Effects of Amlodipine on Sympathetic Nerve Traffic and Baroreflex Control of Circulation in Heart Failure

Guido Grassi, Domenico Spaziani, Gino Seravalle, Giovanni Bertinieri, Raffaella Dell’Oro, Cesare Cuspidi, Giuseppe Mancia

Abstract—Short-acting calcium antagonists exert a sympathoexcitation that in heart failure further enhances an already elevated sympathetic activity. Whether this is also the case for long-acting formulations is not yet established, despite the prognostic importance of sympathetic activation in heart failure. It is also undetermined whether in this condition long-acting calcium antagonists favorably affect a mechanism potentially responsible for the sympathetic activation, ie, the baroreflex impairment.

In 28 heart failure patients (NYHA functional class II) under conventional treatment we measured plasma norepinephrine and efferent postganglionic muscle sympathetic nerve activity (microneurography) at rest and during arterial baroreceptor stimulation and deactivation induced by stepwise intravenous infusions of phenylephrine and nitroprusside, respectively. Measurements were performed at baseline and after 8 weeks of daily oral amlodipine administration (10 mg/d, 14 patients) or before and after an 8-week period without calcium antagonist administration (14 patients). Amlodipine caused a small and insignificant blood pressure reduction. Heart rate, left ventricular ejection fraction, and plasma renin and aldosterone concentrations were not affected. This was the case also for plasma norepinephrine (from 2.43 ± 0.41 to 2.50 ± 0.34 nmol/L, mean ± SEM), muscle sympathetic nerve activity (from 54.4 ± 5.9 to 51.0 ± 4.3 bursts/min), and arterial baroreflex responses.

No change in the above-mentioned variables was seen in the control group. Thus, in mild heart failure amlodipine treatment does not adversely affect sympathetic activity and baroreflex control of the heart and sympathetic tone. This implies that in this condition long-acting calcium antagonists can be administered without untoward neurohumoral effects anytime conventional treatment needs to be complemented by drugs causing additional vasodilatation. (Hypertension. 1999;33:671-675.)

Key Words: nervous system, sympathetic ■ nervous system, autonomic ■ baroreceptors ■ calcium antagonists ■ heart failure

Calcium antagonists have been regarded as harmful in the treatment of congestive heart failure (CHF).1–3 Recent studies, however, have somewhat modified this widely held opinion because of the evidence that, if longer-acting dihydropyridines are used, patients’ hemodynamics, clinic status, and mortality rate can be either improved or left unaffected.4,5

Mortality of patients with CHF is related to, among other factors, the sympathetic activation typical of this condition,6 which is the reason for the belief that drugs to be used in CHF patients should avoid any further increase and possibly reduce sympathetic influences on the heart and peripheral circulation.7 Whether this can be the case for long-acting dihydropyridines has not been established, however, because (1) short-acting dihydropyridines have been shown to increase sympathetic activity in hypertension8,9 and CHF10,11 and (2) previous reports on long-acting dihydropyridines have been based on norepinephrine (NE) values,11,12 ie, on values that vary in CHF also as function of changes in peripheral blood flow and tissue clearance of this adrenergic neurotransmitter.13

In the present study, we have quantified sympathetic activity in patients with CHF before and after the daily addition of amlodipine to the existing treatment. The quantification was obtained not only through NE but also through direct assessment of muscle sympathetic nerve activity (MSNA) by microneurography. Baroreflex modulation of MSNA was also quantified because in CHF, impairment and recovery of this reflex parallel (and perhaps cause) the sympathetic activation and inactivation seen before and after drug treatment, respectively.14,15 To the best of our knowledge, this is the first study to evaluate via microneurography the effects of long-term amiodipine treatment on sympathetic activity and reflex sympathetic cardiovascular control in CHF.

