The pathogenic role of T cells in the development of hypertension has been documented well in recent animal studies. However, the existence of T-cell–driven inflammation in human hypertension has not been confirmed. Therefore, we undertook immunologic characterization of T cells from patients with hypertension and measured circulating levels of C-X-C chemokine receptor type 3 chemokines, which are well-known tissue-homing chemokines for T cells. We analyzed immunologic markers on T cells from patients with hypertension by multicolor flow cytometry. We then measured circulating levels of the C-X-C chemokine receptor type 3 chemokines, monokine induced by γ interferon (IFN), IFN-γ–induced protein 10, and IFN-inducible T-cell chemokine receptor type 3 chemokines, in patients with hypertension and in age- and sex-matched control subjects by the cytometric bead array method. In addition, we examined histological features of IFN-inducible T-cell chemokine receptor type 3 chemokines expression in renal biopsy specimens of patients with hypertensive nephrosclerosis and control subjects. The total T-cell population from patients with hypertension showed an increased fraction of immunosenescent, proinflammatory, cytotoxic CD8+ T cells. Circulating levels of C-X-C chemokine receptor type 3 chemokines were significantly higher in patients with hypertension than in control subjects. Furthermore, immunohistochemical staining revealed increased expression of the T-cell chemokine, IFN-inducible T-cell chemokine receptor type 3 chemokines, in the proximal and distal tubules of patients with hypertensive nephrosclerosis. Immunosenescent CD8+ T cells and C-X-C chemokine receptor type 3 chemokines are increased in human hypertension, suggesting a role for T-cell–driven inflammation in hypertension. A more detailed characterization of CD8+ T cells may offer new opportunities for the prevention and treatment of human hypertension. (Hypertension. 2013;62:126-133.)

**Key Words:** aging ■ chemokine ■ hypertension ■ inflammation ■ T cell

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**Abstract**—The pathogenic role of T cells in hypertension has been documented well in recent animal studies. However, the existence of T-cell–driven inflammation in human hypertension has not been confirmed. Therefore, we undertook immunologic characterization of T cells from patients with hypertension and measured circulating levels of C-X-C chemokine receptor type 3 chemokines, which are well-known tissue-homing chemokines for T cells. We analyzed immunologic markers on T cells from patients with hypertension by multicolor flow cytometry. We then measured circulating levels of the C-X-C chemokine receptor type 3 chemokines, monokine induced by γ interferon (IFN), IFN-γ–induced protein 10, and IFN-inducible T-cell chemokine receptor type 3 chemokines, in patients with hypertension and in age- and sex-matched control subjects by the cytometric bead array method. In addition, we examined histological features of IFN-inducible T-cell chemokine receptor type 3 chemokines expression in renal biopsy specimens of patients with hypertensive nephrosclerosis and control subjects. The total T-cell population from patients with hypertension showed an increased fraction of immunosenescent, proinflammatory, cytotoxic CD8+ T cells. Circulating levels of C-X-C chemokine receptor type 3 chemokines were significantly higher in patients with hypertension than in control subjects. Furthermore, immunohistochemical staining revealed increased expression of the T-cell chemokine, IFN-inducible T-cell chemokine receptor type 3 chemokines, in the proximal and distal tubules of patients with hypertensive nephrosclerosis. Immunosenescent CD8+ T cells and C-X-C chemokine receptor type 3 chemokines are increased in human hypertension, suggesting a role for T-cell–driven inflammation in hypertension. A more detailed characterization of CD8+ T cells may offer new opportunities for the prevention and treatment of human hypertension. (Hypertension. 2013;62:126-133.)

**Key Words:** aging ■ chemokine ■ hypertension ■ inflammation ■ T cell
of CXCR3 chemokines in newly diagnosed, treatment-naive patients with hypertension and in age- and sex-matched, normotensive control subjects by cytometric bead array. Finally, we examined renal expression of a CXCR3 chemokine, interferon (IFN)-inducible T-cell α chemokreceptor (I-TAC), in biopsy specimens of patients with hypertensive nephrosclerosis and normotensive control subjects. Because hypertension is a disease process that is tied to aging associated with vascular aging, we tried to elucidate the relationship between hypertension and T-cell immunosenescence by proving the existence of T-cell–driven inflammation in human hypertension.

