Antifibrotic Effect of Tamoxifen in a Model of Progressive Renal Disease
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ABSTRACT
Tamoxifen, a selective estrogen receptor modulator, has antifibrotic properties; however, whether it can attenuate renal fibrosis is unknown. In this study, we tested the effects of tamoxifen in a model of hypertensive nephrosclerosis (chronic inhibition of nitric oxide synthesis with L-NAME). After 30 days, treated rats had significantly lower levels of albuminuria as well as lower histologic scores for glomerulosclerosis and interstitial fibrosis than untreated controls. Tamoxifen was renoprotective despite having no effect on the sustained, severe hypertension induced by L-NAME. Tamoxifen prevented the accumulation of extracellular matrix by decreasing the expression of collagen I, collagen III, and fibronectin mRNA and protein. These renoprotective effects associated with inhibition of TGF-β1 and plasminogen activator inhibitor-1, and with a significant reduction in α-smooth muscle actin-positive cells in the renal interstitium. Furthermore, tamoxifen abrogated IL-1β– and angiotensin-II–induced proliferation of fibroblasts from both kidney explants and from the NRK-49F cell line. Tamoxifen also inhibited the expression of extracellular matrix components and the production and release of TGF-β1 into the supernatant of these cells. In summary, tamoxifen exhibits antifibrotic effects in the L-NAME model of hypertensive nephrosclerosis, likely through the inhibition of TGF-β1, suggesting that it may have therapeutic use in CKD treatment.


The pathogenesis of most CKD involves a complex mechanism of hemodynamic and inflammatory processes that leads to renal fibrosis and tubulointerstitial scarring with subsequent progression toward ESRD.1 Studies show that therapeutic interventions such as the blockade of the renin–angiotensin–aldosterone system and immunosuppressive drugs slow the progression of renal disease in experimental models2,3 and human CKD clinical trials.4–8 Although these strategies promote renoprotective effects, they do not halt the progression of renal fibrosis and scarring. Considering that interstitial fibrosis represents the final common pathway of CKD, therapeutic intervention with drugs that display antifibrotic properties may represent an attractive choice of therapy for arresting the autonomous fibrogenic process in chronic progressive nephropathies.

In this context, tamoxifen, a selective estrogen receptor modulator (SERM), may represent a novel therapeutic option for promoting the blockade of fibrogenesis. Tamoxifen, a drug clinically used to prevent and treat breast cancer, is effective in treating abnormal healing disorders. Of particular interest are several reports that describe the efficacy of tamoxifen in promoting regression of fibrosis not only in idiopathic retroperitoneal fibrosis,9–11 but also in fibrosclerotic disorders such as desmoid tumors,12,13 encapsulating peritoneal sclerosis,14,15 sclerosing cervicitis, and fibrosing mediastinitis.16 In addition to clinical evidence of fibrosis regression with tamoxifen treatment, in vitro studies also suggest that tamoxifen

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possesses antifibrotic properties. Tamoxifen suppresses transcription and synthesis of collagen in mesangial cells in culture,\textsuperscript{17} inhibits proliferation of human dermal fibroblasts,\textsuperscript{18} decreases fibroblast function,\textsuperscript{19} and inhibits wound contraction.\textsuperscript{20}

Considering that these fibroproliferative diseases, characterized by increased fibroblast proliferation and excessive deposition of extracellular matrix (ECM) proteins, have common features with the fibrogenic process of progressive renal diseases, we hypothesized that tamoxifen might have a potential benefit in the treatment of abnormal renal scarring. This hypothesis led us to test this drug in an experimental model of chronic progressive renal disease (the NAME model), characterized by severe hypertension, albuminuria, glomerulosclerosis, interstitial fibrosis, and progressive renal injury.\textsuperscript{21} In addition, considering that TGF-\(\beta\) is an important mediator of renal fibrogenesis, we investigated whether the antifibrotic effect of tamoxifen might be related to TGF-\(\beta\)1 production.

