Differential Effects of T- and L-Type Calcium Antagonists on Glomerular Dynamics in Spontaneously Hypertensive Rats

Yasuyuki Nakamura, Hidehiko Ono, Edward D. Frohlich

Abstract—To determine whether there is a difference in the effects of T- and L-type calcium antagonists on systemic, renal, and glomerular hemodynamics, the pathological changes of N\textsuperscript{\textcircled{-}}-nitro-L-arginine methyl ester (L-NAME)–exacerbated nephrosclerosis and clinical alterations were investigated in spontaneously hypertensive rats (SHR). Seven groups of 17-week-old male SHRs were studied: Group 1, control; Group 2, mibefradil, 50 mg · kg\textsuperscript{-1} · d\textsuperscript{-1}; Group 3, L-NAME in drinking water, 50 mg/L; Group 4, L-NAME (50 mg/L) plus mibefradil (50 mg · kg\textsuperscript{-1} · d\textsuperscript{-1}); Group 5, L-NAME (50 mg/L) plus amlodipine (10 mg · kg\textsuperscript{-1} · d\textsuperscript{-1}); Group 6 and 7, L-NAME (50 mg/L) for 3 weeks followed by mibefradil (50 mg · kg\textsuperscript{-1} · d\textsuperscript{-1}) or amlodipine (10 mg · kg\textsuperscript{-1} · d\textsuperscript{-1}), respectively, for the subsequent 3 weeks. Both the T- and L-channel calcium antagonists similarly reduced mean arterial pressure and total peripheral resistance index. These changes were associated with significant decreases in afferent and efferent glomerular arteriolar resistances and the ultrafiltration coefficient ($P<0.01$). Furthermore, the histopathological glomerular and arterial injury scores and urinary protein excretion were also significantly improved ($P<0.01$), and left ventricular and aortic masses were significantly diminished in all treated groups. Both drugs, mibefradil and amlodipine, had effects of increasing the single-nephron glomerular filtration ratio (SNGFR), and single-nephron plasma flow (SNPF), and of reducing glomerular afferent arteriolar resistance and urinary protein excretion. Thus, the T-type (mibefradil) and L-type (amlodipine) calcium antagonists each prevented and reversed the pathophysiological alterations of L-NAME–exacerbated hypertensive nephrosclerosis in SHR. The T-type calcium antagonist (mibefradil) seemed to have been more effective than the L-type amlodipine antagonist and it produced a greater reduction in afferent arteriolar resistance while preserving SNGFR.

Key Words: L-type receptor calcium antagonist ■ mibefradil ■ amlodipine ■ systemic hemodynamics ■ L-NAME ■ glomerular arteriolar injury ■ proteinuria ■ T-type receptor calcium antagonist ■ renal hemodynamics ■ glomerular dynamics ■ arteriolar injury

The calcium antagonists are widely used for the treatment of hypertension and coronary artery disease.\textsuperscript{5–13} They have been said to belong to 3 chemical subgroups (dihydropyridines, phenylalkylamines, and benzothiazepines), although at least 5 types of receptors (L, T, N, P/Q, and R), have been identified and cloned that control their respective voltage-gated calcium channels. Moreover, their intracellular effects on controlling free calcium ions are also extremely variable. This class of compounds is highly heterogeneous, and each agent may be distinguished by location and function, structure, pharmacological sensitivities, and electrophysiological and physiological characteristics.\textsuperscript{4} Indeed, in no one organ is their variability more evident than with respect to their renal effects.\textsuperscript{5–14}

Recently, the T-type calcium antagonist mibefradil was demonstrated to have developed an ability to inhibit both L- (long lasting) and T- (transient) types of calcium channel receptor sites, with greater selectivity for the T-type channel receptor.\textsuperscript{15–18} Little is known on the comparative or differential effects of these 2 receptor antagonists on systemic, renal, and glomerular hemodynamic effects.\textsuperscript{19,20} The present study, therefore, was designed to determine whether differences exist between these 2 types of calcium antagonists. To this end, the effects of the L-type calcium antagonist amlodipine and the T-type calcium antagonist mibefradil on systemic and renal hemodynamics and glomerular dynamics were studied in spontaneously hypertensive rats (SHR) with N\textsuperscript{\textcircled{-}}-nitro-L-arginine methyl ester (L-NAME)–exacerbated nephrosclerosis.\textsuperscript{21}