**Methods**

**Study Participants**

Seventy-one newly diagnosed, treatment-naive, patients with hypertension were prospectively and consecutively enrolled in this study. We recruited patients with hypertension who had a systolic blood pressure >140 mm Hg or a diastolic blood pressure >90 mm Hg after ≥5 minutes at rest, measured during ≥2 independent visits. Patients with any of the following conditions were excluded from participation: significant valvular heart disease, previous myocardial infarction, unstable angina, congestive heart failure, peripheral vascular disease, malignant debilitating disease, severe respiratory disease, renal failure (creatinine >1.4 mg/dL), anemia (hemoglobin <12 g%), history of any cancer, inflammatory disease, and on anti-inflammatorily medications, clinically significant atrioventricular conduction disturbance, a history of atrial fibrillation or other serious arrhythmia, or malignant hypertension (>200/140 mm Hg). Age- and sex-matched healthy control subjects (n=71) were randomly selected, and their health status was evaluated by routine physical examinations, laboratory tests, and radiological examinations. Healthy control subjects, enrolled in the Yonsei Cardiovascular Genome Center, were defined as individuals without a history of hypertension and with a normal baseline blood pressure. Baseline characteristics of both patients with hypertension and normotensive control subjects are summarized in the Table. Blood pressure, body weight, body mass index, and laboratory values, including fasting blood sugar and creatinine, are increased in patients with hypertension. All participants provided informed consent, and study approval was obtained from the Institutional Review Board of Yonsei University College of Medicine.

**Surface Phenotype Analysis and Intracellular Cytokine Staining**

Peripheral blood mononuclear cells (PBMCs) from anticoagulated blood were isolated by density gradient centrifugation. For surface staining, PBMCs were incubated with directly conjugated monoclonal antibodies for 20 minutes at 4°C. The antibodies used were anti–CD57-APC (fluorescein isothiocyanate), anti–HLA (human leukocyte antigen)-DR-fluorescein isothiocyanate, anti–Fas-fluorescein isothiocyanate, anti–FasL-PE (phycoerythrin), anti–PD-1 (programmed death-1)-PE, anti–CD4-PE-Cy7, anti–CD3-Amcyan, anti–CD28-cyanate, anti–FasL-PE, anti–PD-1-PE, anti–CD8-APC-Cy7, and anti–CD8-PECy5 (Becton Dickinson, Franklin Lakes, NJ) was added to prevent protein secretion. After surface staining with anti–CD4-PE-Cy7, anti–CD3-Amcyan, and anti–CD8-APC-Cy7, cells were fixed and permeabilized using fixation/permeabilization buffer (eBioscience, San Diego, CA) and stained with anti–IFN-γ-APC and anti–TNF-α-fluorescein isothiocyanate, anti–IL-17A-PE, and anti–IFN-γ-PECy7 for 30 minutes at 4°C. Permeabilized cells were washed and resuspended in 1% formaldehyde. PBMCs were also directly assessed for intracellular levels of perforin and granzyme B without anti–CD3 antibody stimulation, using antiperforin-PE and antigranzyme B-APC. Finally, for defining regulatory T cells, surface staining was performed with anti–CD3-Amcyan, anti–CD4-Alexa Fluor 700, anti–CD25-PE-Cy7, and anti–CD127-eFluor450, and staining of intracellular transcriptional factors was performed with anti–FoxP3-PE. All samples were assessed on an LSR II Flow Cytometer, and the data were analyzed with FlowJo software version 9.2 for Mac.

**Cytometric Bead Array**

The concentrations of serum CXCR3 cytokines (monokine induced by γ IFN [MIG], IFN γ–induced protein 10, and I-TAC) and granzyme B were determined by flow cytometry using the BD cytometric bead array technique. Sample processing was performed according to manufacturer instructions (BD Biosciences, San Jose, CA). Briefly, 50 μL of mixed capture beads and 50 μL of each serum sample were incubated for 1 hour at room temperature. Next, 50 μL of mixed phycoerythrin detection reagents were added to the bead-sample mixture and incubated for 2 h at room temperature. The samples were washed and assessed with an LSR II Flow Cytometer (BD Biosciences, San Jose, CA). The data were analyzed with FlowJo software version 9.2 for Mac (TreeStar, Ashland, OR).