Renal fibroblasts are the major source of ECM production in the kidney. To further investigate whether tamoxifen directly affects the effector cells of renal fibrogenesis, we grew renal fibroblasts in culture, submitted them to specific stimuli, and treated them with tamoxifen. The \textit{in vitro} stimuli consisted of IL-1\(\beta\) and angiotensin-II (Ang-II) to resemble some of the recognized pathogenic stimuli involved in the process of renal interstitial inflammation and fibrosis.\textsuperscript{22,23} We analyzed the effect of tamoxifen on cell proliferation, ECM, and TGF-\(\beta\) production in these stimulated cells.

**RESULTS**

**Tamoxifen Treatment Induces Renoprotective Effects**

After 30 days of treatment, the body weight of the NAME rats was 18\% lower than the control rats (255\(\pm\)27 versus 310\(\pm\)24 g, respectively; \(P<0.05\)). Tamoxifen treatment was well tolerated without affecting body weight (255\(\pm\)5 g; \(P<0.05\) versus controls).

Rats treated with L-NAME developed severe hypertension (Figure 1A and Supplemental Table 1). Tamoxifen treatment had no effect on arterial pressure, and NAME

![Figure 1](image-url)
rats receiving tamoxifen displayed sustained hypertension. As expected, the NAME group exhibited a marked increase in albuminuria (Figure 1B and Supplemental Table 1). Although the NAME+TAM group showed severe hypertension, tamoxifen treatment significantly diminished urinary albumin excretion.

**Tamoxifen Prevents Glomerulosclerosis and Interstitial Fibrosis**
NAME rats developed significant glomerulosclerosis ($5.2\% \pm 1.9\%$ versus $0.5\% \pm 0.4\%$ in controls; $P<0.05$). Tamoxifen treatment significantly decreased the percentage of glomerulosclerosis ($1.0\% \pm 0.3\%; P<0.05$ versus NAME), reaching values similar to controls (Figures 1C and 2, A and B).

Collapsed glomeruli, characterized by glomerular basement membrane wrinkling and capillary lumen diameter reduction, were increased in the NAME group compared with controls ($13.1\% \pm 3.4\%$ versus $1.8\% \pm 0.6\%$, respectively; $P<0.05$), and tamoxifen significantly reduced the percentage of collapsed glomeruli ($4.7\% \pm 0.7\%; P<0.05$ versus NAME).

Interstitial fibrosis was markedly increased in the NAME group ($1.8\% \pm 0.4\%$ versus $0.3\% \pm 0.1\%$ in controls; $P<0.05$). Tamoxifen treatment drastically reduced interstitial fibrosis ($0.4\% \pm 0.1\%; P<0.05$ versus NAME) (Figures 1 and 2, C and D).

**Tamoxifen Diminishes Renal ECM Protein Expression**
ECM protein expression, as analyzed by real-time PCR, was significantly increased in the NAME group, whereas tamoxifen treatment significantly reduced expression of collagen I and collagen III mRNA (Figure 3 and Supplemental Table 1). Similar results were observed at the protein level (Figure 4 and Supplemental Table 1).

**Tamoxifen Inhibits Plasminogen Activator Inhibitor-1 Expression in the Kidney**
Plasminogen activator inhibitor-1 (PAI-1) expression, analyzed by real-time PCR, was markedly elevated in the NAME rats (Figure 5 and Supplemental Table 1). Tamoxifen treatment significantly decreased PAI-1 expression (by more than 10-fold), maintaining the mRNA levels in the treated group at levels similar to controls.

**TGF-β1 Downregulation May Mediate the Antifibrotic Effects of Tamoxifen**
As illustrated in Figure 6A, NAME rats exhibited significantly increased expression of TGF-β1, as assessed by Western blot, in the renal tissue. By contrast, tamoxifen treatment of the diseased rats induced a significant decrease in TGF-β1 expression. Urinary TGF-β1, measured by ELISA, was significantly higher in NAME rats compared with controls (Figure 6B). The effect of tamoxifen in decreasing urinary TGF-β1 excretion was unremarkable.

**Analysis of the Renal Inflammatory Infiltrate**
We observed a high number of interstitial macrophages and T lymphocytes in the kidneys of NAME animals, predominantly around glomeruli and injured vessels. Tamoxifen treatment had no significant effect on the number of renal macrophages.

