Inducible Co-Stimulatory Molecule Ligand Is Protective during the Induction and Effector Phases of Crescentic Glomerulonephritis

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The inducible co-stimulatory molecule (ICOS)/ICOS ligand (ICOSL) co-stimulatory pathway is critical in T cell activation, differentiation, and effector function. Its role was investigated in a model of Th1-driven crescentic glomerulonephritis (GN). GN was induced by sensitizing mice to sheep globulin (day 0) and challenging them with sheep anti-mouse glomerular basement membrane antibody (Ab; day 10). Disease and immune responses were assessed on day 20. For testing the role of ICOSL in the induction of GN, control or anti-ICOSL mAb were administered from days 0 to 8. For examining the role of ICOSL in the effector phase of GN, treatment lasted from days 10 to 18. Blockade of ICOSL during the induction of GN increased glomerular accumulation of CD4+ T cells and macrophages and augmented renal injury. These results correlated with attenuated splenocyte production of protective Th2 cytokines IL-4 and IL-10 and decreased apoptosis of splenic CD4+ T cells. ICOSL was upregulated within glomeruli of mice with GN. Inhibition of ICOSL during the effector phase of GN enhanced glomerular T cell and macrophage accumulation and augmented disease, without affecting the systemic immune response (cytokine production, T cell apoptosis/proliferation, Ab levels). Increased presence of leukocytes in glomeruli of mice that received anti-ICOSL mAb was associated with enhanced cellular proliferation and upregulation of P-selectin and intercellular adhesion molecule-1 within glomeruli. These studies demonstrate that ICOSL is protective during the induction of GN by augmenting Th2 responses and CD4+ T cell apoptosis. They also show that ICOSL is upregulated in nephritic glomeruli, where it locally reduces accumulation of T cells and macrophages and attenuates renal injury.

merular basement membrane (anti-GBM) globulin acts as a planted antigen in glomeruli. The development of crescentic GN in this model occurs in two phases. During the induction phase, animals are sensitized to a foreign Ig. The effector phase is initiated in the kidney by challenging sensitized animals with foreign anti-mouse GBM globulin. It is mediated by infiltrating CD4+ Th1 cells that direct recruitment of macrophages (20–22), attenuated by Th2 cytokines (23–25), and independent of CD8+ T cells (26) and autologous antibodies (Ab) (27). Similarly, the development of human crescentic GN is thought to be mediated by CD4+ Th1 cells and macrophages, which invariably are present in glomeruli of patients with the disease (28).

The role of the ICOS/ICOSL pathway has been investigated in several models of GN. In lupus nephritis, both early and late blockade of ICOSL ameliorated clinical signs of disease (29). Inhibition of ICOS attenuated the development of GN in Th2-driven and exacerbated disease in Th1-mediated graft-versus-host disease (GVHD) (30). In contrast, recent studies have driven and exacerbated disease in Th1-mediated graft-versus-host disease (GVHD) (30). In contrast, recent studies have shown that ICOSL is expressed by renal tubular epithelial cells (TEC) negatively regulates T cell activation and cytokine production in the kidney (6,31). The role of the ICOS/ICOSL co-stimulatory pathway in crescentic GN has not been defined clearly. The purpose of these studies was to investigate the role of ICOSL during the induction and effector phases of Th1-mediated crescentic GN using a model of NTN.

**Materials and Methods**

**Experimental Design**

**Animals.** Eight- to 10-wk-old male C57BL/6 mice that were obtained from Monash University Animal Services (Melbourne, Australia) were used for experiments.

**Induction of Crescentic GN.** Mice were sensitized by a subcutaneous injection of 0.5 mg of normal sheep globulin in complete Freund’s adjuvant (day 0). Sheep anti-mouse GBM globulin was given intravenously at a dose of 14 mg/mouse (day 10). Unless otherwise stated, immune responses and renal injury were assessed on day 20.

**Monoclonal Ab Treatment.** Each mouse received 250 μg of protein G-purified inhibitory rat anti-mouse ICOSL (HK5.3; hybridoma provided by Prof. Hideo Yagita, Juntendo University School of Medicine, Tokyo, Japan) mAb, which has been characterized previously (13), or control rat IgG intraperitoneally. For testing the role of ICOSL in the induction phase of GN, mice received anti-ICOSL mAb (n = 6) or rat IgG (n = 6) on days 0, 2, 4, 6, and 8. To investigate the role of ICOSL in the effector phase of GN, mice received anti-ICOSL mAb (n = 7) or rat IgG (n = 7) on days 10, 12, 14, 16, and 18. Nonimmunized mice (n = 8) provided normal controls without GN.