**Immunohistochemical Tissue Staining**

Seven renal biopsies from patients diagnosed with hypertensive nephrosclerosis were retrieved from the Department of Pathology, Yonsei University College of Medicine. Primary glomerular or tubulointerstitial lesions were ruled out in all the cases. Nine renal biopsies from patients with essential hematuria, but normal blood pressure, were used as normotensive controls. The reason for biopsy was microscopic hematuria, and there was no evidence of specific glomerular disease in all cases. Tissues were fixed in 4% paraformaldehyde solution, embedded in paraffin, and sliced into 4-μm thick-sections. The primary monoclonal antibodies used to detect T cells were anti–CD3 (Laboratory Vision, Fremont, CA), anti–CD4 (Cell Marque, Rocklin, CA), and anti–CD8 (Laboratory Vision, Fremont, CA). The number of lymphocytes showing immunoreactivity to CD3, CD4, and CD8 was counted in 10 high-power fields (×400). The count was done exclusively in the cortex, and the result was expressed as cell number/high power field. Because chemokine staining, sections were depleted of endogenous peroxidase activity by immersion in methanolic H₂O₂ and blocked with normal rabbit serum for 30 minutes. The sections were stained with rabbit antimouse I-TAC (Abcam Inc, Cambridge, MA) and labeled with biotinylated antirabbit immunoglobin G for 20 minutes. Sections were incubated with streptavidin–peroxidase complex (Vector, Peterborough, United Kingdom) for 1 hour, followed by incubation with 3,3-diaminobenzidine (Dako, Glostrup, Denmark). All sections were counterstained with hematoxylin.

**Statistical Analysis**

Continuous variables are summarized as a mean±SD. Categorical variables are summarized as a percentage of the group total. Discrete variables are compared using the χ² method, and independent t tests were used for continuous variables. Pearson correlation analysis was used for the simple correlation between continuous variables. All statistical analyses were performed with Statistical Product and Service Solutions 13.0 (SPSS Inc, Chicago, IL).

**Results**

**Immunosenescent CD8⁺ T Cells Are Increased in Patients With Hypertension**

To evaluate the immune phenotype of T cells isolated from patients with hypertension, we compared the surface markers of T cells from 19 patients with hypertension and 19 age- and sex-matched normotensive control subjects. CD28null or CD57+ are well-known markers of immunosenescence in T cells. Our results show a significant increase in both CD28null and CD57+ CD8⁺ T-cell fractions in patients with hypertension compared
Table. Clinical Characteristics and Laboratory Findings of Newly Diagnosed, Treatment-Naive Patients With Hypertension and Age- and Sex-Matched Control Subjects

<table>
<thead>
<tr>
<th>Variables</th>
<th>HTN (n=71)</th>
<th>Control (n=71)</th>
<th>P* Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>51.6±11.2</td>
<td>51.5±12.2</td>
<td>0.926</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>35 (49.3%)</td>
<td>35 (49.3%)</td>
<td>...</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>67.4±13.8</td>
<td>62.5±10.7</td>
<td>0.021*</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>25.0±4.2</td>
<td>23.3±2.6</td>
<td>0.003*</td>
</tr>
<tr>
<td>Current smoking, n (%)</td>
<td>8 (14.5%)</td>
<td>18 (25.4%)</td>
<td>0.102</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>152.5±14.6</td>
<td>113.9±15.5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>97.4±18.7</td>
<td>84.0±9.4</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>HDL-C, mg/dL</td>
<td>120.2±30.4</td>
<td>114.8±26.5</td>
<td>0.025*</td>
</tr>
<tr>
<td>LDL-C, mg/dL</td>
<td>25.0±4.2</td>
<td>23.3±2.6</td>
<td>0.003*</td>
</tr>
<tr>
<td>Creatinine, mg/dL</td>
<td>67.4±13.8</td>
<td>62.5±10.7</td>
<td>0.021*</td>
</tr>
<tr>
<td>WBC (×103/μL)</td>
<td>9.1±3.1</td>
<td>7.5±2.6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Hemoglobin, g/dL</td>
<td>14.4±1.9</td>
<td>13.8±1.5</td>
<td>0.040*</td>
</tr>
<tr>
<td>T. chol, mg/dL</td>
<td>200.0±33.2</td>
<td>187.8±30.8</td>
<td>0.025*</td>
</tr>
<tr>
<td>TG, mg/dL</td>
<td>145.8±86.7</td>
<td>114.0±54.2</td>
<td>0.011*</td>
</tr>
<tr>
<td>HDL-C, mg/dL</td>
<td>49.4±11.6</td>
<td>50.2±10.8</td>
<td>0.680</td>
</tr>
<tr>
<td>LDL-C, mg/dL</td>
<td>120.2±30.4</td>
<td>114.8±26.5</td>
<td>0.278</td>
</tr>
<tr>
<td>FBS, mg/dL</td>
<td>97.4±18.7</td>
<td>84.0±9.4</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Creatinine, mg/dL</td>
<td>0.89±0.17</td>
<td>0.69±0.20</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