Figure 2. Effect of tamoxifen on glomerulosclerosis, interstitial fibrosis, and α-smooth muscle actin expression on NAME rats. (A) Periodic acid–Schiff staining in kidney sections showing glomerulosclerosis in NAME rats, and (B) amelioration of glomerulosclerosis in NAME rats treated with tamoxifen. (C) Prominent interstitial expansion in NAME rats, analyzed by Masson Trichrome staining. (D) Tamoxifen attenuated the interstitial expansion. (E) Immunohistochemistry for α-SMA. NAME rats presenting an accumulation of myofibroblasts in the interstitium. (F) A striking reduction of myofibroblasts was observed with tamoxifen treatment.
in this model and no influence on the number of T lymphocytes in the renal tissue (Table 1).

Control rats exhibited a constitutive expression of α-smooth muscle actin (α-SMA) in the vessels and an absence of α-SMA in the interstitial compartment. By contrast, NAME rats displayed enhanced α-SMA expression in the interstitium, reflecting an elevated number of myofibroblasts in this compartment (Figure 2E). Tamoxifen treatment significantly reduced the α-SMA expression in the renal interstitium (Figure 2F).

Cell Culture Experiments and Characterization of Renal Fibroblasts
Phenotypic characterization using specific antibodies showed that fibroblasts isolated from rat kidney explants were positive for vimentin (Figure 7A) and α-SMA (Figure 7C) and negative for desmin (Figure 7E), vWF, and pancytokeratin, supporting the hypothesis that these cells were myofibroblasts. However, NRK-49F cells grown in culture were positive for vimentin (Figure 7B) and negative for α-SMA (Figure 7D), desmin (Figure 7F), vWF, and pancytokeratin, which characterized them as fibroblasts from a stable cell line.

Tamoxifen Blocks Renal Fibroblast Proliferation in Culture
Analysis of the proliferative activity of rat renal fibroblasts, assessed by the[^3H]-thymidine incorporation assay, showed that tamoxifen significantly decreased the proliferation rate of both types of fibroblasts; this effect was already observed at 12 hours of treatment and reached growth inhibition of <60% after 24 hours and 48 hours in culture (Figure 8 and Supplemental Table 2). However, we observed the most striking antiproliferative effect of tamoxifen in fibroblasts previously stimulated with IL-1β and Ang-II. Tamoxifen substantially blocked the mitogenic effect of profibrogenic factors IL-1β and Ang-II on cultured renal fibroblasts at all observation times.

Tamoxifen Decreases the Expression of ECM Components in Cultured Fibroblasts
The effect of tamoxifen on the expression of ECM components (collagen I, collagen III, and fibronectin) was analyzed in NRK-49F fibroblasts (Table 2). Tamoxifen added to the culture at a concentration of 5 μM did not cause any significant change in ECM component expression. However, exposure of IL-1β and Ang-II–stimulated fibroblasts to tamoxifen resulted in a significant decrease in ECM expression at 24 hours.

Tamoxifen Decreases TGF-β Synthesis and Secretion in Cultured Fibroblasts
Exposure of IL-1β or Ang-II–stimulated rat renal fibroblasts to tamoxifen in culture had a significant effect in reducing TGF-β1 mRNA expression at 24 hours (Table 2). These findings parallel the measurements of TGF-β1 protein in the supernatants of both the primary culture of renal fibroblasts and fibroblasts of the NRK-49F cell line that were stimulated with IL-1β and Ang-II (Figure 9 and Supplemental Table 2). Hence, these findings suggest that the downregulation of TGF-β1 may mediate the antifibrotic effects of tamoxifen.

DISCUSSION
In this study, we demonstrated that tamoxifen administration induces renoprotective and potent antifibrogenic effects in an experimental model of chronic progressive renal disease. In the NAME model, tamoxifen promoted a reduction in urinary albumin levels of >80% and caused a marked decrease in the histologic parameters of glomerular and tubulointerstitial damage, reducing the degree of glomerulosclerosis and collapsed glomeruli as well as the severity of interstitial fibrosis. It is noteworthy that tamoxifen displayed no effects on arterial pressure levels. These findings are remarkable because the renoprotective...
effects were achieved even in a setting of sustained, severe hypertension. The negative effect of sustained hypertension was likely overcome by the protective effects of tamoxifen on renal architecture, resulting in a final balance of renoprotection.