Methods

Male SHR (Charles River Laboratories, Wilmington, Mass) aged 17 weeks were housed in plastic cages and maintained at 20°C in a light-controlled room with free access to food, standard rat chow (PMI Feeds Inc, St. Louis, Mo), and tap water. All experimental

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studies had been approved previously by our institutional (Alton Ochsner Medical Foundation) animal care and use committee. The rats were divided into 7 groups: Group 1, control (n=10); Group 2, mibefradil (50 mg · kg⁻¹ · d⁻¹) by gastric gavage for 3 weeks; n=9; Group 3, L-NAME (Sigma Chemical Co, St. Louis, Mo); (50 mg/L in drinking water for 3 weeks; n=13); Group 4, L-NAME (50 mg/L) plus mibefradil (50 mg · kg⁻¹ · d⁻¹) for three weeks by gastric gavage; n=10); Group 5, L-NAME (50 mg/L) plus amlodipine (10 mg · kg⁻¹ · d⁻¹) for 3 weeks by gastric gavage; n=7); Group 6, (n=9), L-NAME (50 mg/L) for 3 weeks; and mibefradil (50 mg · kg⁻¹ · d⁻¹) for 3 weeks; and Group 7 (n=8) L-NAME (50 mg/L) for 3 weeks then amlodipine (10 mg · kg⁻¹ · d⁻¹) for 3 weeks. The average daily dose of L-NAME (7.6±0.7 mg/d in drinking water) was calculated from water intake and determined in our earlier studies.11,21–23 The 24-hour urinary protein (Uₕₕₕ, Lowry method)24 and sodium (Uₛₛₛ, Beckman Astra 8 frame photometer) excretion rates were measured before all renal micropuncture studies as described previously.11,21–23

Micropuncture Technique

Rats were anesthetized with thiobutabarbital (Inactin, 100 mg/kg IP; Byk-Gulden) and then placed on a temperature-regulated table to maintain rectal temperature at 37°C throughout the study.

Inactin was selected for the anesthetic agent because, in our past studies this agent had less effect on renal function. However, micropuncture studies are extensive and long, and we cannot exclude this factor in altering such renal phenomena such as glomerulotubular feedback. After a tracheotomy (with insertion of polyethylene tubing), an indwelling polyethylene catheter was cannulated with a polyethylene catheter (PE-50) for infusion of saline at room temperature. Cardiac output was displayed on a digital solutions. A high-precision syringe (CR-700-200; Hamilton Co; Clifton, NJ) that was connected to a thermodilution device with a thermistor microprobe (Type IT-18; Physitemp Instruments, Oxnard, Calif) that was connected to a multichannel polygraph (Sensor Medics R612, Beckman Instruments; San Diego, Calif) as reported previously.11,21–23

Physiology and Medicine; San Diego, Calif) as reported previous-ly.11,21–23 The Pₛₛₛ and Pₑₑₑ were obtained from the proximal tubule and the “star vessel”, respectively. Pₑₑₑ was calculated from the sum of the Pₛₛₛ and Pₑₑₑ the plasma Pₑₑₑ. Arterial plasma protein concentration (Cₐₐₐ) was determined, and and Pₑₑₑ were calculated using the Landis-Pappenheimer equation.22 The pressure gradient across the glomeru-lar capillary wall was calculated as ΔP=Pₛₛₛ−Pₑₑₑ the transmembrane colloid osmotic pressure difference (Δπ) was calculated according to the equation of Deen et al as modified by Arendshorst and Gottschalk.22 The Pₛₛₛ, Pₑₑₑ, and Pₛₛₛ measurements were made 3 times and their averages were determined.

