IFNγ peptidomimetic targeted to interstitial myofibroblasts attenuates renal fibrosis in unilateral ureteral obstruction in mice

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Chapter 5

ABSTRACT

Renal fibrosis leads to progressive renal dysfunction and cannot be adequately treated since effective anti-fibrotic treatment modalities are lacking. Interferon-gamma (IFNγ) is a pro-inflammatory cytokine with anti-fibrotic properties. Clinical application of IFNγ as anti-fibrotic drug is hampered due to inflammation-mediated systemic side-effects. To reduce pro-inflammatory effects we developed an IFNγ-peptidomimetic (mimγ) lacking the extracellular IFNγReceptor recognition domain and coupled it to the PDGFβR-recognizing peptide BiPPB. Here we tested the hypothesis that, compared to non-targeted full-length IFNγ, specific delivery of mimγ () to PDGFβR-overexpressing interstitial myofibroblasts attenuates renal fibrosis and reduces inflammation-mediated side-effects in the mouse unilateral ureter obstruction (UUO) model.

After UUO severe renal fibrosis developed in vehicle-treated mice characterized by significantly increased α-SMA, TGFβ1, fibronectin, and collagens I and III protein and/or mRNA expression. Compared to vehicle treatment, mimγ-BiPPB significantly reduced expression of these fibrotic markers. Compared to full-length IFNγ, the anti-fibrotic effect of mimγ-BiPPB was more pronounced. UUO-induced fibrosis was associated with increased lymph capillary and vascular capillary density. Lymphangiogenesis was significantly reduced by mimγ-BiPPB but not full-length IFNγ. Finally, in contrast to full-length IFNγ mimγ-BiPPB did not induce IFNγ-related side-effects evidenced by normalized brain MHC II expression, lowered plasma triglyceride levels, and improved weight gain after UUO induction.

In conclusion, compared to full-length IFNγ, specific targeting of mimγ-BiPPB to PDGFβR-expressing myofibroblasts attenuates renal fibrosis in the absence of IFNγ-mediated adverse effects.
INTRODUCTION

Patients with chronic kidney disease (CKD) are at increased risk of progression to end-stage renal disease (ESRD). Virtually all forms of CKD are characterized by significant amounts of renal fibrosis (1, 2). Renal interstitial fibrosis is the final common process observed in various kidney diseases that leads to renal failure and is associated with tubular atrophy and dilation, interstitial matrix deposition, accumulation of interstitial fibroblasts, and inflammatory cell infiltration (3). There is still no effective therapy to halt renal fibrogenesis and to prevent progression to ESRD which requires renal replacement therapy eventually (4). Among the characteristic changes in the kidney during development of fibrosis, interstitial extracellular matrix (ECM) deposition is the key step. Interstitial fibroblasts are the predominant source of ECM constituents, therefore dampening interstitial fibroblast activation, and thereby differentiation into ECM-producing myofibroblasts, is an attractive approach to inhibit or reverse development of renal interstitial fibrosis (5-7).

Interferon gamma (IFNγ) is a cytokine primarily produced by T cells and natural killer (NK) cells. It is a pleiotropic cytokine with anti-viral, anti-bacterial, anti-tumor, pro-inflammatory but also anti-fibrotic activities (8). Because of its anti-fibrotic activity, IFNγ is a potential effective biological to treat or prevent renal fibrosis (9-12). However, its potential therapeutic value in fibrosis has been limited so far due to the systemic side effects (because of widespread IFNγ receptor [IFNγR] expression) and rapid renal clearance (13-15). In order to overcome these problems as well as to attain high concentrations in the target cells, cell-specific targeting of biologicals is an attractive approach which can be achieved via receptor-mediated uptake.

