Original Contributions

ST Segment Depression Elicited by Dipyridamole Infusion in Asymptomatic Hypertensive Patients

Eugenio Picano, Alessandra R. Lucarini, Fabio Lattanzi, Cecilia Marini, Alessandro Distante, Antonio Salvetti, and Antonio L'Abbate

In asymptomatic patients with essential hypertension, electrocardiographic changes suggestive of myocardial ischemia can be elicited by rapid pressure lowering or by pronounced coronary arteriolar dilation. The aim of this study was to assess whether dipyridamole infusion might induce ischemic-like electrocardiographic changes in asymptomatic essential hypertensive patients and to describe the clinical and echocardiographic correlates possibly associated with this response. We therefore studied a control group of 20 normotensive individuals and a group of 28 asymptomatic patients with mild-to-moderate essential hypertension. All underwent dipyridamole-echocardiography testing (12-lead electrocardiogram and two-dimensional echocardiographic monitoring with dipyridamole infusion, 0.84 mg/kg over 10'). No patient showed transient regional dyssynergy during dipyridamole infusion. None of the normotensive and 10 of 28 of the hypertensive participants had horizontal or downsloping ST segment depression more than 0.1 mV during dipyridamole (9% versus 36%, p<0.01). Hypertensive patients with ("responders") (n=10) and without ("nonresponders") (n=18) ST segment depression showed similar values of percent fractional shortening in baseline conditions (32±5 versus 33±6, p=NS) and at peak dipyridamole infusion (45±8 versus 43±5, p=NS). The peak early to peak late velocity ratio values (evaluated from transmitral flow tracings by Doppler technique) were also similar in baseline conditions (0.86±0.14 versus 0.94±0.10, p=NS) and at peak dipyridamole (0.72±0.15 versus 0.78±0.32, p=NS). Responders had higher values of left ventricular mass index (149±35 versus 124±28 g/m², p<0.05) and duration of hypertension (11.0±6.7 versus 5.5±4.7 years, p<0.05) than nonresponders. All responders showed angiographically normal coronary arteries. Thus, a significant number of asymptomatic essential hypertensive patients showed dipyridamole-induced ischemic-like ST segment depression, in spite of angiographically normal coronary arteries, in the absence of any detectable regional or global, systolic or diastolic, left ventricular dysfunction. (Hypertension 1990;16:19-25)
and no detectable coronary artery disease, with or without left ventricular hypertrophy.\textsuperscript{7,12} In fact, left ventricular hypertrophy\textsuperscript{13} or microvascular coronary disease\textsuperscript{14} might decrease flow reserve in hypertensive patients, even in the absence of epicardial coronary stenoses.\textsuperscript{15,16}

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\textbf{Methods}

\textit{Selection of Patients}

A control group of 20 young normotensive subjects (10 men and 10 women, 20–30 years old) was studied. All were asymptomatic with normal resting and exercise electrocardiographic findings, normal baseline echocardiographic findings, and no family history of hypertension or coronary artery disease.

Twenty-eight asymptomatic hospitalized patients (15 men and 13 women, 32–66 years old, mean 53 years) with mild-to-moderate essential hypertension and echocardiographic correlates possibly associated with a dipyridamole effect, when the maximal changes in transmural flow were recorded. For each time point in each

kg over 4 minutes followed by 4 minutes of no dose and then 0.28 mg/kg in 2 minutes. The cumulative dose was, therefore, 0.84 mg/kg over 10 minutes.\textsuperscript{5}

Aminophylline, which promptly reverses the effects of dipyridamole, was readily available and was routinely given at the end of each test (80 mg over 1 minute). During the procedure, the blood pressure and a 12-lead electrocardiogram were recorded each minute. Electrocardiographic tracings were independently read by two experienced cardiologists blind to clinical and angiographic information. The tracings were considered diagnostic for myocardial ischemia when there was a horizontal or downsloping ST segment shift of at least 0.1 mV 0.08 second after the J point compared with baseline. The decision was unanimously reached in 46 cases; in the two split cases, a consensus was reached.