[¹⁴C]inulin radioactivity of all tubular fluid, urine, and plasma samples were counted to determine SNGFR, GFR, and ERPF. These measurements were used to calculate πₑₑₑ, Pₑₑₑ, Rₑₑₑ, and glomerular capillary Kₑₑₑ. At the termination of each study, blood was withdrawn for measurement of serum creatinine and uric acid concentrations using a 747-100 Analyzer (Boehringer Mannheim/Hitachi).

Renal Morphology

After being fixed in 10% buffered formalin and embedded in paraffin for light microscopy, the kidneys were cut at a thickness of 2 to 3 μm and stained with hematoxylin and eosin, periodic acid-Schiff, and periodic acid-methenamine-silver as also reported previously.11,21–23 Histological examination was conducted in a blinded fashion, and glomerular and arteriolar injury scores were calculated as described previously.11,21–23 Approximately 50 subcapsular and 50 juxtaglomeru-lary capillaries from each specimen were analyzed for glomerular injury as described in previous studies: Grade 1, normal glomerulus by light microscopy; Grade 2, involvement of up to one-third of the glomerular area; Grade 3, involvement of one to two thirds of the glomerulus; and Grade 4, two-thirds to global sclerosis. Each scoring permitted calculation of a glomerular injury score (GIS): [(1× number of Grade 2 glomeruli)+(2× number of Grade 3 glomeru-lii)+(3× number of Grade 4 glomeruli)]×100/(number of glomeruli studied).

Forty to 50 afferent arterioles were also examined from each specimen in order to determine an arteriolar injury score (AIS) using the serial sections stained with periodic-acid-Schiff. Grading was performed as described previously:11,21–23 Grade 1, no arteriolar changes; Grade 2, arteriolar wall hyalinosis up to 50% of circumference; Grade 3, 50% to 100% hyalinosis of the wall circumference but without luminal narrowing; and Grade 4, complete hyalinosis of the wall with evidence of luminal encroachment. Each score was then calculated according to the formula for arteriolar injury score: [(1× number of Grade 2 arterioles)+(2× number of Grade 3 arterioles)+(3× number of Grade 4 arterioles)]×100/(number of arterioles observed).

Statistical Analysis

All data are expressed as mean±1 SEM. A 1-way ANOVA, followed by Duncan’s multiple range test, was performed for between-group significance.22 The confidence level was considered to be statistically significant when the probability value was less than 0.05.

Results

Organ Weights

Left ventricular and aortic masses were significantly increased by L-NAME and reduced by mibefradil, with respect to the control group (P<0.001). Moreover, left ventricular and aortic masses were also reduced by both calcium antagonists (with and after L-NAME). In contrast, right ventricular and left kidney masses did not change (Table 1). Body weight was greater in Group 6 rats because they were 3 weeks older.

Systemic and Cardiac, and Whole Kidney Hemodynamics

Mibefradil (Group 2) slightly decreased MAP and TPR as compared with the control group (Table 2). On the other
TABLE 1. Body and Organ Weights

<table>
<thead>
<tr>
<th></th>
<th>Group 1, Control (n=10)</th>
<th>Group 2, Mibefradil (n=9)</th>
<th>Group 3, L-NAME (n=9)</th>
<th>Group 4, L-NAME+ Mibefradil (n=13)</th>
<th>Group 5, L-NAME+ Amlodipine (n=7)</th>
<th>Group 6, L-NAME then Mibefradil (n=8)</th>
<th>Group 7, L-NAME then Amlodipine (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight, g</td>
<td>345±4.6</td>
<td>351±5.2</td>
<td>345±3.8</td>
<td>354±6.4</td>
<td>348±4.6</td>
<td>368±5.5†</td>
<td>354±4.1</td>
</tr>
<tr>
<td>Left ventricular, mg/g</td>
<td>2.9±0.04</td>
<td>2.6±0.1*</td>
<td>3.2±0.1*</td>
<td>2.7±0.1†</td>
<td>2.9±0.05†</td>
<td>2.7±0.1†</td>
<td>2.9±0.05§</td>
</tr>
<tr>
<td>Right ventricular, mg/g</td>
<td>0.53±0.01</td>
<td>0.51±0.01</td>
<td>0.52±0.01</td>
<td>0.50±0.02</td>
<td>0.52±0.01</td>
<td>0.52±0.01</td>
<td>0.52±0.01</td>
</tr>
<tr>
<td>Left Kidney, mg/g</td>
<td>3.4±0.1</td>
<td>3.3±0.2</td>
<td>3.4±0.1</td>
<td>3.3±0.2</td>
<td>3.5±0.1</td>
<td>3.4±0.1</td>
<td>3.5±0.1</td>
</tr>
<tr>
<td>Aorta, mg · mm⁻¹ · kg⁻¹</td>
<td>3.1±0.1</td>
<td>2.7±0.1*</td>
<td>3.6±0.1*</td>
<td>3.0±0.1†</td>
<td>3.1±0.1†</td>
<td>2.9±0.1†</td>
<td>3.0±0.1†</td>
</tr>
</tbody>
</table>