Activated fibroblasts in fibrotic tissue are characterized by increased platelet-derived growth factor receptor-beta (PDGFβR) expression (16, 17), and this prompted us to use the PDGFβR for receptor-mediated uptake of biologicals. To do so, pegylated full length IFNγ was conjugated to PDGFβR-recognizing peptide (PPB) (18) and by using this conjugate (i.e. PPB-PEG-IFNγ) we were able to demonstrate anti-fibrotic effects in the CCl4-induced liver fibrosis mouse model (19) and anti-tumorigenic effects by targeting stromal cells in the B16 melanoma tumor mouse model (20). Recently we used the same targeting approach as proof of concept in the mouse unilateral ureteral obstruction (UUO) model of renal fibrosis in which anti-fibrotic effects of the PPB-PEG-IFNγ conjugate were demonstrated (12). Despite the anti-fibrotic effects of PPB-PEG-IFNγ, systemic side effects were mildly reduced compared to full length IFNγ but remained still present as evidenced by increased brain MHC class II expression. This side effect was most likely due to binding of the full length IFNγ to the ubiquitously expressed IFNγR.

To overcome the problem of systemic side effects we recently designed a new IFNγ-based biological which lacks the amino-terminal IFNγR-binding sequence (21). This IFNγ-peptidomimetic (mimγ) was conjugated to the bicyclic platelet-derived growth factor receptor-beta recognizing peptide (BIPPB) for targeting to PDGFβR-expressing cells (schematically depicted in Figure 1A). Here we tested the hypothesis that, compared to
non-targeted full-length IFNγ, specific delivery of mimγ (coupled to the PDGFβR-recognizing peptide BiPPB) to PDGFβR-overexpressing interstitial myofibroblasts attenuates renal fibrosis and reduces inflammation-mediated side-effects in the mouse UUO model.

**Figure 1:** Schematic representation of the structure of the targeted IFNγ peptidomimetic (mimγ-BiPPB) and its binding to PDGFRβ-expressing myofibroblasts (A), and the in vivo treatment regimen in the mouse unilateral ureter obstruction (UUO) model (B).

**RESULTS**

**PDGFβR expression is increased on interstitial myofibroblasts in UUO mouse kidneys**
We first analyzed PDGFβR expression in mouse sham and fibrotic (UUO) kidneys. Fibrosis is characterized by increased interstitial PDGFβR expression as revealed by enhanced mRNA
expression level (Fig. 2A) which was confirmed by immunohistochemistry (Figure 2B). Mimγ-BiPPB did not significantly alter the level of PDGFβR expression (Figure 2A) indicating that targeting to this receptor does not influence its expression.

**Figure 2:** UUO increases PDGFβR expression on mRNA (A) and protein (B) expression level. (A) Relative gene expression of PDGFβR in UUO (treated with vehicle, mimγ-BiPPB, and free IFNγ) and sham-operated control kidneys at day 7 post surgery. **p<0.01 vs. sham. Bars represent mean ± SEM of 5–6 mice per group. (B) Representative photomicrographs of PDGFβR-stained kidney sections of sham-operated and vehicle-treated UUO mice (200x).

**Mimγ-BiPPB reduces renal fibroblast activation**
In order to determine whether mimγ-BiPPB reduces renal fibroblast activation in vivo, α-SMA expression was determined at both mRNA and protein level. As shown in Figure 3A, UUO (receiving subsequent treatment with vehicle) resulted in increased (p<0.001) α-SMA mRNA expression compared to sham controls. α-SMA mRNA expression was normalized after treatment with mimγ-BiPPB and non-targeted full length IFNγ (p<0.05 vs. vehicle). Immunohistochemistry confirmed increased α-SMA expression in UUO kidneys (vehicle treatment, p<0.01 vs. sham, Figure 3B&C). Representative photomicrographs of α-SMA staining are shown in Figure 3B. Quantitative analysis revealed significantly reduced α-SMA protein expression after mimγ-BiPPB treatment when compared to vehicle treatment (p<0.05 vs. vehicle, Figure 3C).
Since TGFβ1 is known to induce α-SMA expression in fibroblasts (22) we also analyzed TGFβ1 mRNA expression in sham and UUO kidneys. UUO (vehicle) significantly increased renal TGFβ1 expression (p<0.01 vs. sham), which was not significantly reduced after mimγ-BiPPB or IFNγ treatment. (Figure 3D).

Figure 3: IFNγ peptidomimetic (mimγ-BiPPB) reduces α-SMA expression in mouse UUO kidneys.