**Renal Injury**

Renal formation was assessed on periodic acid-Schiff-stained, Bouin-fixed 3-μm-thick paraffin sections. Glomeruli were considered to be crescentic when two or more cell layers were observed in Bowman’s space. At least 50 glomeruli/animal were counted to determine the percentage of crescent formation. Proteinuria (mg/24 h) was measured by a modified Bradford method (21) on urine that was collected during the final 24 h of experiments.

**Glomerular Macrophages and CD4+ T Cells**

Macrophages and CD4+ T cells were demonstrated by immunoperoxidase staining of periodate-lysine paraformaldehyde–fixed frozen 6-μm-thick kidney sections, as described previously (22,32), using FA/11 (rat anti-mouse CD68; ATCC, Manassas, VA) for macrophages and GK1.5 (rat anti-mouse CD4; ATCC) for CD4+ T cells. A minimum of 20 glomeruli/animal were assessed, and results are expressed as cells per glomerular cross-section.

**Circulating Ab Levels**

Serum Ab-specific Ab levels were assessed by ELISA on serum that was collected at the end of experiments, as described previously (33), using horseradish peroxidase–sheep anti-mouse Ig (Amersham, Little Chalfont, UK). Results are expressed as the mean OD492 ± SEM. Sera from nonimmunized mice provided baseline Ab levels.

**Splenocyte Production of IFN-γ, IL-4, and IL-10**

Spleens were removed from mice, and single-cell suspensions were obtained. Splenocytes (4 × 10⁶ cells/ml per well) were cultured in DMEM (10% FCS) in the presence of 10 μg/ml sheep globulin for 72 h. Concentrations of IFN-γ, IL-4, and IL-10 in splenocyte supernatants were measured by ELISA, as described previously (23), using rat anti-mouse IFN-γ (Pharmingen, San Diego, CA), biotinylated rat anti-mouse IFN-γ (Pharmingen), rat anti-mouse IL-4 (ATCC), biotinylated rat anti-mouse IL-4 (BVD6; DNAX, Palo Alto, CA), rat anti-mouse IL-10 (Pharmingen), and biotinylated rat anti-mouse IL-10 (Pharmingen).

**Expression of CD44 on CD4+ T Cells**

Expression of CD44 on CD4+ cells was determined by flow cytometry. Spleens were obtained from mice, and single-cell suspensions were prepared. Splenocytes were labeled with allophycocyanin-conjugated anti-mouse CD44 (Pharmingen) and phycoerythrin-conjugated rat anti-mouse CD4 (Pharmingen). Results are expressed as percentage of CD44+ CD4 cells.

**Apoptosis of CD4+ T Cells**

Apoptosis of CD4+ cells was assessed by flow cytometric analysis of Annexin-V staining according to the manufacturer’s instructions (Roche Diagnostics, Penzberg, Germany). Briefly, splenocytes that were isolated from mice on days 5, 10, and 20 were stained with phycoerythrin-conjugated anti-mouse CD4 Ab (Pharmingen), Annexin-V-Fluos (Roche Diagnostics), and propidium iodide. Results are expressed as percentage of Annexin-V+ propidium iodide− CD4+ cells.

**Proliferation of CD4+ T Cells**

Mice received intraperitoneal injections of 1 mg of 5-bromo-2’-deoxyuridine (BrDU; Sigma, St. Louis, MO) in saline 48, 36, 24, and 12 h before the end of experiments. As a negative control, one mouse received an injection of saline only. Proliferation of CD4+ cells from isolated splenocytes was assessed by flow cytometric analysis of intracellular BrDU incorporation, as described previously (34). Results are expressed as percentage of BrDU+ CD4+ cells.