Data is mean ± SEM. *P<0.01, **P<0.05 vs Group 1; †P<0.01, ‡P<0.05 vs Group 3; §P<0.01 vs Group 6.

hand, ERPF and GFR increased significantly (P<0.01, P<0.05, respectively). L-NAME treatment (Group 3) significantly increased MAP, TPRI, and renal vascular resistance (RVR; P<0.01) and decreased ERPF and GFR (P<0.05 at least). Significantly, treatment with mibefradil and L-NAME (Group 4) prevented L-NAME-induced alterations in MAP, GFR (P<0.05) and TPRI, RVR (P<0.01), although ERPF remained unaltered. Amlodipine (with and after L-NAME) also significantly prevented and reversed the adverse hemodynamic alterations on MAP, TPRI, GFR, and RVR (as compared with L-NAME treatment; Group 3). Moreover, when either mibefradil or amlodipine followed the 3-week administration of L-NAME (Groups 6 and 7), the changes in MAP, TPRI, and RVR and decreases in GFR were reversed significantly as compared with L-NAME treatment (Group 3; Table 2). There were no significant differences between Groups 6 and 7.

Glomerular Dynamics

SNGFR and SNPF were increased (P<0.05 at least) and Rₕ decreased (P<0.01) by mibefradil (Group 2). L-NAME (Group 3) decreased SNGFR, SNPF, and Kₙ, whereas SFP, ΔP, Pₒ, Rₕ, and Rₖ were increased significantly (Table 3). L-NAME co-treatment with mibefradil (Group 4) or amlodipine (Group 5) reduced SFP, ΔP, Rₖ, Rₖ, and Kₙ significantly (Table 3); however, the preventive effects of mibefradil were greater than amlodipine. Moreover, when mibefradil or amlodipine were administered after the 3-week course treatment with L-NAME (Groups 6 and 7), SNGFR, SNPF, ΔP, Pₒ, Rₖ, Rₖ, and Kₙ were reversibly and beneficially changed (as compared with the L-NAME treatment Group 3; at least P<0.05). These reversal effects in SNGFR, SNPF, Rₖ, and Kₙ seemed to be greater with mibefradil than with amlodipine, but they were not significant statistically. Although the concentrations of serum creatinine and uric acid were increased by L-NAME (Group 3), they were not increased significantly so as compared with the control group (Group 1). Uₚₐₒ₂V were significantly increased by L-NAME; these changes were prevented and reversed by mibefradil or amlodipine (Table 4). These effects seemed to be greater with mibefradil rather than amlodipine.