(A) Relative gene expression of α-SMA in fibrotic UUO and sham-operated control kidneys at day 7 post surgery. (B) Representative photomicrographs of α-SMA stained kidney sections of sham-operated and UUO mice treated with vehicle (PBS), mimγ-BiPPB or (non-targeted full length) IFNγ (200x). Scale bar: 120 μm. (C) Computerized quantitative analysis of α-SMA protein expression in UUO and sham-operated kidneys. (D) Relative gene expression of TGFβ1 in UUO and sham-operated kidneys. Quantitative data of UUO are expressed relative to sham. *p≤0.05, **p<0.01, ***p<0.001. Bars represent mean ± SEM of 5–6 mice per group.
**mimγ-BiPPB reduces extracellular matrix (ECM) deposition in UUO kidneys**

Next we analyzed the effects of mimγ-BiPPB on ECM constituent expression. As shown in Supplemental Figure 1A, UUO (vehicle) increased fibronectin mRNA expression (p<0.001 vs. sham) which was partly prevented by mimγ-BiPPB and non-targeted full length IFNγ (not significant). Similar results were obtained for collagen I (Suppl. Figure 1B) and collagen III (Supplemental Figure 1C) mRNA expression.

In contrast to the mRNA expression data, clear differences in protein expression were observed when comparing the different treatment groups (Figure 4). In UUO (vehicle) significantly increased protein expression levels for interstitial fibronectin (Figure 4A), collagen I (Figure 4B), and collagen III (Figure 4C) were observed 7 days post-UUO compared to sham-operated mice (all p<0.01 vs. sham). Compared to vehicle treatment, only mimγ-BiPPB treatment resulted in significantly reduced fibronectin (Figure 4A, p≤0.05), collagen I (Figure 4B, p<0.01), and collagen III (Figure 4C, p≤0.05) expression. Protein expression in non-targeted full length IFNγ did not statistically differ from vehicle-treated mice. Compared with non-targeted full length IFNγ, these data indicate that mimγ-BiPPB is more effective in reducing ECM constituents expression.

**Effects of mimγ-BiPPB on renal inflammation in UUO**

IFNγ exerts systemic pro-inflammatory effects but possibly also local intra-renal inflammatory responses. To analyze the latter, we determined whether treatment with non-targeted full length IFNγ and mimγ-BiPPB resulted in different intra-renal inflammatory responses as determined by qPCR analyses, and CD3+ T cell infiltration. As shown in Supplemental Figure 2, compared to sham-operated UUO (subsequent vehicle treatment) resulted in significantly increased MCP-1 (A), TNF-α (B), IL-1β (C) and IL-6 (D) mRNA expressions (all p<0.01 vs. sham). Although mimγ-BiPPB tended to reduce, and non-targeted full length IFNγ tended to increase pro-inflammatory cytokine production (vs. vehicle), no statistically significant differences were observed.

UUO (vehicle) significantly increased MHC class II expression which was reduced after mimγ-BiPPB treatment when compared with non-targeted full length IFNγ (Supplemental Figure 2E). This might be explained by increased IFNγ-induced macrophage activation rather than macrophage influx (Supplemental Figure 2F). Additionally, UUO resulted in increased CD3+ T cell influx as determined by immunohistochemistry (p<0.01 vs. sham) which was reduced by mimγ-BiPPB (58% reduction) and non-targeted full length IFNγ-treated mice (42% reduction) (Supplemental Figure 2G).

**mimγ-BiPPB treatment reduces lymphangiogenesis**

New lymph vessel formation (lymphangiogenesis) has been shown in different renal disease models, including UUO (23). This led us to hypothesize that UUO-induced renal lymphangiogenesis might be attenuated following mimγ-BiPPB treatment. Compared to sham, UUO (vehicle treatment) indeed increased numbers of podoplanin'-lymph capillaries (p<0.01 vs. sham) which were significantly lower in mimγ-BiPPB-treated (p≤0.05 vs. vehicle),
**Figure 4:** IFNγ peptidomimetic (mimγ-BiPPB) reduces extracellular matrix deposition (fibronectin, collagen I, and collagen III) in mouse UUO kidneys.