Values are presented as n (%) or mean±SD. BMI indicates body mass index; DBP, diastolic blood pressure; FBS, fasting blood sugar; HDL-C, high-density lipoprotein cholesterol; HTN, hypertensives; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; T. chol, total cholesterol; TG, triacylglyceride; and WBC, white blood cell.

*P<0.05 is considered significant.

with control (CD28null CD8+ T-cell fraction: 29.5±15.5% versus 41.9±13.4%; P=0.003; CD57+ CD8+ T-cell fraction: 28.8±15.7% versus 40.0±12%; P=0.008; Figure 1A). In CD4+ T cells, the CD28null and CD57+ CD4+ T-cell fractions seemed to be increased in patients with hypertension (CD28null CD4+ T-cell fraction: 3.5±3.1% versus 4.1±2.9%; P=0.517; CD57+ CD4+ T-cell fraction: 3.4±2.3% versus 4.7±2.9%; P=0.093), however, this difference was not statistically significant (Figure 1B). The majority of CD28null CD8+ T cells were also CD57+ as shown in representative flow cytometry plots (Figure 1C). When immunosenescent T cells are defined as being both CD28null and CD57+, the increased fraction of CD28null/CD57+ CD8+ T cells in patients with hypertension compared with controls is more clearly demonstrated (CD28null CD57+ CD8+ T-cell fraction: 24.4±15.1% versus 35.4±11.9%; P=0.005; Figure 1D). Other T-cell surface markers, such as HLA-DR, PD-1, FasL, Fas, and IL-7Rα, exhibit no significant differences between patients with hypertension and control subjects (Figure 1E). Also, there was no significant difference in the frequencies of CD25hiCD127loFoxP3+ regulatory T cells in CD4+ T cells between patients with hypertension and normotensive control subjects (4.4±1.2% versus 4.4±1.1%; P=0.967; Figure 1F).

Proinflammatory CD8+ T Cells With Cytotoxic Ability Are Increased in Patients With Hypertension

We examined functional features of T cells from both patients with hypertension and control subjects, to reveal the profiles of cytokine-producing ability. Intracellular staining for cytokine molecules revealed that the fraction of perforin+ or granzyme B+ CD8+ T cell is increased in patients with hypertension (Perforin+ CD8+ T-cell fraction: 12.2±11.9% versus 20.9±12.3%, P=0.017; Granzyme B+ CD8+ T-cell fraction: 31.4±14.2% versus 45.1±12.3%, P=0.001; Figure 2A). Also, a significant increase in the fractions of IFN-γ–producing CD8+ T cells and TNF-α–producing CD8+ T cells was noted in patients with hypertension (IFN-γ CD8+ T-cell fraction: 14.2±6.7% versus 20.5±6.8%, P=0.001; TNF-α CD8+ T-cell fraction: 5.4±5.3% versus 8.5±7.0%, P=0.007). However, there was no difference in IL-17A–producing CD8+ T cells between the 2 groups (Figure 2B). Representative flow cytometry plots are presented for perforin expression and IFN-γ–production from CD8+ T cells (Figure 2C). We also measured levels of circulating granzyme B in 71 treatment-naive patients with hypertension and 71 age- and sex-matched normotensive control subjects. Circulating granzyme B levels were significantly higher in patients with hypertension versus normotensive subjects (91.2±44.7 pg/mL versus 25.0±18.9 pg/mL, respectively, P<0.001; Figure 2D). In CD4+ T cells, except for perforin, there were no statistically significant differences in intracellular cytokine staining between patients with hypertension and control subjects (Figure 2E and 2F). These data altogether suggest that patients with hypertension display an increased fraction of immunosenescent, proinflammatory, cytotoxic CD8+ T cells.