Glomerular and Arteriolar Injury Scores

Histological study demonstrated that L-NAME (Group 3) exacerbated both the GUS (29±6 versus 126±28; P<0.01) and AIS (43±2 versus 104±24; P<0.01) as compared with controls (Group 1). The GIS of both subcapsular (14±3 versus 62±14; P<0.01) and juxtamedullary (14±4 versus

TABLE 2. Systemic and Whole Kidney Hemodynamics

<table>
<thead>
<tr>
<th></th>
<th>Group 1, Control (n=10)</th>
<th>Group 2, Mibefradil (n=9)</th>
<th>Group 3, L-NAME (n=9)</th>
<th>Group 4, L-NAME+ Mibefradil (n=13)</th>
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<th>Group 6, L-NAME then Mibefradil (n=8)</th>
<th>Group 7, L-NAME then Amlodipine (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean arterial pressure, mm Hg</td>
<td>184±2</td>
<td>174±4</td>
<td>213±4*</td>
<td>188±5†</td>
<td>187±5‡</td>
<td>181±4†</td>
<td>182±3†</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>335±9</td>
<td>335±10</td>
<td>346±8</td>
<td>344±11</td>
<td>318±3‡</td>
<td>339±9†</td>
<td>321±5†</td>
</tr>
<tr>
<td>Cardiac index, mL · min⁻¹ · kg⁻¹</td>
<td>192±6</td>
<td>208±6</td>
<td>176±9</td>
<td>204±12</td>
<td>184±6</td>
<td>200±15†</td>
<td>196±8</td>
</tr>
<tr>
<td>Total peripheral resistance index, U/kg</td>
<td>0.96±0.03</td>
<td>0.84±0.03</td>
<td>1.28±0.09*</td>
<td>0.95±0.06†</td>
<td>1.03±0.06‡</td>
<td>0.96±0.09†</td>
<td>0.94±0.04‡</td>
</tr>
<tr>
<td>Stroke Index, mL · beat⁻¹ · kg⁻¹</td>
<td>0.58±0.03</td>
<td>0.63±0.03</td>
<td>0.52±0.03</td>
<td>0.55±0.06</td>
<td>0.58±0.02</td>
<td>0.58±0.05</td>
<td>0.61±0.02</td>
</tr>
<tr>
<td>Effective renal plasma flow, mL/min</td>
<td>2.9±0.1</td>
<td>3.9±0.2*</td>
<td>1.7±0.3*</td>
<td>2.2±0.2**</td>
<td>2.4±0.3</td>
<td>2.3±0.4</td>
<td>2.4±0.3</td>
</tr>
<tr>
<td>Glomerular filtration rate, mL · min⁻¹ · 100 g⁻¹</td>
<td>0.26±0.02</td>
<td>1.35±0.01**</td>
<td>0.16±0.02*</td>
<td>0.25±0.02‡</td>
<td>0.23±0.03‡</td>
<td>0.22±0.03‡</td>
<td>0.25±0.03‡</td>
</tr>
<tr>
<td>Filtration fraction, %</td>
<td>32±2</td>
<td>32±2</td>
<td>43±9</td>
<td>41±3</td>
<td>32±3</td>
<td>34±5</td>
<td>37±3</td>
</tr>
<tr>
<td>Renal vascular resistance, U</td>
<td>30±2</td>
<td>22±1</td>
<td>103±25*</td>
<td>48±7†</td>
<td>43±6‡</td>
<td>39±4†</td>
<td>41±5†</td>
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<tr>
<td>Hematocrit, %</td>
<td>53±0.4</td>
<td>52±1.0</td>
<td>52±0.6</td>
<td>51±0.7</td>
<td>51±0.6</td>
<td>51±1</td>
<td>52±0.3</td>
</tr>
</tbody>
</table>

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other hand, Saruta et al.5 demonstrated a protective action of amlodipine in uninephrectomized SHR since there was no improvement in proteinuria, FF, and GIS. On the other hand, Saruta et al.5 demonstrated a protective action in 5/6 nephrectomized SHR. These workers also reported that most L-type calcium antagonists, including amlodipine, dilated only the afferent glomerular arterioles.

In general, most reports on the effects of calcium antagonists, such as an L-type agent, suggest that these agents dilate only the afferent arterioles and have little effect on the efferent vessels (eg, nifedipine in the isolated perfused hydroenephrotic model,25 diltiazem in vasconstricted isolated perfused kidney,21 and verapamil in rats in which responses to angiotensin II were determined from perfused juxtamedullary nephrone32).