Two-dimensional echocardiograms were continuously recorded during and up to 10 minutes after dipyridamole administration.\textsuperscript{5,6} In the baseline studies, all standard echocardiographic views were obtained when possible. During the test, new areas of abnormal wall motion were looked for on multiple views (mainly parasternal, long and short axis, and apical, four, and two chamber view) by rapidly moving the ultrasonic transducer through various positions.\textsuperscript{5}

A commercially available, wide-angle, phased-array imaging system (model 77020, 2.5 and 3.5 MHz transducers, Hewlett Packard, Andover, Mass.) was used.

The videotapes were analyzed by two independent observers blinded to the clinical information. Segmental anatomy and wall motion were assessed in a qualitative manner as previously reported.\textsuperscript{5} Wall motion was graded as hyperkinetic, normal, hypokinetic, akinetic, or dyskinetic. Positivity of the test for ischemia due to angiographically assessed coronary artery disease was linked to the detection of a transient asynergy of contraction. A unanimous decision was reached in all studies.

In each study subject, percent fractional shortening was calculated as:

$$\frac{\text{end-diastolic diameter} - \text{end-systolic diameter}}{\text{end-diastolic diameter}} \times 100$$

This variable was measured during two conditions: baseline state and peak changes. Measurements were made by two-dimensional targeted M-mode tracings obtained from the parasternal long axis view.

\textbf{Pulsed Doppler Examination}

The Doppler diastolic transmural flow velocity waveform, which is an index of diastolic function,\textsuperscript{20} was recorded in resting conditions and every minute during dipyridamole stress according to a methodology previously described in detail.\textsuperscript{21}

For each test, two time points were considered for quantitative evaluation: basal state and peak dipyridamole effect, when the maximal changes in transmural flow were recorded. For each time point in each
test, left ventricular diastolic flow velocity waveforms from at least three cardiac cycles were characterized quantitatively and the values averaged. For each tracing, the following measurements were obtained: 1) peak velocity of early diastolic rapid inflow (E, in cm/sec), 2) peak velocity of late diastolic inflow due to the atrial contraction (A, in cm/sec), and 3) the ratio of the peak early to peak late velocity (E/A).

The Doppler study was attempted in all hypertensive patients. Interpretable Doppler tracings during control and at peak changes were obtained in 22 of 28 hypertensive patients (feasibility, 79%). A total of six hypertensive patients, four with and two without echocardiographically assessed left ventricular hypertrophy, had resting or stress-induced tachycardia that precluded the acquisition of readable Doppler tracings. Of these six, two were responders and four were nonresponders.

Coronary Arteriography
Fourteen hypertensive patients underwent coronary arteriography for clinical diagnostic needs for one of the following reasons: 1) development of an atypical chest pain syndrome 8 months after the enrollment into the study (one patient), 2) presence of a positive exercise electrocardiography stress test (seven patients), 3) presence of a "false positive" exercise Thallium scintigraphy (two patients) with transient reversible perfusion defect either in the apical (one patient) or anterolateral (one patient) wall, 4) strongly positive (ST segment depression >0.2 mV from baseline) dipyridamole-electrocardiography test (this response is believed to be highly suspect for presence of coronary artery disease22) (four patients).

All patients underwent selective coronary arteriography using the Judkins technique. Multiple views of each vessel were filmed. A vessel was considered to have significant obstruction if its diameter was narrowed by 50% or more with respect to the prestenotic tract.

Statistical Analysis
Mean±SD are given for each value.
Differences were tested for significance by paired and unpaired Student's t test or by χ² test. A p value <0.05 was considered statistically significant.
TABLE 1. Hemodynamic Findings During Dipyridamole Stress in Hypertensive Patients

<table>
<thead>
<tr>
<th></th>
<th>Basal Responders</th>
<th>Basal Nonresponders</th>
<th>Dipyridamole Responders</th>
<th>Dipyridamole Nonresponders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>76±10</td>
<td>NS</td>
<td>105±17</td>
<td>NS</td>
</tr>
<tr>
<td>Systolic arterial pressure (mm Hg)</td>
<td>164±14</td>
<td>NS</td>
<td>165±11</td>
<td>NS</td>
</tr>
<tr>
<td>Diastolic arterial pressure (mm Hg)</td>
<td>100±4</td>
<td>NS</td>
<td>103±8</td>
<td>NS</td>
</tr>
<tr>
<td>Rate pressure product (mm Hg x beats/min x 1/100)</td>
<td>125±23</td>
<td>NS</td>
<td>122±16</td>
<td>NS</td>
</tr>
<tr>
<td>Responders</td>
<td>99±12</td>
<td>NS</td>
<td>153±20</td>
<td>NS</td>
</tr>
<tr>
<td>Nonresponders</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values given are mean±SD. NS, p=not significant.