**Renal Expression of P-Selectin and Intercellular Adhesion Molecule-1**

P-selectin and intercellular adhesion molecule-1 (ICAM-1) were identified in 6-μm-thick frozen kidney sections by immunofluorescence, as described previously (35). Intraglomerular P-selectin and ICAM-1 expression was scored from 0 to 3 as follows: 0, background staining; 1, low positive staining; 2, moderate positive staining; and 3, very strong positive staining. A minimum of 20 glomeruli/animal were assessed to determine the average score.
Renal mRNA Expression of Chemokines and Chemokine Receptors

Renal mRNA expression of chemokines (regulated upon activation, normal T cell expressed and secreted [RANTES], macrophage inflammatory protein-1α [MIP-1α], interferon-γ-inducible protein 10 [IP-10], monocyte chemoattractant protein-1, and TCA-3; template set mCK-5c) and chemokine receptors (CCR1, CCR2, CCR5, and CXCR3; template set mCR-5 including template for CXCR3) was measured by RNAse protection assay as described previously (36) using Pharmingen’s Ribonuclease protection assay. The results (mRNA levels) are expressed as arbitrary units relative to the housekeeping gene L32.

Intraglomerular Proliferation

Proliferating cells were identified in 6-μm-thick frozen kidney sections by immunohistochemistry, as described previously (35), using rat anti-mouse Ki-67 mAb (DakoCytomation, Glostrup, Denmark). A minimum of 20 glomeruli/animal were examined to determine the number of Ki-67+ cells per glomerular cross-section.

Renal Expression of ICOSL

ICOSL was detected in 6-μm-thick frozen kidney sections by immunofluorescence. Sections were blocked with 10% normal sheep serum in 5% BSA/PBS for 30 min and then incubated with rat anti-mouse ICOSL mAb (HK5.3) overnight at 4°C. Isotype-matched rat IgG2a (Pharmingen) was used as a negative control. Sections were washed, incubated with FITC-conjugated sheep anti-rat IgG (DakoCytomation) for 1 h, and analyzed by fluorescence microscopy.

Statistical Analyses

Results are expressed as the mean ± SEM. Unpaired t test was used for statistical analysis (GraphPad Prism; GraphPad Software Inc., San Diego, CA). Differences were considered to be statistically significant at P < 0.05.

Results

Effect of ICOSL Blockade during the Initiation Phase of GN on Disease Outcome and Immune Responses

Renal Injury and Glomerular Accumulation of Effector Leukocytes. Mice that were treated with control rat IgG developed proliferative and crescentic GN (Figures 1A and 2A) with significant proteinuria (Figure 1B) and CD4+ T cells (Figure 1C) and macrophages (Figure 1D) present in their glomeruli. The development of GN was exacerbated significantly after ICOSL blockade during the induction phase of the disease. Crescent formation (Figures 1A and 2) and proteinuria (Figure 1B) were enhanced by inhibition of the ICOS/ICOSL pathway. Exacerbated renal injury was associated with increased accumulation of CD4+ T cells (Figure 1C) and macrophages (Figure 1D) in glomeruli of mice that were treated with anti-ICOSL Ab compared with controls.

Th1/Th2 Balance. Production of IL-4 (Figure 3A) and IL-10 (Figure 3B) by splenocytes that were cultured ex vivo in the presence of antigen was significantly reduced in mice that were treated with anti-ICOSL Ab compared with controls. In contrast, splenocyte IFN-γ (Figure 3C) production was not affected by ICOSL inhibition.

CD4+ T Cell Apoptosis, Proliferation, and Activation. Apoptosis of splenic CD4+ T cells that were collected at the end of the experiment (day 20) was significantly reduced by ICOSL blockade (Figure 4A) compared with controls. Similarly, there was a trend toward reduced apoptosis of splenic CD4+ cells on day 5 (3.9 ± 0.3 versus 3.3 ± 0.1%; P = 0.07) and day 10 (12.4 ± 0.8 versus 10.1 ± 1.1%; P = 0.098) in mice that received anti-ICOSL Ab. Inhibition of ICOSL did not significantly affect proliferation of splenic CD4+ T cells (Figure 4B) or their activation (Figure 4C).
Ab Production. Control Ab-treated mice developed significant humoral immunity against the immunizing antigen as assessed by circulating Ab levels (Figure 5). ICOSL blockade during the induction phase of GN significantly reduced IL-4 and IL-10 production while having no effect on IFN-γ levels. *P < 0.05.