A significant finding of this study was the marked reduction in the relative area of renal interstitial fibrosis achieved with tamoxifen treatment, reaching values similar to the control group. Considering that the magnitude of interstitial fibrosis strongly predicts the degree and progression to renal failure, the antifibrotic effect of tamoxifen in this compartment may possibly be crucially relevant in attenuating the progression of renal disease. The effect of tamoxifen in ameliorating tubulointerstitial fibrosis seems directly related to a reduction in the synthesis of major ECM components, as demonstrated by the diminished production of collagen I, collagen III, and fibronectin in kidney tissue of tamoxifen-treated NAME rats. The effect of tamoxifen in decreasing renal fibrosis was also demonstrated in rats with unilateral urethral obstruction, a model characterized by severe renal fibrosis.

The decreased production of collagen I, collagen III, and fibronectin associated with tamoxifen treatment may be a consequence of its effect on myofibroblasts. In fact, immunohistochemical analysis demonstrated a significant decrease in α-SMA expression. Although studies show that tamoxifen decreases inflammation and disease severity in NZB/W F1 mice, we observed no substantial effect on the number of macrophages or T cells in this study.

The antifibrotic effects observed in kidneys of tamoxifen-treated NAME rats were further analyzed in vitro by investigating the direct effect of tamoxifen on the effector cells of renal fibrogenesis. Renal myofibroblasts isolated from rat kidney and renal fibroblasts from a rat cell line (NRK-49F) were stimulated with IL-1β or Ang-II to mimic the inflammatory and profibrogenic environment involved in the development of renal fibrogenesis. In fact, both IL-1β and Ang-II induced in vitro fibroblast proliferation. Exposure to tamoxifen in the conditioning media promoted pronounced inhibitory effects on fibroblast proliferation, which were particularly remarkable in the activated fibroblasts stimulated with IL-1β and Ang-II.

These results parallel our in vivo findings on the effect of tamoxifen in decreasing myofibroblast proliferation in NAME rats. Similarly, previous reports documented that tamoxifen negatively affects the proliferation of vascular smooth muscle...
Figure 5. PAS-1 expression in renal tissue analyzed by real-time PCR in the different experimental groups. Control group, animals receiving only high-salt diet; NAME group, animals receiving L-NAME plus high-salt diet; and NAME+TAM group, NAME animals treated with tamoxifen.

Figure 6. Effect of tamoxifen on TGF-β1 in the different experimental groups. (A) Expression of TGF-β1 in renal tissue was analyzed by Western blot. (B) Twenty-four-hour urinary levels of TGF-β1 were analyzed by ELISA. Control group, animals receiving only high-salt diet; NAME group, animals receiving L-NAME plus high-salt diet; and NAME+TAM group, NAME animals treated with tamoxifen.

Table 1. Mean number of macrophages (ED-1+), lymphocytes (CD-3+), and myofibroblasts (α-SMA) in the study groups

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Control</th>
<th>NAME</th>
<th>NAME+TAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED-1+ (cells/mm²)</td>
<td>8 ± 2</td>
<td>57 ± 11a</td>
<td>25 ± 7</td>
</tr>
<tr>
<td>CD-3+ (cells/mm²)</td>
<td>32 ± 4</td>
<td>65 ± 9a</td>
<td>84 ± 13a</td>
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<td>α-SMA (%)</td>
<td>0.2 ± 0.1</td>
<td>11.6 ± 2.9a</td>
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Control, animals receiving only high-salt diet; NAME group, animals receiving L-NAME plus high-salt diet; NAME+TAM group, NAME animals treated with tamoxifen.

A large body of evidence points to the protective effect of estrogen in renal disease progression. Women with CKD show a slower decline in renal function over time compared with men.17,36 It is not clear whether these differences are related to differences in the hormonal environment, such as estrogen levels, or other factors.