Representative photomicrographs (200X) and computerized quantitative analysis of (A) fibronectin, (B) collagen I, and (C) collagen III protein expression in UUO and sham-operated kidneys. Scale bar: 120 μm. Quantitative data of UUO are expressed relative to sham. *p≤0.05, **p<0.01. Bars represent mean ± SEM of 5–6 mice per group.
Figure 5: IFNγ peptidomimetic (mimγ-BiPPB) reduces UUO-induced lymphangiogenesis.

Representative photomicrographs and quantitative analysis of (A) the numbers of podoplanin+ lymphatic capillaries and (B) the numbers of CD31+ peritubular capillaries 7 days post surgery. Arrows indicate podoplanin+ lymphatic capillaries in sham kidney. Scale bar: 50 μm. Quantitative data of UUO are expressed relative to sham. *p<0.05, **p<0.01. Bars represent mean ± SEM of 5–6 mice per group.
but not in non-targeted full length IFNγ-treated mice (Figure 5A). Depending on the time after UUO induction, both angiogenesis (increase in capillary density) and capillary rarefaction has been described (24). We analyzed the effect of mimγ-BiPPB and non-targeted full length IFNγ on peritubular capillary density. As shown in Figure 5B, UUO (vehicle) was associated with significantly increased numbers of CD31⁺ peritubular capillaries (p<0.01 vs. sham) which was not reduced by mimγ-BiPPB. Microphotographs shown in A and B display representative photos of podoplanin⁺ lymph capillaries and CD31⁺ peritubular capillaries in UUO (vehicle, mimγ-BiPPB, and non-targeted full length IFNγ treatment) and sham kidneys, respectively.

Figure 6: IFNγ peptidomimetic (mimγ-BiPPB) prevents IFNγ-related systemic side effects and improve weight gain after surgery.

(A) mRNA expression of brain MHC class II in UUO mice treated with vehicle (PBS), mimγ-BiPPB or non-targeted full length IFNγ (7 days post surgery). Data of UUO groups are expressed relative to sham. **p<0.01, Student’s t-test. Bars represent mean ± SEM of 3 mice per group. (B) Plasma triglyceride levels in UUO mice treated with vehicle (PBS), mimγ-BiPPB or non-targeted full length IFNγ, 7 days post surgery. *p<0.05. Bars represent mean ± SEM of 5-6 mice per group. (C) Weight loss and recovery in UUO mice treated with vehicle (PBS), mimγ-BiPPB, and (non-targeted full length) IFNγ. ****p<0.001. Change in weight expressed as mean ± SD of 6 mice per group/time point.
mimγ-BiPPB is accompanied by less systemic side effects

To assess whether treatment with mimγ-BiPPB reduces systemic side effects compared with non-targeted full length IFNγ, brain MHC class II mRNA expression (as a measure of IFNγ-induced microglia activation) and plasma triglyceride levels (as a measure of IFNγ-induced lypolysis in adipose tissue) were determined. As shown in Figure 6A, in line with our previous observations (12, 19, 21) treatment with non-targeted full length IFNγ caused significant (p<0.01) up-regulation of brain MHC class II expression. In contrast, upon mimγ-BiPPB treatment brain MHC class II expression was similar to vehicle-treatment. Compared with non-targeted full length IFNγ, mimγ-BiPPB treatment significantly reduced plasma triglyceride levels (p<0.05, Figure 6B). Compared with vehicle, plasma triglyceride levels were not significantly increased after non-targeted full length IFNγ treatment (not shown) which might be explained by the fact that we used non-pegylated full length IFNγ. Finally, we determined weight loss and recovery after induction of UUO in the various treatment groups. As shown in Figure 6C, mice receiving mimγ-BiPPB displayed less weight loss and accelerated weight gain after UUO when compared to non-targeted full length IFNγ treated mice, which might be explained either by attenuating the renal damage and/or by reducing side effects in mice receiving mimγ-BiPPB.

DISCUSSION

In this study we demonstrate pronounced anti-fibrotic effects of targeted IFNγ peptidomimetic to PDGFβR-expressing cells (using mimγ-BiPPB) without identifiable systemic side effects in the UUO mouse model of renal fibrosis. This novel kidney targeting a chimeric anti-fibrotic biological to PDGFβR provides new opportunities for the treatment of renal fibrosis as well as other conditions associated with enhanced PDGFβR expression.