ICOSL Expression in Glomeruli of Mice with Crescentic GN

Immunofluorescent staining demonstrated that ICOSL was absent from kidneys of normal nonimmunized mice (Figure 6A) but was strongly upregulated within glomeruli of mice with crescentic GN (Figure 6B). No staining was observed when isotype control Ab was used (Figure 6C).

Effect of ICOSL Blockade during the Effector Phase of GN on Disease Outcome and Immune Responses

Renal Injury and Glomerular Accumulation of Effector Leukocytes. Blockade of the ICOS/ICOSL pathway during the effector phase of GN exacerbated the development of disease. Mice that were treated with anti-ICOSL Ab had increased numbers of CD4+ T cells (Figure 7A) and macrophages (Figure 7B) present in glomeruli compared with controls that received rat IgG. Increased accumulation of effector leukocytes in glomeruli of mice that were treated with anti-ICOSL Ab was associated with enhanced crescent formation (Figures 7C and 8). No difference in urinary protein excretion was detected between controls that received rat IgG and mice that were treated with anti-ICOSL Ab (12.4 ± 2.3 versus 11.0 ± 2.3 mg/24 h; P = 0.7).

Intraglomerular Proliferation. Cellular proliferation within glomeruli was significantly increased in controls with GN compared with nondiseased mice (Figure 9). Blockade of ICOSL during the effector phase of the disease significantly enhanced intraglomerular proliferation compared with controls that received rat IgG (Figure 9).

Glomerular Expression of Adhesion Molecules. P-selectin was absent from kidneys of nondiseased mice but was upregulated within glomeruli of mice that had GN and received control Ab (12.4 ± 2.3 versus 11.0 ± 2.3 mg/24 h; P = 0.7). ICAM-1 was constitutively expressed in nondiseased mice in interstitial and glomerular areas and was upregulated in control Ab-treated mice with GN (Figures 10B and 11C). Administration of anti-ICOSL mAb during the effector phase of the disease significantly
increased intraglomerular expression of P-selectin (Figures 10A and 11B) and ICAM-1 (Figures 10B and 11D).

**Renal Chemokine and Chemokine Receptor Expression.** Several chemokines (IP-10 and MIP-2) and chemokine receptors (CCR1 and CCR2) were not affected by the blockade of ICOSL during the effector phase of GN (Table 1). However, there was a trend toward increased levels of some chemokines (monocyte chemoattractant protein-1, MIP-1a, RANTES, and TCA-3) and chemokine receptors (CCR5 and CXCR3) in the kidneys of mice that were treated with anti-ICOSL mAb compared with controls (Table 1).

**Systemic Immunity.** The systemic immune response was not affected by inhibition of ICOSL during the effector phase of GN. Production of cytokines, IFN-γ, IL-4, and IL-10 was not altered significantly in mice that were treated with anti-ICOSL Ab compared with controls (Table 2). ICOSL blockade did not result in statistically significant changes in splenic CD4+ T cell proliferation or apoptosis (Table 2). Circulating Ag-specific Ig levels also were not significantly affected by inhibition of ICOSL during the effector phase of the disease (Figure 12).

**Discussion**

These studies examined the role of the ICOS/ICOSL co-stimulatory pathway in the induction and effector phases of a
Th1-mediated model of crescentic GN. For testing the role of ICOSL during the induction of GN, ICOSL was blocked only during the initiation of the immune response (days 0 to 8). Inhibition of ICOSL augmented renal injury as assessed by crescent formation and proteinuria, which was associated with increased numbers of effector leukocytes, CD4+ T cells and macrophages, in glomeruli. These results suggest that ICOS-mediated co-stimulation plays a protective role during the initiation phase of crescentic GN.

The co-stimulatory signal through ICOS can affect the Th1/Th2 balance. Although several studies have shown that ICOS is important for the production of both Th1 and Th2 cytokines (13,14), the majority of evidence suggests that ICOS co-stimulation is more important for the development of Th2 than Th1 responses (37), most likely because of the higher expression levels of ICOS on differentiated Th2 than Th1 lymphocytes (1,38). For example, ICOS is critical for the production of IL-10 (11,15), and ICOS-deficient T cells produce reduced amounts of IL-4 but are fully competent to produce IFN-γ (9). The development of crescentic GN in NTN is exacerbated by Th1 cytokines such as IFN-γ (39) and attenuated by Th2 cytokines.