Clinical use of tamoxifen to treat breast cancer seems to rely on its anti-estrogenic effect in this tissue. Paradoxically, tamoxifen has estrogenic effects in other tissues, and thus has been more correctly classified as a SERM.34,35 Considering that tamoxifen is an estrogen receptor (ER) modulator, its renoprotective effects may be related to its influence on the estrogen signaling pathway. A large body of evidence points to the protective effect of estrogens on renal disease progression. Women with CKD show a slower decline in renal function over time compared with men with CKD.17,36–39 In addition, premenopausal women have a lower prevalence of CKD compared with age-matched men, but the incidence of the disease increases after menopause.40

Experimental models of renal disease are widely established in male animals, which develop a more severe disease at a more rapid rate than female animals.41 It is not clear whether these models may rely on the blockade of TGF-β1, a key profibrotic growth factor involved in renal fibrogenesis. In the renal tissue of diseased NAME rats, tamoxifen significantly reduced the upregulated expression of TGF-β1, suggesting a direct effect of tamoxifen on the TGF-β-mediated mechanisms. In addition, the urinary levels of TGF-β1 were substantially reduced in tamoxifen-treated NAME rats. In parallel, tamoxifen exposure also markedly reduced the synthesis of TGF-β1 by IL-1β or Ang-II–stimulated renal fibroblasts in culture.

Studies focused on elucidating the pathophysiologic mechanisms of keloid, a fibroproliferative skin disorder characterized by overproduction of collagen proteins, provide evidence that tamoxifen downregulates TGF-β production. Researchers showed that tamoxifen downregulates TGF-β1 in keloid fibroblasts in a dose-dependent manner.30,31 These studies proposed that the antifibrotic effect afforded by tamoxifen in activated fibroblasts could be mediated by TGF-β downregulation, corroborating our results. In contrast, some tumor cell lines and breast cancer cells have a different response to tamoxifen, consisting of an increase in TGF-β production.32,33 Thus, the exact mechanisms involved in these discordant effects have not been completely clarified.

The action of PAI-1, a major inhibitor of ECM degradation, could also mediate the antifibrotic effect afforded by tamoxifen.43 Although diseased NAME rats overexpressed PAI-1 mRNA, tamoxifen treatment induced a marked downregulation of PAI-1 in renal tissue. PAI-1 inhibition associated with tamoxifen treatment may contribute to amelioration of ECM turnover.

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NRK-49F cells were positive for vimentin (B) and negative for PAI-1 levels.50 The estrogen-like anti-
disease in several models of kidney disease.42 to worsen renal damage and accelerate the progression of renal
such as estrogen de-
J Am Soc Nephrol
testosterone. However, modi-
effects are caused by the low levels of estrogens or the presence of
testosterone. However, modifications of sex hormone status,
such as estrogen deficiency induced by ovariectomy, are shown
to worsen renal damage and accelerate the progression of renal
disease in several models of kidney disease.42–46
Studies using 17\textbeta\textendash estradiol, 2-hydroxyestradiol, or estriol
replacement provide evidence that estrogen or estrogen
metabolites have a beneficial effect ameliorating renal dam-
age.43–48 For example, the data showed that estrogen or estrogen
metabolites reduced albuminuria, attenuated renal
lesions, and prevented disease progression in a wide variety
of experimental models of renal disease. Renoprotective ef-
effects were observed even when estrogen supplementation was
initiated after disease onset.49 The favorable effects of estro-
gens in the kidney are possibly related to their known effects
on mesangial cells, as demonstrated both in vitro and in vivo,
by reducing proliferation\textsuperscript{40} and synthesis of collagen and other
ECM components,\textsuperscript{43,47,51,52} which contributes to preventing the
development of glomerulosclerosis\textsuperscript{42–47} and tubulointerstitial
fibrosis.\textsuperscript{43–45,48} In addition, estrogens induce a reduction in
PAI-1 levels.\textsuperscript{50} The estrogen-like antifibrotic effects are possibly
related to the reduction in TGF-\textbeta expression.\textsuperscript{43–45,49,50,53,54} It is
interesting to note that these reported renoprotective effects of
estrogens parallel the findings observed for tamoxifen in this study.\textsuperscript{47}
All effects of estrogens are mediated via
ER, intracellular transcription factors that
regulate the transcription of target genes. There are two ER subtypes, ER-\textalpha and ER-\textbeta, with quite different tissue distributions.\textsuperscript{55}
The biologic relevance of the two subtypes is still unclear, but they may determine
the distinct cellular effects of estrogens in
different tissues.\textsuperscript{55} In the kidney, ER-\textalpha is the predominant receptor subtype, partic-
ularly expressed in mesangial cells of the
glomerulus.\textsuperscript{55,56} suggesting that this ER
subtype mediates the renoprotective effects
of estrogens.\textsuperscript{57} Accordingly, ER-\textalpha\textsuperscript{–/–}
knockout animals, lacking ER-\textalpha but not
ER-\textbeta, develop GN, proteinuria, and tubu-
lar cell destruction.\textsuperscript{58}
Similarly to estrogen, tamoxifen binds to
ER in a specific region called the C-terminal
ligand-binding domain.\textsuperscript{59} The complex
ER/ligand (estrogen, tamoxifen, or other
SERMs) binds to the respective estrogen-
response element displayed in the pro-