Renal fibrosis is the result of tissue injury and remodeling and is a common hallmark and cause of ESRD (25). Myofibroblast activation and proliferation play a fundamental role in fibrosis progression (26). Recent progress in understanding the mechanisms underlying the pathogenesis of fibrosis has led to the expectation that various cytokines such as IFNγ could be potentially useful therapeutics to halt or even prevent fibrosis (27). However, the major obstacle in IFNγ-based therapy is the manifestation of clinical side effects which has led to abortion of clinical trials or restricted diverse clinical use of IFNγ (14, 15, 28, 29). These adverse effects often preclude with administration of anticipated therapeutic effective dose, leading to lack of efficacy in patients. In line with this, we previously showed that systemic delivery of non-targeted full length IFNγ in mice results in leukocytosis and endothelial cell activation, flu-like symptoms, neurotropic effects, hyperlipidemia, elevated TNF-α and IL-6, inflammation of the central nervous system, and elevated triglyceride levels (19), effects most likely mediated through binding to the widely expressed IFNγR. To overcome this hurdle, cell-specific delivery of IFNγ provides a new approach to improve its efficacy and to ameliorate potential systemic side effects. To prevent canonical, we used IFNγ signaling,
which lacks the IFNγ-receptor binding domain. Mimγ targeted to liver stellate cells was recently shown to exert anti-fibrotic activity in vivo (21). Here we tested the anti-fibrotic effects of mimγ targeted to PDGFβR-expressing cells in a model of renal fibrosis. Mimγ was directed to interstitial myofibroblasts using a bicyclic PDGFβR-recognizing peptide (Bi-PPB). Interstitial myofibroblasts are characterized by increased expression of PDGFβR in the human and mouse fibrotic kidney (12). Bi-PPB is a bi-cyclic peptide that binds to the dimeric PDGFβ-receptor and may thus be used to deliver the mimγ peptide to the target cells. To determine its anti-fibrotic effects, we first examined α-SMA expression both at the mRNA and protein levels since increased α-SMA levels indicate renal myofibroblast activation, the hallmark of fibrogenesis. We indeed observed a clear inhibitory effect of mimγ-BiPPB on myofibroblast activation (i.e. reduced α-SMA expression). ECM composition is significantly altered and expanded during fibrogenesis, which can severely compromise resident cell function (e.g. tubular epithelium) (5, 30). We therefore analyzed expression of the most prominent ECM constituents fibronectin, and collagens I and III. Again, a pharmacological effect of our chimeric molecule was noted and compared to non-targeted full length IFNg the efficacy of mimγ-BiPPB in reducing ECM deposition was significantly higher, illustrating the potency of our cell-specific targeting strategy. TGFβ1 is a pro-fibrotic protein which instigates fibroblast activation and transformation into myofibroblasts, resulting in collagen synthesis and ECM contraction (22). However, we did not observe altered TGFβ1 expression after IFNg or mimγ-BiPPB treatment.

Inflammation commonly precedes and accompanies fibrosis (31). There is evidence for a direct role of T cells in the pathogenesis of renal interstitial fibrosis which can be explained through different mechanisms (32, 33): (1) direct effects on fibroblast activation and ECM deposition, (2) indirect effects on fibroblasts via induction of a pro-fibrotic phenotype of infiltrating macrophages resulting in fibroblast activation through profibrotic cytokines and growth factors (e.g. PDGF, CTGF, TGFβ1), and (3) indirect effects on fibroblasts via tubular epithelial cell activation and subsequent production of cytokines and growth factors that act on fibroblasts. We indeed observed an almost two-fold reduction in the number of infiltrating T cells after mimγ-BiPPB treatment, possibly mediated via reduced expression of T cell chemoattractants that are shown to be produced by myofibroblasts (34, 35).