Methods

Subjects

Our study was performed in 28 male patients under long-term drug treatment for a CHF caused either by coronary heart disease (n = 18) or by idiopathic dilated cardiomyopathy (n = 10). Patients were...
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included if (1) their CHF was mild (New York Heart Association functional class II), because we have recently reported that mild CHF already shows in several instances an increase in MSNA and a baroreflex impairment;14 (2) there was no history of myocardial infarction in the 6 months preceding the study or symptoms/evidence of angina pectoris, and (3) there was no clinical or laboratory evidence of valvular heart disease, renal insufficiency, diabetes mellitus, or any other condition known to affect the autonomic nervous system.16 In 14 patients (8 with coronary heart disease and 6 with dilated cardiomyopathy; age, 53.7±2.8 years, mean±SEM) amlodipine was added to their long-term treatment (see below). In the remaining 14 patients (9 with coronary heart disease and 5 with dilated cardiomyopathy; age, 59.1±2.9 years) current treatment was left unchanged to allow us to use them as controls. Patients were addressed to the amlodipine or control group on a sequential basis, ie, when 1 patient was assigned to 1 treatment group, the next patient fitting the inclusion criteria was assigned to the other treatment group. Long-term treatment consisted of oral furosemide (20 to 40 mg daily), and angiotensin-converting enzyme (ACE) inhibitors (enalapril, 10 mg daily) were part of the long-term drug assumption schedule in 15 patients (7 in the amlodipine and 8 in the control groups), their use in the remaining ones having been stopped for the occurrence of cough or hypotension. Digoxin (0.125 mg/d) was administered in 5 patients (3 in the amlodipine and 2 in the control groups). All patients included in the study were normotensive and in sinus rhythm. Body mass index was 25 kg/m², the ‘radiographic’ cardiothoracic ratio was >0.55, and the ‘echocardiographic’ left ventricular end diameter was >55 mm. The study protocol was approved by the Institutional Ethics Committee. All patients gave their written consent to participate after being informed of the study nature and purpose.

Measurements
Supine blood pressure (BP) was measured by a mercury sphygmomanometer and by a finger photoplethysmographic device (Finapres, Ohmeda 2300) capable of providing accurate and reproducible beat-to-beat systolic and diastolic BP values.17 In 11 patients, 5 of the amlodipine group and 6 of the control group, central venous pressure (CVP) was measured by a catheter placed in the right atrium from an antecubital vein of the right arm and connected with a transducer (model P23XL; Gould Instruments) positioned at the mid-chest level. Heart rate (HR) was continuously monitored by a cardiocathetertriggered by the R wave of an ECG lead. Left ventricular end-diastolic diameter (LVEDD) and left ventricular ejection fraction (LVEF) were obtained by standard B- and M-mode echocardiography. NE concentration was measured by high-perform ance liquid chromatography18 and plasma renin activity (PRA) and plasma aldosterone (ALDO) concentrations were measured by radioimmunoassay.19,20 The measurements were obtained from a blood sample drawn from a cannula placed in an antecubital vein of the arm contralateral to that used for finger BP measurements.

Multunit recording of MSNA was obtained through a tungsten microelectrode inserted into the right or left peroneal nerve, as previously described in detail.14,15,21 In baseline conditions, MSNA values (Table and Figure 1). Sphygmomanometric BPs and finger mean BP that did not occur in all patients and thus fell short of statistical significance. LVEDD, LVEF, PRA, and ALDO were not significantly different before and after receiving the drug, which also did not affect NE or MSNA (Figure 1). Sphygmomanometric BPs were slightly and not significantly less in the second study compared with the first study in control patients, which showed in the 2 circumstances superimposable average CVP, echocardiographic, humoral, and MSNA values (Table and Figure 1).

Baroreflex Responses
Figure 2 shows the results obtained during baroreceptor stimulation and deactivation by infusion of vasoactive drugs. HR and the number of sympathetic bursts/min both were (1) progressively reduced by progressively increasing mean BP via phenylephrine and (2) progressively increased by progressively reducing mean BP via nitroprusside. All responses were superimposable before and after the administration of amlodipine. Baroreflex responses to vasoactive drug infusions were superimposable between the first and second studies also in control patients (Figure 2, right top and central panels). Similar resting and baroreflex values were obtained when data were analyzed separately in heart failures of ischemic and dilated idiopathic nature.
The progressive increase and decrease in mean BP caused by phenylephrine and nitroprusside infusions were accompanied by CVP increases and reductions, respectively. The changes were small, only significant from the second step of the vasoactive drug infused, and similar at baseline and after 8 weeks in the control and amlodipine groups (Figure 2, bottom panels).