In contrast, L-type receptor antagonists, such as enfnidipine and manidipine, have been shown to dilate both afferent and efferent glomerular arterioles. Similarly, Ménard et al.20 reported that mibefradil diminished proteinuria and prevented glomerular lesions in DOCA-salt hypertensive rats. These investigators also suggested that mibefradil may dilate both afferent arterioles and efferent arterioles. Our data support this finding since mibefradil reduced P, R, and R. Our data further suggest that amlodipine also dilated both afferent and efferent arterioles, findings which are consistent with the report by Hayashi et al.31

### Discussion

The results of this study clearly demonstrate that both mibefradil and amlodipine improved systemic and renal hemodynamics as well as intrarenal glomerular dynamics. These findings are similar to our previous findings11 concerning the renoprotective effects of felodipine, an L-type channel calcium receptor antagonist. In that study, felodipine not only prevented but also reversed L-NAME-exacerbated hypertensive nephrosclerosis in SHR. On the other hand, prior reports describing the effects by amlodipine, another L-type channel antagonist, have been inconsistent. Dworkin et al.9 found no renoprotective effects of amlodipine in uninephrectomized SHR since there was no improvement in proteinuria, FF, and GIS. On the other hand, Saruta et al.5 demonstrated a protective action in 5/6 nephrectomized SHR. These workers also reported that most L-type calcium antagonists, including amlodipine, dilated only the afferent glomerular arterioles.

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### Table 3. Glomerular Dynamics

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>Mibefradil</th>
<th>L-NAME</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
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</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>31.2±1.1</td>
<td>36.9±0.8*</td>
<td>23.7±1.9*</td>
<td>33.8±0.6†</td>
<td>28.0±1.7‡§</td>
<td>31.5±1.5†</td>
<td>28.3±1.3‡</td>
<td>31.5±1.5†</td>
<td>28.3±1.3‡</td>
<td>31.5±1.5†</td>
<td>28.3±1.3‡</td>
</tr>
<tr>
<td>Group 2</td>
<td>105±4</td>
<td>134±7‡‡</td>
<td>79±8*</td>
<td>121±10¶</td>
<td>91±8§</td>
<td>104±10¶</td>
<td>92±6‡</td>
<td>131±0.4¶</td>
<td>131±0.5¶</td>
<td>13.1±0.5¶</td>
<td>131±0.5¶</td>
</tr>
<tr>
<td>Group 3</td>
<td>12.1±0.5</td>
<td>12.1±0.3</td>
<td>11.3±0.4</td>
<td>12.5±0.2</td>
<td>12.4±0.4</td>
<td>13.1±0.4¶</td>
<td>13.1±0.5¶</td>
<td>13.1±0.5¶</td>
<td>13.1±0.5¶</td>
<td>13.1±0.5¶</td>
<td>13.1±0.5¶</td>
</tr>
<tr>
<td>Group 4</td>
<td>17.2±0.8</td>
<td>17.5±0.5</td>
<td>18.5±0.3</td>
<td>17.0±0.3</td>
<td>16.5±0.4</td>
<td>17.7±0.5</td>
<td>18.6±0.4</td>
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<tr>
<td>Group 5</td>
<td>33±0.7</td>
<td>32±0.6</td>
<td>38±0.9*</td>
<td>32±0.7†</td>
<td>30±0.9‡</td>
<td>33±0.6†</td>
<td>33±0.4‡</td>
<td>33±0.4‡</td>
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</tr>
<tr>
<td>Group 6</td>
<td>19±0.3</td>
<td>21±0.5</td>
<td>18±0.5</td>
<td>22±1.2†</td>
<td>18±0.4‡§</td>
<td>20±0.8</td>
<td>19±0.4</td>
<td>19±0.4</td>
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<tr>
<td>Group 7</td>
<td>33±1.1</td>
<td>34±1.2</td>
<td>33±1.6</td>
<td>39±2.7**†</td>
<td>33±1.0‡</td>
<td>36±1.4</td>
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</table>

Data is mean±1 SEM.