tromoter region of the estrogen-responsive
genes, recruiting coactivators or corepres-
sors that activate or inhibit, respectively,
the transcription machinery.\textsuperscript{60} Thus,
the combination of ER with transcription coac-
vitators and corepressors has been suggested
as the determinant mechanism that explains
the different effects triggered by these receptors.\textsuperscript{60}
Efficacy and safety make tamoxifen a useful drug in breast
cancer treatment. The most important side effects reported
in patients undergoing long-term tamoxifen treatment consist
of visual impairment, cataracts,\textsuperscript{61} and risk of thromboembolic
events.\textsuperscript{62,63} Tamoxifen has weak estrogenic properties that can
induce endometrial cell proliferation and, consequently,
endometrial cancer.\textsuperscript{64} In addition, tamoxifen seems to increase
the risk of radiation-induced lung and skin fibrosis.\textsuperscript{65–67} This
paradoxical effect aggravating pulmonary fibrosis is likely
dependent on the concurrent exposition to radiotherapy. Thus,
its seems reasonable to assume that tamoxifen may not be ap-
propriate for all fibrotic diseases.
In summary, our study demonstrated that tamoxifen
ameliorates renal injury in a model of chronic nephropathy
(the NAME model), preventing albuminuria, glomeruloscle-
rosis, and interstitial fibrosis. These effects, demonstrated both
in vivo and in vitro, were related to the direct action of tamox-
ifen in the myofibroblasts and consequent action on ECM
synthesis. This study strongly supports the hypothesis that
tamoxifen inhibits renal fibrogenesis by TGF-\textbeta1 blockade,
providing evidence that tamoxifen is a potentially useful anti-

Figure 7. Immunocytochemistry for phenotypic characterization of fibroblasts obtained
from primary culture of kidney explants or stable line (NRK-49F). Cells derived from
kidney explants were positive for vimentin (A) and \alpha-SMA (C) and negative for desmin (E).
NRK-49F cells were positive for vimentin (B) and negative for \alpha-SMA (D) and desmin (F).
Animal Model and Experimental Groups

In this study, we used 35 adult male Wistar rats, weighing 240–270 g, obtained from an established colony at the University of São Paulo, São Paulo, Brazil. All experimental procedures were conducted in accordance with institutional guidelines. The animals received a 3.2% high-salt diet (Nuvital, São Paulo, Brazil) for 2 weeks and were then divided into three groups: the control group, receiving only the high-salt diet; the NAME group, receiving L-NAME (Sigma Chemical Company, St. Louis, MO), 200 mg/L dissolved in drinking water, and the high-salt diet; and the NAME+TAM group, receiving L-NAME, tamoxifen. 

CONCISE METHODS

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the high-salt diet, and tamoxifen citrate treatment 10 mg/kg per day (Nolvadex; AstraZeneca, London, UK) by gavage. The groups were followed for 30 days and then sacrificed. One day before sacrifice, rats were maintained in metabolic cages for 24-hour urine collection to determine urinary albumin excretion (by radial immunodiffusion) and urinary TGF-β1 excretion (ELISA technique; Promega, San Luis Obispo, CA). Systolic BP was determined by tail cuff manometry with tail plethysmography (Harvard Apparatus, Eden Bridge, UK). Euthanasia was performed by anesthesia with sodium pentobarbital 25–50 mg/kg intraperitoneally, and renal tissue was collected.