Results

Fifteen hypertensive patients had echocardiographic and 10 of these 15 also had electrocardiographic evidence of left ventricular hypertrophy.

DET was completed in all patients. Side effects appeared in 12 of 20 in the normotensive control group and 20 of 28 in the hypertensive group (60 versus 71%, p=NS). In order of frequency they were: headache (36%), flushing (19%), and nausea (7%). The side effects were always of mild severity, well tolerated by the patient, and reversed by aminophyl- line routinely given at the end of the test. None of the participants had severe hypotension, vomiting, or significant ventricular arrhythmias during the test. Three control subjects and five hypertensive patients had mild, atypical chest discomfort during DET (15 versus 18%, p=NS) (Figure 1). Regional wall motion asynergy during DET did not develop in any of the study subjects, either normotensive or hypertensive.

Electrocardiographic Findings

None of the control subjects and 10 of the hypertensive patients had diagnostic ST segment depression during DET (0% versus 36%, p<0.01) (Figures 1 and 2).

On the basis of the electrocardiographic response, two subsets of hypertensive patients were identified: "responders" (10 patients with dipyridamole-induced ST segment depression) and "nonresponders" (18 patients without dipyridamole-induced ST segment depression). The blood pressure values were similar in the two groups (systolic blood pressure: 165±15 versus 164±10 mm Hg, p=NS; diastolic blood pressure: 104±7 versus 104±7 mm Hg, p=NS); the duration of
hypertension was longer in responders (11.0±6.3 versus 5.5±4.7 years, p<0.05). The heart rate and blood pressure responses to dipyridamole infusion were similar in the two groups (Table 1).

**Echocardiographic Findings**

Responders and nonresponders could not be differentiated on the basis of resting or stress-induced global systolic (percent fractional shortening) or diastolic (E/A ratio) function indexes (Figure 3). Echocardiographically assessed left ventricular hypertrophy was present in 7 of 10 responders and 8 of 18 nonresponders (70% versus 44%, p=NS). A greater value of left ventricular mass index was present in responders (149±35 versus 124±38 g/m², p<0.05).

**Coronary Angiographic Findings**

Coronary angiography showed only minimal epicardial coronary artery lumen narrowing (<30%) in three patients (two responders and one nonresponder) and entirely normal vessels in 11 patients (eight responders and three nonresponders).

**Discussion**

The findings of this study are fully consistent with data previously obtained by our group in symptomatic hypertensive patients, showing that: 1) ST segment depression can frequently be elicited, together with chest pain, in patients with angiographically normal coronary arteries; 2) this electrocardiographic response is not necessarily associated with left ventricular hypertrophy; and 3) the specificity of the dipyridamole test for angiographically assessed coronary artery disease is dramatically low with echocardiographic criteria, but it remains excellent with echocardiographic criteria.

**Two-Dimensional and Doppler Findings During Dipyridamole**

In both responders and nonresponders, there was a similar, clear-cut modification induced by dipyridamole in indexes of global systolic and diastolic function. Percent fractional shortening increased significantly at peak dipyridamole in a way similar to what has been described in patients without coronary artery disease and normal mechanical response to dipyridamole infusion.23 A transient hyperkinetic phase is usually detected during dipyridamole testing, and left ventricular hemodynamic monitoring showed a pronounced rise in dP/dt of contraction in patients without echocardiographic evidence of myocardial ischemia.

We have previously shown that during dipyridamole infusion there is a "pseudoischemic" pattern in transmural inflow velocity curve that can be found even in the absence of coronary artery disease or dipyridamole-induced systolic dysfunction.21 This pseudoischemic pattern consists of a relative increase in the atrial component of the transmural inflow velocity profile. This same pattern was found in hypertensive patients, possibly explained by the hemodynamic changes induced by the drug (increase in heart rate and changes in loading conditions of the left ventricle), which may very well mimic the effect of left ventricular ischemia on transmirtal flow pattern.