*P<0.01, **P<0.05 vs Group 1; †P<0.01, ‡P<0.05 vs Group 3, §P<0.01, ††P<0.05 vs Group 4.

### Table 4. Serum Creatinine and Uric Acid Concentrations

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>Mibefradil</th>
<th>L-NAME</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
<th>Mibefradil</th>
<th>Amlodipine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>0.05±0.05</td>
<td>0.60±0.05</td>
<td>0.74±0.05</td>
<td>0.74±0.06</td>
<td>0.71±0.07</td>
<td>0.71±0.06</td>
<td>0.68±0.08</td>
<td>0.68±0.08</td>
<td>0.68±0.08</td>
<td>0.68±0.08</td>
<td>0.68±0.08</td>
</tr>
<tr>
<td>Group 2</td>
<td>1.6±0.2</td>
<td>1.2±0.2</td>
<td>2.1±0.4</td>
<td>1.6±0.2</td>
<td>2.1±0.3</td>
<td>1.5±0.2</td>
<td>1.3±0.1</td>
<td>1.3±0.1</td>
<td>1.3±0.1</td>
<td>1.3±0.1</td>
<td>1.3±0.1</td>
</tr>
<tr>
<td>Group 3</td>
<td>15±1.1</td>
<td>14±1.1</td>
<td>55±10*</td>
<td>13±1.9†</td>
<td>21±1.6†</td>
<td>17±1.6†</td>
<td>19±1.9†</td>
<td>19±1.9†</td>
<td>19±1.9†</td>
<td>19±1.9†</td>
<td>19±1.9†</td>
</tr>
<tr>
<td>Group 4</td>
<td>1.4±0.1</td>
<td>1.3±0.1</td>
<td>1.5±0.1</td>
<td>1.6±0.1</td>
<td>1.8±0.1*</td>
<td>1.5±0.1</td>
<td>1.7±0.1</td>
<td>1.7±0.1</td>
<td>1.7±0.1</td>
<td>1.7±0.1</td>
<td>1.7±0.1</td>
</tr>
</tbody>
</table>

Data is mean±1 SEM.

*P<0.01, **P<0.05 vs Group 1, †P<0.01 vs Group 3.
Our study does not define the mechanism by which either mibebradil or amlodipine dilate afferent and efferent arterioles although these 2 agents clearly reduce the arteriolar smooth muscle tone. Some studies have suggested that angiotensin II-induced afferent arteriolar vasoconstriction may be mediated by activation of the voltagged calcium channels. Both voltage-operated T- and L-type calcium channels prevail in afferent arterioles, although similar actions may be lacking in the efferent arterioles. Saruta et al. have demonstrated that efonidipine and mandipine not only inhibited voltage-operated calcium channels but also seem to affect other mechanisms involved in arteriolar smooth muscle contraction, because these agents inhibited angiotensin II-induced vasoconstriction of effec-
tant arterioles.

In a recent report, we have summarized the results of those studies that examined the nephroprotective effects of calcium antagonists in hypertension. In that review we emphasized that the nephroprotective effect of all calcium antagonists were inconsistent and appeared to vary with the experimental model, the type and dose of the calcium antagonist used, and their inconsistent and appeared to vary with the experimental model.

### Conclusion

These data, therefore, suggest that despite their action through 2 calcium channel receptors and similar systemic hemodynamic effects, the T- and L-type calcium antagonists each prevented and reversed L-NAME exacerbated hypertensive nephrosclerosis in SHR. Although both T- and L-type agents studied herein dilated the afferent and efferent arterioles, the T-channel antagonist mibebradil seemed to have a greater effect than the L-type antagonist amlodipine in reducing afferent arteriolar resistance and on maintaining and preserving SNGFR. Mibebradil and amlodipine each reduced left ventricular and aortic mass without changing right ventricular mass.

### References


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Differential Effects of T- and L-Type Calcium Antagonists on Glomerular Dynamics in Spontaneously Hypertensive Rats
Yasuyuki Nakamura, Hidehiko Ono and Edward D. Frohlich

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