Renal Histology
One midcoronal section of the left kidney was fixed in Dubosq-Brazil solution for 45 minutes and then postfixed in buffered 10% formaldehyde solution. We stained 2- to 3-μm-thick sections with periodic acid–Schiff reagent and with the Masson Trichrome technique. The extent of glomerulosclerosis was evaluated by attributing a score to each glomerulus according to the extent of sclerotic lesions.3 Collapsed glomeruli were defined as glomeruli reduced in size and exhibiting basement membrane wrinkling with collapsed segmental capillary loops. The frequency of each category of glomerular injury was expressed as the percentage of the total number of glomeruli examined. The extent of interstitial expansion was quantitatively evaluated in Masson-stained sections by a point-counting technique.68 All morphometric evaluations were performed in a blinded manner by a single observer.

Immunohistochemistry
Paraffin sections of renal tissue were cut at 4-μm thickness and subjected to microwave irradiation in citrate buffer to enhance antigen retrieval. The following monoclonal antibodies were used as primary antibodies: anti-rat ED-1 (Serotec, Oxford, UK), anti-rat CD-3

### Table 2. Expression of ECM components (collagen I, collagen III, and fibronectin) and TGF-β1 from rat renal fibroblast cell line NRK-49F after 24 hours in culture

<table>
<thead>
<tr>
<th>ECM Components</th>
<th>Control</th>
<th>TAM</th>
<th>IL-1β</th>
<th>Ang-II</th>
<th>IL-1β+TAM</th>
<th>Ang-II+TAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collagen I (ratio/GAPDH)</td>
<td>1.00±0.45</td>
<td>0.89±0.40</td>
<td>2.62±0.26a</td>
<td>2.83±0.22b</td>
<td>1.12±0.26c</td>
<td>0.94±0.53d</td>
</tr>
<tr>
<td>Collagen III (ratio/GAPDH)</td>
<td>1.00±0.80</td>
<td>0.60±0.50</td>
<td>1.75±0.17</td>
<td>2.72±0.17b</td>
<td>0.79±0.20</td>
<td>0.74±0.34d</td>
</tr>
<tr>
<td>Fibronectin (ratio/GAPDH)</td>
<td>1.00±0.69</td>
<td>1.02±0.33</td>
<td>3.08±0.20a</td>
<td>2.06±0.55</td>
<td>1.06±0.24c</td>
<td>0.98±0.49</td>
</tr>
<tr>
<td>TGF-β1 (ratio/GAPDH)</td>
<td>1.00±0.33</td>
<td>0.91±0.13</td>
<td>2.37±0.21a</td>
<td>2.16±0.21b</td>
<td>1.02±0.35c</td>
<td>0.51±0.21d</td>
</tr>
</tbody>
</table>

Control, nonstimulated renal fibroblasts; TAM, renal fibroblasts treated with tamoxifen; IL-1β, renal fibroblasts stimulated with IL-1β; Ang-II, renal fibroblasts stimulated with angiotensin-II; IL-1β+TAM, IL-1β-stimulated renal fibroblasts treated with tamoxifen; Ang-II+TAM, angiotensin-II-stimulated renal fibroblasts treated with tamoxifen; GAPDH, glyceraldehyde 3-phosphate dehydrogenase.

*aP<0.05 versus control and TAM groups.

*bP<0.05 versus control and TAM groups.

*cP<0.05 versus IL-1β (one-way ANOVA between control, TAM, IL-1β, and IL-1β+TAM groups).

*dP<0.05 versus Ang-II (one-way ANOVA between control, TAM, Ang-II, and Ang-II+TAM groups).
(Seralab, Oxford, UK), and anti-rat α-SMA (Sigma Chemical Company) to identify macrophages, lymphocytes, and myofibroblasts, respectively. After incubation with the primary antibodies, the slides were submitted to a second reaction either with rat-adsorbed biotinylated anti-mouse IgG (Vector Labs, Burlingame, CA) or with biotinylated anti-rabbit IgG (Vector Labs). To complete the sandwich, sections were incubated with streptavidin-biotin-alkaline phosphatase complex (Dako, Glostrup, Denmark) for ED-1, CD-3, and α-SMA. Finally, sections were incubated with a freshly prepared substrate, consisting of naphthol-AS-MX-phosphate (Sigma Chemical Company) and fast red dye (Sigma Chemical Company). Proliferating cell nuclear antigen staining was performed as previously described.3