### Discussion

In our patients with mildly symptomatic CHF, the administration of a therapeutic dose of amlodipine for several weeks was associated with (1) no improvement but also no deterioration in cardiac and hemodynamic parameters and (2) no activation of the sympathetic nervous system as assessed either indirectly by NE or directly by quantification of MSNA through microneurography. Because the ability of sympathetic nerve traffic to change in response to an appropriate stimulus was documented in the same patients by vasoactive drug infusion, this provides the first evidence that this long-acting dihydropyridine can be administered in patients with CHF, without aggravating the sympathoactivation typical of this condition.

The ability of amlodipine to be sympathetically neutral in CHF represents an advantage over short-acting dihydropyridines and other vasodilators, the administration of which leads to an additional increase in sympathetic cardiovascular drive of CHF patients.\(^{10,11}\) In this context, however, the drug’s effect remains different from that of CHF treatments such as digitalis, which lowers MSNA when given acutely,\(^{23}\) and NE, when given on a different from that of CHF treatments such as digitalis, which lowers MSNA when given acutely,\(^{23}\) and NE, when given on a long-term basis.\(^{24}\) It also remains different from treatment with an ACE inhibitor, which markedly reduces NE and MSNA when administered in patients with mild CHF for a period of time identical to that adopted for amlodipine administration in the present study.\(^{15}\) Whether this difference persists over longer treatment time spans and includes patients with more severe CHF remains to be determined.

Our study shows that the sympathoinhibitory and sympathoexcitatory responses to vasoactive drug-induced baroreceptor stimulation and deactivation are also unaffected by amlodipine. This marks a further difference with the ACE inhibitor treatment, which in CHF improves the baroreflex ability to restrain sympathetic nerve firing.\(^{15}\) Whether this dissimilarity is responsible for the concomitant difference in the effects of the 2 treatments on sympathetic tone remains to be determined, also considering that other factors not explored in the present study (ie, other reflexes, central factors, renin-angiotensin system, insulin sensitivity, and other metabolic factors) and probably involved in the neurohumoral profile of untreated and treated CHF patients, may play a role.

Several other results should be mentioned. First, in our patients, the pressor and depressor effects of vasoactive drug infusions triggered some alterations in CVP, possibly altering cardiac receptor activity.\(^{16}\) However, the changes were (1) inconsistent at doses of vasoactive drugs that already caused clear-cut reflex alterations in sympathetic activity and (2) small at all vasoactive drug doses used. Thus, although a contribution of cardiac receptors cannot be excluded, the reflex sympathetic responses largely depended on arterial baroreceptors both before and during amlodipine administration. Second, because in humans sympathetic nerve traffic can only be measured from superficial nerves, whether the sympatho-neutrality of amlodipine in heart failure extends to visceral areas cannot be determined. This is an important issue because recent evidence has been obtained that shows short-term administration of amlodipine reduces sympathetic activity and NE levels in healthy subjects.\(^{25}\)

### Table

<table>
<thead>
<tr>
<th>Variable</th>
<th>Amlodipine Group (n=14)</th>
<th>Control Group (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After 8 Weeks</td>
</tr>
<tr>
<td>Sphygmo systolic BP, mm Hg</td>
<td>129.4±2.6</td>
<td>125.7±3.1</td>
</tr>
<tr>
<td>Sphygmo diastolic BP, mm Hg</td>
<td>78.6±2.4</td>
<td>74.8±2.8</td>
</tr>
<tr>
<td>Finger mean BP, mm Hg</td>
<td>91.8±2.2</td>
<td>86.9±2.9</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>74.0±4.1</td>
<td>69.8±3.7</td>
</tr>
<tr>
<td>CVP, mm Hg</td>
<td>4.1±0.4</td>
<td>3.6±0.5</td>
</tr>
<tr>
<td>LVEDD, mm</td>
<td>66.3±2.9</td>
<td>65.1±3.0</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>39.7±2.1</td>
<td>40.5±2.0</td>
</tr>
<tr>
<td>PRA, µg·L⁻¹·h⁻¹</td>
<td>6.4±1.5</td>
<td>6.2±1.1</td>
</tr>
<tr>
<td>ALDO, pmol/L</td>
<td>1944.5±138.7</td>
<td>1850.2±196.9</td>
</tr>
</tbody>
</table>