Renal Infiltration of T Cells in Patients With Hypertension

Previous animal studies revealed that renal infiltration of T cells is associated with the development of hypertension.7,8 We attempted to confirm the histological evidence for T-cell–driven inflammation in patients with hypertension with renal biopsy specimens taken from patients with hypertensive nephrosclerosis and from normotensive control subjects. Immunohistochemical staining revealed that T cells, both CD4+ and CD8+, were more infiltrated in the tubulointerstitial nephrosclerosis and from normotensive control subjects. Circulating levels of CXCR3 Chemokines Are Increased in Patients With Hypertension

Based on previous renal histological findings, we studied chemokines likely responsible for T-cell infiltration in hypertension. Circulating levels of CXCR3 chemokines, which are well-known tissue-homing chemokines for proinflammatory T cells, were assessed in 71 newly diagnosed, treatment-naive patients with hypertension and 71 age- and sex-matched normotensive control subjects. All 3 CXCR3 chemokines measured (MIG, IFN-γ–induced protein 10, and I-TAC) were significantly increased in patients with hypertension (MIG: 125.8±130.0 pg/mL versus 501.9±335.7 pg/mL, P<0.0001; IFN-γ–induced protein 10: 105.8±58.4 pg/mL versus 281.9±103.2 pg/mL, P<0.0001; I-TAC: 11.2±9.1 pg/mL versus 35.4±21.1 pg/mL, P<0.0001; Figure 4). In addition, serum MIG levels were significantly correlated with age (P=0.002).

Renal Expression of Tissue-Homing Chemokines for Proinflammatory T Cells

Finally, we evaluated histological evidence for chemokine expression in renal biopsy specimens. I-TAC, one of the CXCR3 chemokines, was found to be expressed within the...
Figure 1. Surface immunophenotyping of T cells from patients with hypertension and control subjects. Immunophenotyping of peripheral blood mononuclear cells from 19 patients with hypertension and 19 age- and sex-matched control subjects was performed. Both CD28null and CD57+ fractions are significantly increased in CD8+ T cells of patients with hypertension (A), but not in CD4+ T cells (B). Representative flow cytometry plots are presented for CD28 and CD57 expression in the CD8+ T-cell population of control subjects and patients with hypertension (C). CD28nullCD57+ fraction is also significantly increased in CD8+ T cells of patients with hypertension compared with controls (D). The percentage of cell population was presented for CD28null, CD57+, CD28nullCD57+, HLA-DR+, and PD-1+ cells, and mean fluorescent intensity (MFI) was presented for FasL, Fas, and IL (interleukin)-7Rα (E). The percentage of T reg, defined by CD25hi CD127lo FoxP3+CD4+ T cells, showed no significant difference between patients with hypertension and control subjects (F). Each bar represents mean±SD. **P<0.01. HTN indicates hypertension.
Figure 2. Functional characterizations of T cells from patients with hypertension and control subjects. Functional features of T cells were studied by flow cytometry analysis of peripheral blood mononuclear cells (PBMCs) from 19 patients with hypertension and 19 age- and sex-matched control subjects. Intracellular staining of perforin and granzyme B was performed in the CD8+ T-cell population (A) or CD4+ T-cell population (E). PBMCs were stimulated with anti-CD3 antibody, and intracellular cytokine staining of interferon (IFN)-γ, tumor necrosis factor (TNF)-α, and interleukin (IL)-17A was performed in the CD8+ T-cell population (B) or the CD4+ T-cell population (F). Each bar represents mean±SD. Representative flow cytometry plots are presented for perforin expression or IFN-γ production in CD8+ T cells with gating on CD3+ cells (C). Circulating level of granzyme B was analyzed in sera of 71 newly diagnosed treatment-naive patients with hypertension and 71 age- and sex-matched control subjects (D). *P<0.05; **P<0.01. HTN indicates hypertension.
arterioles, proximal and distal tubules, interstitium, and glomeruli of patients with hypertensive nephrosclerosis. However, in normotensive control subjects, I-TAC was expressed in the arterioles and glomeruli, but not in the proximal and distal tubules. When we compared 7 patients with hypertensive nephrosclerosis with 9 essential hematuria control subjects, more abundant expression of I-TAC in the proximal and distal tubules is clearly demonstrated (proximal tubule: 0% versus 57.1±18.7%, P=0.019; distal tubule: 11.1±10.5% versus 71.4±17.1%, P=0.035; interstitium: 22.2±13.9% versus 71.4±17.1%, P=0.126; Figure 5A). Representative data of I-TAC expression in the renal tubules are presented in Figure 5B.