We conducted quantitative analysis of ED-1 and CD-3–positive cells in a blinded fashion under ×200 microscopic magnification, expressed as cells per millimeter squared. The fraction of the cortical interstitium positive for expressed as cells per millimeter squared. The fraction of the cortical interstitium positive for α-SMA was quantified by a point-counting technique.68

**Real-Time PCR and Western Blot**

We used real-time PCR to analyze expression of collagen type I, collagen type III, fibronectin, and PAI-1 in kidney samples. Total RNA was extracted by the guanidinium thiocyanate-phenol-chloroform method, and cDNA was synthesized by Moloney murine leukemia virus reverse transcriptase enzyme (Promega). The SsoFast EvaGreen Supermix (Bio-Rad Laboratories, Hercules, CA) and the StepOne real-time PCR system (Applied Biosystems, Foster City, CA) were used to analyze collagen type I, collagen type III, and fibronectin. Briefly, quantitative PCR experiments were conducted in 20-μl reactions containing 3 μl of cDNA, 1 μl of each primer (10 μM) (Table 3), 10 μl of SsoFast EvaGreen Supermix 2×, and water. We used the following PCR cycle profile: 10 minutes at 95°C, followed by 40 cycles of 15 seconds at 95°C for denaturation, 20 seconds at 60°C for combined annealing, and 10 seconds at 72°C for extension. Glyceraldehyde-3-phosphate dehydrogenase was used as the housekeeping control (Table 3).

To analyze PAI-1 expression, PCR reactions were performed in the ABI Prism 7700 Sequence Detection System using Syber Green PCR Master Mix (Applied Biosystems), as previously described.70

**Statistical Analyses**

Data are presented as mean±SEM, and statistical analyses were performed with the Prism statistical program (GraphPad, San Diego, CA). We used one-way ANOVA with pairwise comparisons according to the Newman-Keuls formulation. P<0.05 was considered significant.

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**Table 3. Primers used for real-time PCR**

<table>
<thead>
<tr>
<th>Gene Target</th>
<th>Sense and Antisense (5’-3’)</th>
<th>Product (bp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collagen type I</td>
<td>CACCTCCGGAGCAGGACGGA</td>
<td>80</td>
</tr>
<tr>
<td>Collagen type III</td>
<td>CTCTTTGCGGCTGGGTTGG</td>
<td>92</td>
</tr>
<tr>
<td>Fibronectin</td>
<td>TGACCCAGACTTACCGTGCA</td>
<td>80</td>
</tr>
<tr>
<td>TGF-β1</td>
<td>CAACCCGGGTGCTCCCGCAT</td>
<td>96</td>
</tr>
<tr>
<td>PAI-1</td>
<td>GATGGACATCTTCACTACACC</td>
<td>101</td>
</tr>
<tr>
<td>β-actin</td>
<td>GACGCTTGAGTACGTCGCC</td>
<td>70</td>
</tr>
</tbody>
</table>

Western blot was used to analyze the expression of collagen type I, collagen type III, fibronectin, and TGF-β1, performed as previously described.21 Briefly, 30 μg of total protein extracted from renal tissue was denatured and separated on 8% (for collagen type I and III) or 14% (for TGF-β1) SDS-PAGE gels, and transferred to a nitrocellulose membrane by electroblotting. Mouse anti-rat collagen type I (Sigma Chemical Company), mouse anti-rat collagen type III (Santa Cruz Biotechnology, Santa Cruz, CA), mouse anti-rat fibronectin (Calbiochem), and mouse anti-rat TGF-β1 primary antibodies (Genzyme Corp, Cambridge, MA) were used in 1:200, 1:250, 1:250, and 1:500 dilutions, respectively. After washing, the blots were incubated in a 1:5000 dilution of goat anti-mouse IgG horseradish peroxidase-conjugated antibody (Santa Cruz Biotechnology). Blots were detected by enhanced chemiluminescence. The band density was semi-quantified using ImageMaster software (version 2.0; Pharmacia Biotech, Buckinghamshire, UK).
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DISCLOSURES
None.

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