In the setting of renal fibrosis, injured renal cells and inflammatory cells secrete mediators and growth factors that promote angiogenesis and/or lymphangiogenesis (34-38). Since anti-lymphangiogenic effects of IFNg have been reported (39), we analyzed the potential inhibitory effect of mimγ-BiPPB on lymphangiogenesis. Renal lymphangiogenesis in UUO kidneys was significantly reduced following mimγ-BiPPB treatment which was not observed after treatment with non-targeted full length IFNg. Angiogenesis was also shown to occur during the progression of fibrosis in UUO (40) which was confirmed in our study. A reduction, though non-significant, was observed in the percentage surface area of CD31+ peritubular capillaries following mimγ-BiPPB treatment. Reduced lymphangiogenesis and angiogenesis most likely reflect indirect effects secondary to the direct anti-fibrotic effects of mimγ-BiPPB on myofibroblasts.
Recently we reported on the anti-fibrotic effects of full length IFNγ targeted to PDGFβR-expressing myofibroblasts in UUO mice (12). When comparing the antifibrotic effects of targeted full length IFNγ and IFNγ peptidomimetic (mimγ-BiPPB), the attenuating effects on αSMA and ECM constituents are comparable. However, clear differences were observed in favor of mimγ-BiPPB with respect to CNS and renal inflammation. Compared with targeted full length IFNγ, brain MHC class II expression was 79% reduced upon mimγ-BiPPB treatment. Similarly, renal F4/80 and MHC class II expression were significantly reduced with 33% and 53%, respectively. We used MHC class II expression as a marker of macrophage activation. Macrophages are the main target cells for native INFγ. For anti-fibrotic therapies, generalized macrophage activation is an off-target effect leading to serious adverse effects, and the brain is an off-target organ for renal diseases. Our data indicate that targeted mimγ lacks this off-target effect, in contrast to targeted full length IFNγ which can be explained by the lack of mimγ binding to the IFNγR.

The mechanism by which mimγ exerts its protective effects is not yet fully elucidated. We previously demonstrated mimγ playing a direct role in the activation and nuclear translocation of the transcription factor STAT1α via the nuclear signaling sequence (NLS) present in the intracellular C-terminus region of IFNγR. This region is able to modulate IFNγ-responsive genes through activation of the JAK/STAT pathway (21). Mimγ does not recognize the extracellular domain of IFNγR but rather binds to the cytoplasmic domain of the receptor chain 1 (IFNγR1), and thereby initiates cellular signaling (41-46). Binding of Bi-PPB to the PDGF-β-R has been demonstrated in previous studies (21). We propose that mimγ-BiPPB binds to the PDGFβR and following internalization, the construct is able to interact with the intracellular part of IFNγR1 and initiates phosphorylation of STAT1 thereby eliciting IFNγ-related biological effects. Mimγ-BiPPB just has the IFNγ signaling moiety and is only biologically active once it is internalized. This premise needs further study though.

In conclusion, in this study we demonstrate the benefits of targeted delivery of IFNγ peptidomimetic over non-targeted full length IFNγ with respect to its anti-fibrotic effects and the development of off-target systemic side effects. We demonstrate a proof-of-concept strategy for the use of targeted IFNγ-based biologicals to reduce renal fibrosis by removing the extracellular receptor recognition sequence and directing it to myofibroblasts. The small size and increased stability of mimγ-BiPPB compared to the full length targeted IFNγ will provide better therapeutic benefits and more possibilities for subcutaneous or muscular administration. In addition, it also offers high specificity and low toxicity with full agonistic activity, therefore has highly favorable characteristics for the prolonged administration to patients with chronic diseases. This strategy is one of the first examples of re-direction of a cytokine by creating a chimeric peptide. Our data warrant further exploration of the possibility to use IFNγ peptidomimetic to target fibrosis in a clinical setting.
Chapter 5

METHODOLOGIES

Experimental animals and surgical procedures
Male C57Bl/6 mice (9–12 wks; 28–30 g) were obtained from Harlan (Zeist, the Netherlands). Animals were housed in cages with free access to food and water. During the operation the abdomen was opened by a midline incision under general anesthesia (2% isoflurane/O_2). All mice were subjected to unilateral ureteral obstruction (UUO) by a double-ligation (using 6–0 silk suture) of the left ureter proximal to the kidney. Right kidneys were used as sham controls and were manipulated but not ligated. After surgery, mice were i.v. injected (penile vein) at days 2, 4 and 6 after surgery (see Figure 1B) with either 1) UUO, vehicle (saline), 2) UUO, mimγ-BiPPB (5 µg/mouse/injection), 3) UUO, non-targeted full-length IFNγ (5 µg/mouse/injection). Total follow-up time was 7 days during which mice were weighed daily. Group size was n=6/group/time point. The experimental protocol adhered to the national guidelines for the care and use of laboratory animals and was approved by the local Animal Ethics Committee of the University of Groningen (DEC 6066B).