**Table 1. Effect of ICOSL blockade during the effector phase of GN on the renal mRNA expression of chemokines and chemokine receptors**

<table>
<thead>
<tr>
<th>Chemokines</th>
<th>Control (mRNA, AU)</th>
<th>Anti-ICOSL (mRNA, AU)</th>
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<tr>
<td>RANTES</td>
<td>226.4 ± 13.8</td>
<td>275.6 ± 41.6</td>
</tr>
<tr>
<td>MIP-1α</td>
<td>10.0 ± 1.3</td>
<td>12.2 ± 2.7</td>
</tr>
<tr>
<td>MIP-2</td>
<td>39.6 ± 8.3</td>
<td>44.5 ± 4.0</td>
</tr>
<tr>
<td>MCP-1</td>
<td>102.3 ± 19.7</td>
<td>124.8 ± 17.9</td>
</tr>
<tr>
<td>IP-10</td>
<td>28.1 ± 3.5</td>
<td>29.5 ± 5.3</td>
</tr>
<tr>
<td>TCA-3</td>
<td>50.6 ± 8.5</td>
<td>63.8 ± 8.9</td>
</tr>
<tr>
<td>Chemokine receptors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCR1</td>
<td>6.1 ± 0.7</td>
<td>6.5 ± 1.0</td>
</tr>
<tr>
<td>CCR2</td>
<td>40.8 ± 5.7</td>
<td>45.0 ± 6.3</td>
</tr>
<tr>
<td>CCR5</td>
<td>25.9 ± 3.8</td>
<td>32.7 ± 3.9</td>
</tr>
<tr>
<td>CXCR3</td>
<td>2.6 ± 0.6</td>
<td>3.3 ± 0.5</td>
</tr>
</tbody>
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*AU, arbitrary units; GN, glomerulonephritis; ICOSL, inducible co-stimulatory molecule ligand; IP-10, interferon-γ-inducible protein 10; MCP, monocyte chemoattractant protein; MIP, macrophage inflammatory protein; RANTES, regulated upon activation, normal T cell expressed and secreted.

**Table 2. Effect of ICOSL inhibition during the effector phase of GN on splenic CD4+ cell apoptosis and proliferation and cytokine production by Ag-challenged splenocytes**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Anti-ICOSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD4+ cell apoptosis (%)</td>
<td>6.1 ± 0.5</td>
<td>7.6 ± 0.7b</td>
</tr>
<tr>
<td>CD4+ cell proliferation (%)</td>
<td>19.3 ± 1.2</td>
<td>19.2 ± 0.9</td>
</tr>
<tr>
<td>IL-4 (pg/ml)</td>
<td>54.3 ± 7.8</td>
<td>56.6 ± 8.1</td>
</tr>
<tr>
<td>IL-10 (pg/ml)</td>
<td>118.3 ± 28.8</td>
<td>126.0 ± 22.6</td>
</tr>
<tr>
<td>IFN-γ (pg/ml)</td>
<td>634.6 ± 176.1</td>
<td>528.0 ± 184.8</td>
</tr>
</tbody>
</table>

*Ag, antigen; PI, propidium iodide; BrdU, 5-bromo-2′-deoxyuridine.

**bP = 0.12.**
Numerous experiments have demonstrated an important role of ICOS in T cell–dependent humoral immunity, including germinal center formation and Ab production (8,10,13). In our study, neutralization of ICOSL during the initiation of GN decreased antigen-specific Ab levels, suggesting an important role of ICOSL-mediated co-stimulation in Ab production during the induction of the disease. Despite reduced Ab levels, mice that received anti-ICOSL mAb developed more severe GN. This is explained by previous evidence demonstrating that the development of severe crescentic GN in NTN is not dependent on autologous Ab (27) but on the glomerular accumulation of CD4+ T cells and macrophages (20,22,26), which was increased after ICOSL inhibition. Our study suggests that inhibition of the ICOSL/ICOS pathway may be more beneficial in forms of GN that are Ab mediated, such as lupus nephritis. In fact, attenuated injury in mice that have lupus nephritis and receive anti-ICOSL mAb is associated with decreased Ab levels (29). Furthermore, in contrast to our study, Okano et al. (41) demonstrated improved renal function after early ICOS blockade during the development of NTN that was associated with reduced Ab levels and deposition in the kidney. The discrepancy between the two results may be explained by the observation that glomerular injury in the study by Okano et al. was much milder than in these experiments, in which case there may be a greater involvement of the deposited autologous Ab, which does not play a role in the development of severe crescentic GN observed in our study (27).

