 1 stimulation. Their results are similar to our findings, suggesting that secretion of MCP-1 and IL-8 by tubular epithelial cells plays an important role in tubulointerstitial fibrosis and lesion formation<sup>[24]</sup>.

PPAR- $\gamma$  is a member of the ligand-activated transcription factor superfamily, which participates in a wide range of biological activities, including cell differentiation, fat metabolism, glucose metabolism, immune response regulation, inflammation, cell apoptosis and tumorigenesis<sup>[28, 29]</sup>. PPAR- $\gamma$  had some anti-inflammatory effects on inflammatory bowel disease and rheumatoid arthritis<sup>[30, 31]</sup>. It ameliorates the inflammatory cell infiltration and downregulates the proinflammatory cytokine expression in animal models of diabetic nephropathy and lupus nephropathy as well as in mesangial cells, fibroblasts and tubular epithelial cells<sup>[32, 33]</sup>. Li and colleagues demonstrated that eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) could downregulate LPS-induced MCP-1 expression via the PPAR- $\gamma$

pathway<sup>[34]</sup>. In this study, we demonstrated that treatment with either 15d-PGJ2 or TGL counteracts the TGF- $\beta$ 1-induced MCP-1 and IL-8 expression. These findings suggest that PPAR- $\gamma$  has an inhibitory effect on MCP-1 expression. Our results are similar to those reported by Zafiriou *et al*, who demonstrated that pioglitazone downregulates TGF- $\beta$ 1-induced MCP-1 expression in OK cells and that such effects did not depend on NF- $\kappa$ B activity<sup>[35]</sup>. However, our results are different from those of the study reported by Fu *et al*, who found that 15d-PGJ2 upregulated the expression of IL-8 in macrophages<sup>[31]</sup>. Our results suggest that different mechanisms of PPAR- $\gamma$  may occur in different cell types. To date, the molecular details of the antagonizing effects of PPAR- $\gamma$  on TGF- $\beta$ 1-induced proinflammatory cytokine expression are unclear. In our previous study<sup>[25]</sup>, we demonstrated that PPAR- $\gamma$  could counteract the profibrogenic effects of TGF- $\beta$ 1 by downregulating the phosphorylation of Smad 2 and Smad 3. Therefore, the anti-inflammatory effects of PPAR- $\gamma$  on TGF- $\beta$ 1-induced inflammation might target Smad signaling. However, further study is needed to fully elucidate the detailed mechanism by which this process occurs.

We demonstrated that TGF- $\beta$ 1 induced the expression of chemokines in tubular epithelial cells and inflammatory cells. Inflammatory cells participate in tubulointerstitial lesions by infiltrating into the tubulointerstitium mediated by the chemokine receptors on their surface. Both 15d-PGJ2 and TGL had inhibitory effects on MCP-1 and IL-8 expression. Our studies suggest that inhibiting TGF- $\beta$ 1-induced chemokine expression might have therapeutic effects on tubulointerstitial lesions and thus could potentially be used as a regimen for treating chronic kidney disease.

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## Author contribution

Wei-ming WANG and Nan CHEN designed research; Hui-di ZHANG, Yuan-meng JIN, Bing-bing ZHU performed research; Wei-ming WANG and Hui-di ZHANG contributed new analytical tools and reagents; Wei-ming WANG and Hui-di ZHANG analyzed data; Wei-ming WANG wrote the



paper.

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