**Discussion**

The results from this study demonstrate an increased fraction of immunosenescent, proinflammatory, cytotoxic CD8+ T cell and increased circulating levels of CXCR3 chemokines in patients with hypertension. In patients with hypertensive nephrosclerosis, unlike normotensive control subjects, I-TAC was expressed more abundantly in the proximal and distal tubules. This evidence, along with an increased level of serum granzyme B, supports the increased activity of cytotoxic T cells in human hypertension.

There is a growing body of evidence from animal models supporting a role for T-cell–driven inflammation in hypertension.9–11 Harrison et al9 have suggested a working hypothesis for the mechanism behind this phenomenon. They assert that hypertensive stimuli, such as angiotensin II and high salt, cause a modest elevation in blood pressure, resulting in the development of prehypertension. The development of prehypertension may in turn lead to neointagion formation, stimulating T-cell activation. Activated T cells then enter the kidney and vasculature where T-cell–driven inflammation promotes the entry of other inflammatory cells. These inflammatory cells release cytokines that cause vasoconstriction, arteriolar remodeling, and promote sodium and water absorption, ultimately resulting in the development of clinical hypertension.

In response to initial hypertensive stimuli, tissues may secrete various kinds of inflammatory molecules. Among them, CXCR3 chemokines, such as MIG, IFN-γ–induced protein 10, and I-TAC, may be released initiating T-cell–driven inflammation similar to that observed in other systemic inflammatory conditions.12,13 Demonstrating the existence of T-cell–driven inflammation in humans is practically restricted compared with animal models and, realistically, only observational studies are possible. However, we tried to confirm the existence of T-cell–driven inflammation in human hypertension. First, we performed immunologic characterization of T cells from patients with hypertension to determine which subtypes of T cells are involved in elevated blood pressure. Shao et al14 showed a direct role of angiotensin II in the modification of helper T cells into IFN-γ-secreting Th1 cells. In our study, however, changes in the T-cell population were evident in CD8+ T cells, rather than CD4+ T cells. We showed that the fractions of IFN-γ and TNF-α–producing CD8+ T cells are increased in patients with hypertension. CD25+ or CD57+ CD8+ T cells (characteristic of immunosenescence)15,16 are also increased in these patients. These immunosenescent, proinflammatory, and cytotoxic CD8+ T cells might be involved
in the pathogenesis of T-cell–driven inflammation in human hypertension. In addition, increased levels of serum granzyme B have been reported in various disease states where the pathogenic role of T cells is documented well, such as the acute phase of a viral infection,\textsuperscript{17} rheumatoid arthritis,\textsuperscript{18} and hypertension. In addition, increased levels of serum granulocyte-macrophage colony-stimulating factor (GM-CSF) have been reported in various disease states where hypertension. In addition, increased levels of serum granulocyte-macrophage colony-stimulating factor (GM-CSF) have been reported in various disease states where hypertension.

We then aimed to elucidate what causes T-cell migration into the kidney, where T-cell–driven inflammation promotes overt hypertension. Increased levels of CXCR3 chemokines may be evidence of T-cell–driven inflammation in human hypertension. Therefore, we measured circulating levels of CXCR3 chemokines in newly diagnosed, treatment-naive patients with hypertension and in age- and sex-matched control subjects. All 3 CXCR3 chemokines we measured were significantly increased in patients with hypertension, suggesting the existence of T-cell–driven inflammation in human hypertension. In addition, serum MIG levels were significantly correlated with age.