Synthesis of mimγ-BiPPB conjugate
All the chemical reactions were performed in low protein binding tubes (LoBind tubes, Eppendorf, Hamburg, Germany). Bicyclic PDGFβR-recognizing peptide (CSRNLIDC-GGGDGCCSRNLIDC with C-C disulfide bonds, BiPPB, 2223 Da) (18) and peptidomimetic IFNγ (mimIFNγ, 4689 Da) modified with S-acetyl thioacetate were custom-prepared by Genosphere (Paris, France). To synthesize the construct, BiPPB (0.112 µmol) was reacted with 0.337 µmol of Maleimide-PEG-succinimidyl carboxy methyl ester (Mal-PEG-SCM, 2 KDa, Creative PEGworks, Winston-Salem, NC) for 3 h. Thereafter, excess of Mal-PEG-SCM was blocked with lysine (0.337 µmol) for 1 h. Subsequently, the prepared BiPPB-PEG-Mal was reacted overnight with mimIFNγ-ATA in the presence of deacetylating reagent (0.1M hydroxylamine, 25mM EDTA in PBS pH 7.2). The prepared mimIFNγ-PEG-BiPPB (mimγ-BiPPB) conjugate (8.9 KDa) was extensively dialyzed against PBS using 7 kDa dialysis membrane (Thermo Scientific, Rockford, IL).

Antibodies
For immunohistochemistry the following primary antibodies were used: anti-alpha smooth muscle actin (α-SMA, clone ASM-1, Progen Biotechnik, Heidelberg, Germany); anti-fibronectin (ab6584, Abcam, Cambridge, UK); anti-CD3 (A0452, Dako, Glostrup, Denmark); anti-podoplanin (clone RTD4E10, Acris antibodies, Inc, Herford, Germany); anti-PDGFβR (#3169, Cell signaling, Danvers, USA), anti-CD31 (clone 5231, Dianova GmbH, Germany); anti-type I collagen (s1310-01, SouthernBiotech, USA) and anti-type III collagen (s1330-01, SouthernBiotech, USA).
Immunohistochemistry

Immunohistochemistry for α-SMA, fibronectin, type III collagen, CD31, podoplanin, and CD3 was performed on 2 µm paraffin sections. Sections were deparaffinized in xylene and rehydrated in graded alcohol series and distilled water. Antigen retrieval was achieved by overnight incubation at 80°C in 0.1 M Tris/HCl buffer (pH 9.0) for fibronectin and type III collagen staining, and treatment in the microwave for 15 min at 300W with 10 mM citrate buffer (pH 6:0) for podoplanin and CD31 staining. No antigen retrieval was performed for α-SMA staining. Type I collagen and PDGFβR staining was performed on 4 µm acetone-fixed frozen sections. Endogenous peroxidase activity was blocked with 0.03% H2O2 (in PBS) for 30 min. Primary antibody binding was detected by sequential incubations with horseradish peroxidase (HRP)-labeled appropriate secondary and tertiary antibodies (all obtained from DAKO, Glostrup, Denmark). Peroxidase activity was visualized using 3, 3′-diaminobenzidine tetrahydrochloride (DAB, DAKO, Glostrup, Denmark) as chromogen (10 min. incubation). Sections were counterstained with hematoxylin for 1 min and mounted with Kaiser’s glycerin gelatin.

Quantification of immunostaining

The sections were scanned using a NanoZoomer HT (Hamamatsu Photonics K.K., Shizuoka Pref., Japan). The extent of cortico-interstitial α-SMA, fibronectin, type I and III collagens, and CD3 expression was measured as numbers of positive pixels, and the numbers of podoplanin-positive vessel-like structures were counted in 30 cortical areas using Aperio ImageScope software (version 9.1.772.1570, Aperio Technologies Inc, Vista, CA, USA) at 200x magnification. For CD31 staining, 10 cortical areas at 400x magnification were selected, and the percentage of CD31 positive area was measured using ImageJ 1.46r (Rasband, W.S., U.S. National Institutes of Health).