For investigation of the role of the ICOS/ICOSL co-stimulatory pathway during the effector phase of crescentic GN, ICOSL was blocked only during the efferent phase of the nephritogenic immune response (days 10 to 18). We first demonstrated that ICOSL is strongly upregulated in glomeruli of mice with GN, suggesting that glomerular expression of ICOSL may be important in local Th1 effector responses that induce crescentic GN. Inhibition of ICOSL during the effector phase of the disease significantly enhanced glomerular accumulation of T cells and macrophages, resulting in exacerbated renal injury as indicated by crescent formation. No increase was observed in urinary protein excretion, most likely as a result of the control mice having very high proteinuria. The systemic immune response was not significantly affected by ICOSL blockade, indicating that the increased presence of effector leukocytes in glomeruli and enhanced injury cannot be explained by changes in systemic immunity but that ICOSL plays a protective role during the efferent phase of crescentic GN by locally attenuating accumulation of Th1 effectors and macrophages in glomeruli.

This is the first study to demonstrate a protective role of the ICOS/ICOSL co-stimulatory pathway in the in vivo Th1 effector responses. Previously, blockade of this pathway during the efferent phase of Th1-mediated immune diseases such as EAE (16) and experimental autoimmune myocarditis (19) attenuated disease. Furthermore, late inhibition of ICOSL during the development of lupus nephritis improved renal pathology (29); however, reduced disease in that study was due to decreased Ab deposits in the kidney, which play a pathogenic role in lupus nephritis (42) but are not required for the development of crescentic GN in NTN (27). The results of these experiments,
nevertheless, are supported by previous evidence demonstrating that ICOSL that is expressed by renal TEC negatively regulates T cell activation and cytokine production in the kidney (6,31).

The mechanisms by which ICOSL may locally attenuate glomerular accumulation of Th1 effectors and macrophages are unknown, but several possibilities exist. P-selectin and ICAM-1 are upregulated in glomeruli of mice with crescentic GN, where they mediate glomerular infiltration of T cells and macrophages (30,32,35,43,44). In this study, inhibition of ICOSL during the effector phase of GN markedly increased intraglomerular expression of P-selectin and ICAM-1, suggesting that ICOSL might decrease initial glomerular infiltration of Th1 effectors and macrophages by downregulating local adhesion molecules that these cells need to migrate into the target tissue and mediate injury.

ICOSL-provided co-stimulation may alter renal expression of chemokines and/or chemokine receptors that might be important for Th1 effectors and macrophages to migrate into glomeruli and mediate disease (45–49). Previous experiments have demonstrated that blockade of the ICOS/ICOSL pathway in the effector phase of cell-mediated diseases, including EAE, acute cardiac allograft rejection, and lung inflammation, can affect expression of chemokines and chemokine receptors in the target organ (16,17,50). In our study, enhanced leukocyte accumulation as a result of ICOSL inhibition is not likely to be explained by changes in chemokine and/or chemokine receptor expression in the kidney because it was not associated with a significant increase in any chemokine or chemokine receptor.

In addition, increased glomerular accumulation of T cells and macrophages after blockade of ICOSL during the effector phase of the disease was associated with augmented intraglomerular proliferation, suggesting that another mechanism by which ICOSL locally attenuates glomerular leukocyte accumulation is by reducing cellular expansion within glomeruli. Similarly, ICOSL expression by renal TEC negatively regulates T cell activation in the kidney by reducing the production of an essential T cell growth factor, IL-2 (6).

**Conclusion**

Our studies demonstrate, for the first time, that the ICOS/ICOSL co-stimulatory pathway plays a protective role during both the induction and effector phases of Th1-mediated crescentic GN. During the induction phase, ICOSL enhances the production of Th2 cytokines and reduces survival of CD4+ T cells, resulting in decreased renal injury. In the kidney, during the effector phase of the disease, ICOSL is strongly upregulated within nephrictic glomeruli, where it locally attenuates accumulation of effector leukocytes, CD4+ T cells and macrophages, and consequent development of GN, without affecting the systemic immune response.

**Acknowledgments**

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**References**


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