Recently, De Miguel et al\textsuperscript{14} reported that renal infiltration by T cells is associated with the development of hypertension in Dahl salt–sensitive rats with enhanced formation of intrarenal angiotensin II and increased oxidative stress. The suppression of T-cell infiltration with either mycophenolate mofetil or tacrolimus decreased intrarenal angiotensin II and oxidative stress, resulting in the attenuation of hypertension. We sought to determine whether or not there is a significant difference in the renal expression of CXCR3 chemokines, which can cause T-cell infiltration in renal cortex in human hypertension. In this study, we demonstrate that I-TAC is more abundantly expressed in the proximal and distal tubules of patients with hypertension.

The present study had several potential limitations. First, this is a human observational study, rather than an interventional study, which makes identifying a direct cause and effect relationship difficult. Because of the cross-sectional design of the study, we could not assess the effect of blood pressure control on immunosenescent CD8+ T-cell fractions or level of CXCR3 chemokines. Second, the results from our study population cannot be generalized to represent well-controlled, treated patients with hypertension or patients with mild hypertension. Our subjects were newly diagnosed, treatment-naive patients with hypertension with a high proportion (57.7%) of high-risk hypertensives, defined according to the European Society of Cardiology guideline.\textsuperscript{20} Third, increased prevalence of obesity in patients with hypertension can be a significant confounding factor in analyzing the immunologic characteristics of human hypertension. However, previous studies regarding the effect of obesity on T-cell subset has shown conflicting results, and there was no significant difference in the frequency of immunosenescent T cell between obese and lean subjects.\textsuperscript{21,22}

Finally, the T-cell immunologic characterization could only be performed in a small population because of the limited availability of PBMCs. Even with these limitations, our findings are still important because these are the first evidence of immune-mediated hypertension in humans.

Previously, there was no definite evidence that T-cell–driven inflammation exists in human hypertension. In the present study, we showed immunologic, serological, and histological evidence that T-cell–driven inflammation affects hypertension in humans. Hypertension is a well-known phenomenon of vascular aging. We tried to elucidate the relationship between human vascular aging and immune aging by proving the existence of T-cell–driven inflammation in human hypertension.

**Perspectives**

Recent evidence indicates that T cells are prerequisite for the development of hypertension in animal models. However, the existence or the characteristics of T-cell–driven inflammation in human hypertension remained unclear. In this study, we showed an increased level of T-cell chemokines and an increased fraction of immunosenescent, proinflammatory, cytotoxic CD8 T cells in patients with hypertension. Renal immunohistochemical staining revealed an increased expression of the T-cell chemokines, I-TAC, in the tubules and interstitium of patients with hypertensive nephropathy. An increased level of serum granzyme B also supports the existence of T-cell–driven inflammation in human hypertension. A more detailed characterization of T-cell–driven inflammation may offer new opportunities for preventing and treating human hypertension.

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Disclosures
None.

References

Novelty and Significance

What Is New?

- Previously, the existence or the characteristics of inflammation in human hypertension has not been well evaluated. This is the first study to reveal immunologic, serologic, and histological evidences that T-cell–driven inflammation affects hypertension in humans.

What Is Relevant?

- Because hypertension is a disease process that is tied to aging associated with vascular aging, we tried to elucidate the relationship between hypertension and T-cell immunosenescence by showing the existence of T-cell–driven inflammation in human hypertension. A more detailed characterization of T-cell–driven inflammation may offer new opportunities for preventing and treating human hypertension.
Immunosenescent CD8+ T Cells and C-X-C Chemokine Receptor Type 3 Chemokines Are Increased in Human Hypertension

Jong-Chan Youn, Hee Tae Yu, Beom Jin Lim, Myoung Ju Koh, Jino Lee, Dong-Yeop Chang, Yoon Seok Choi, Sang-Hak Lee, Seok-Min Kang, Yangsoo Jang, Ook Joon Yoo, Eui-Cheol Shin and Sungha Park

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