Quantitative Real-Time PCR

Total RNA from kidney tissues was extracted using RNeasy Mini Kit (Qiagen, Hilden, Germany) according to the manufacturer’s instructions. The RNA concentrations were measured on a NanoDrop ND-1000 spectrophotometer (Thermo Scientific, USA). Single-stranded cDNA was synthesized using Superscript II and random hexamer primers (Invitrogen, Carlsbad, CA) in a volume of 20 µl. cDNA’s were diluted to a concentration of 2 ng/µl and 2.5 µl/reaction (5 ng) was used for qRT-PCR analysis. PCR reactions were performed in a 10 µl reaction volume containing 1 x qPCR master mix (EURogentec, Liege, Belgium), 1x Taqman Gene Expression Assay mix (Applied Biosystems, Forster City, CA). The primer reference numbers were as follows: Ywhaz: Mm03950126_s1, Col I: Mm00801666_g1, Col III: Mm01254476_m1, α-SMA/Acta2: Mm01546133_m1, Fn: Mm01256744_m1, MHC-II/CD74: Mm00658576_m1, and PDGFβR: Mm00435546_m1. qRT-PCR reactions were performed on a ABI7900HT thermal cycler (Biosystems, Forster City, CA). Relative gene expression was calculated using the 2^-ΔCt method with Ywhaz (tyrosine 3-monooxygenase/tryptophan 5-monooxygenase
activation protein ζ) as housekeeping gene. Data are expressed as fold-change compared to sham-operated kidneys.

**Plasma triglyceride measurements**
Whole blood was collected into commercially available EDTA-coated tubes (Item No: 450474, Greiner Bio-One, GmbH, Austria). The tubes were kept on ice during processing. Cells were removed from plasma by centrifugation for 10 minutes at 1000-2000 x g using a refrigerated centrifuge. Triglyceride levels were measured on a Vitalab Selectra-E chemistry workstation (Vital Scientific BV, Spankeren, The Netherlands).

**Statistical Analyses**
Statistical analyses were performed using GraphPad Prism 5.0 (GraphPad Software Inc, La Jolla, CA). Differences between multiple groups were calculated using the non-parametric one-way ANOVA (Kruskal-Wallis test) with Dunn’s Multiple Comparison Test post-test. Comparison of two groups was performed using the Mann Whitney test (or Student’s t-test where indicated). Comparison of weight loss and recovery in the various groups was performed using Repeated Measures ANOVA with Bonferroni post-test. p≤0.05 was considered statistically significant. Data are expressed as mean ± standard error of the mean (or mean ± standard deviation where indicated).
Targeted IFNγ peptidomimetic reduces renal fibrosis

REFERENCES


Targeted IFNγ peptidomimetic reduces renal fibrosis

Supplemental Figure 1: IFNγ peptidomimetic (mimγ-BiPPB) causes a non-significant reduction in extracellular matrix mRNA expression in mouse UUO kidneys. Relative gene expression of (A) fibronectin, (B) collagen I, and (C) collagen III in fibrotic and sham-operated kidneys 7 days post surgery. Quantitative data of UUO are expressed relative to sham. ***p<0.001. Bars represent mean ± SEM of 5-6 mice per group.
**Supplemental Figure 2**: UUO induces renal inflammation which is non-significantly reduced by IFNy-peptidomimetic (mimγ-BiPPB).

Relative gene expression of (A) MCP-1, (B) TNF-α, (C) IL-1β, (D) IL-6, (E) F4/80 and (F) MHC II. Computerized quantitative analysis of CD3 (T cells) immunohistochemistry on sham-operated and UUO kidneys treated with vehicle (PBS), mimγ-BiPPB, or (non-targeted full length) IFNy. Analyses were performed 7 days post surgery. Quantitative data of UUO are expressed relative to sham. **p<0.01, *p<0.05. Bars represent mean ± SEM of 5-6 mice per group.