Sphygmo indicates pressures measured via sphygmomanometer. Values are mean±SEM.
a vasodilator does indeed have heterogeneous effects on sympathetic activity in different vascular districts.25 However, Goldsmith26 has recently shown that in patients with CHF, amlodipine does not alter a global marker of sympathetic activity such as NE spillover, which is in line with our finding that in CHF subjects, this drug did not cause any alteration in NE. Furthermore, amlodipine did not cause any alteration in HR, ie, a marker of sympathetic modulation of the sinus node.16 This suggests that neither muscle activity nor visceral sympathetic activity throughout the body was affected by amlodipine treatment. Finally, in our patients, administration of amlodipine was not accompanied by the increase in PRA and ALDO described with the administration of other dihydropyridines both in hypertensives and in patients with CHF.10,11 This may be related to the concomitant lack of sympathetic activation because the renin-angiotensin system and the sympathetic nervous system reinforce each other, ie, although a sympathetic activation directly or indirectly stimulates renin secretion from juxtaglomerular cells,27 the resultant increased production of angiotensin II stimulates, through central and peripheral mechanisms, sympathetic cardiac and vascular effects.27

Our study has some potential limitations but also a clinical implication. One limitation is that when no change from a given intervention is found, the possibility may exist that the study did not have sufficient statistical power. However, the sympathetic and baroreflex data before and after amlodipine administration did not show any trend toward a possible change. Furthermore, previous studies15,23,28 have been able to detect sympathetic and baroreflex changes by various interventions when the study size was smaller than the present one, in which a total of 56 microneurographic recordings was obtained. Finally, the absence of any effect of amlodipine on sympathetic nerve firing was clear not only by between-subject but also by within-subject comparisons, ie, under a condition in which microneurographic data are highly reproducible on a short- and a long-term basis.22 It is therefore unlikely that a statistical shortcoming was responsible for our results. A second limitation is that the study could not be designed to have administration of placebo in the control group. However, administration of placebo has not shown to be associated with changes in sympathetic nerve

Figure 2. Plots showing changes (Δ) in HR, MSNA, and CVP accompanying stepwise increases and reductions in mean BP (ΔMBP), induced by intravenous infusion of phenylephrine and nitroprusside, respectively. Solid lines refer to HR, MSNA, and CVP changes observed before treatment; dashed and dotted lines refer to HR, MSNA, and CVP changes observed after 8 weeks of amlodipine treatment or an observation period, respectively. Values are shown as mean±SEM; n=14 for each group, with the exception of CVP data (n=5 in the amlodipine treated group and n=6 in the control group).
traffic and baroreflex responses in several experimental settings. 24–30 Which makes it unlikely that lack of placebo administration in the control group affected our conclusion. A third limitation is that, because our patients had a mildly symptomatic CHF and a modest impairment of left ventricular function, our conclusion cannot be safely extrapolated to more severe CHF conditions in which the relationship between amlodipine and sympathetic cardiovascular influences may well be different. However, CHF is far more common in its mild than in its severe form, 31 which gives our findings clinical relevance.

The clinical implication is that in CHF, amlodipine and other long-acting dihydropyridines are probably less suitable drugs than ACE-inhibitors, which lower sympathetic activity and enhance baroreflex control of autonomic cardiovascular influences. 15 It should be emphasized, however, that the finding that amlodipine did not increase sympathetic nerve traffic, worsen the baroreflex, or both may also be seen under a more favorable light because it suggests that long-acting dihydropyridines can be used with no adverse neurohumoral consequences anytime traditional treatment of CHF (eg, diuretics, digitalis, or ACE-inhibitors) needs to be complimented by drugs with a vasodilator effect. This may apply to the condition of CHF and hypertension, whereas any extrapolation of this kind to patients with CHF and angina pectoris should be made with caution, without further direct investigation.

References

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