**Possible Pathophysiological Meaning of Dipyridamole-Induced ST Segment Depression**

We speculate that the most likely explanation for ST segment depression induced by dipyridamole and reversed by aminophylline is a transient subendocardial underperfusion. Such underperfusion might be due to several possible causes: epicardial coronary artery stenosis, arterial hypotension, left ventricular hypertrophy, or microvascular coronary disease.15,16

Significant epicardial coronary stenoses were unlikely to be present in our study population as all patients were free of anginal symptoms at the time of study, and we failed to detect significant stenoses in the 14 patients (including the 10 responders to dipyridamole testing) in whom coronary angiography was performed according to clinical and diagnostic needs. Furthermore, the lack of dipyridamole-induced ventricular dyssynergy carries a low probability that an anatomically severe or physiologically important epicardial coronary stenosis is present.

Another contributing mechanism can be arterial hypotension. Harrison et al.26 showed that left ventricular hypertrophy can profoundly impair the lower range of autoregulation in the subendocardial myocardium of hypertensive dogs. As suggested by Pepi et al.,34 it is entirely possible that the high blood pressure becomes a physiological requirement in the myocardium of hypertensive patients so that adequate coronary perfusion pressure and blood flow can be maintained. The subendocardium will tend to suffer first when the coronary perfusion pressure is lowered.13,14 However, after dipyridamole, the mean decrease in blood pressure was mild, without significant differences between responders and nonresponders. Therefore, it appears likely that the hypertensive mechanism plays a minor role when compared with the coronary arteriolar dilation, which is provoked by dipyridamole through adenosine accumulation.

From the theoretical viewpoint, the infusion of a coronary dilator can induce myocardial ischemia in the presence of a reduction in coronary flow reserve.8 In this situation, a vasodilator stimulus will decrease subepicardial resistance but will not alter subendocardial resistance because its vasodilator reserve is already exhausted in resting conditions (the myocardial oxygen demands of the subendocardium are greater than those of the subepicardium).9 In the absence of an epicardial coronary stenosis, the decrease in coronary flow reserve can be obtained through two main mechanisms: left ventricular hypertrophy or disease of small coronary vessels, or both. It is consistent with this interpretation that responders had higher levels of left ventricular mass.13,15 However, left ventricular hypertrophy was not a prerequisite for the development of dipyri-
damole-induced ST segment depression. This finding is in agreement with the documented possibility of a dissociation between left ventricular and vascular hypertrophy in hypertensive patients, determining the reduced coronary flow reserve in hypertensive patients with normal left ventricular mass. It can be considered consistent with this hypothesis that responders had a longer duration of hypertension, which is associated with more profound structural changes in the coronary resistance vessels.

The absence of mechanical changes does not contradict the "ischemic" interpretation of the dipyridamole-induced ST segment depression. In fact, presence or absence of abnormal wall motion appears to relate to the amount of subendocardial tissue rendered ischemic, with minor degrees of transmural involvement less likely to produce regional dysfunction. As in Syndrome X, one must hypothesize that the dipyridamole-induced ischemia is large enough, in a horizontal or circumferential direction, to induce ST segment depression but not so deep, in a transmural or vertical axis, as to provoke wall motion abnormalities. In Syndrome X, this "echocardiographically silent" myocardial ischemia can be associated with a reduction in flow reserve possibly due to microvascular disease.

Limitations of the Study

The evidence reported above renders less likely the viewpoint that dipyridamole-induced ST segment depression might simply be a nonspecific response to drug infusion. In contrast to the exercise stress test, during dipyridamole testing there is no excessive tachycardia and hyperventilation that may easily induce nonspecific ST segment changes. However, the lack of a metabolic or coronary reserve evaluation during dipyridamole in these patients makes the results of this study mostly descriptive and the discussion largely speculative. We believe, therefore, that the ischemic nature of dipyridamole-induced electrocardiographic changes cannot be claimed on the basis of this investigation, and further studies are needed to convincingly demonstrate the pathophysiological and clinical correlates of dipyridamole-induced ST segment depression.

We conclude that a significant number of asymptomatic essential hypertensive patients show dipyridamole-induced ST segment depression in the absence of any detectable regional or global, systolic or diastolic, left ventricular dysfunction. This electrocardiographic finding is more frequent in the presence of left ventricular hypertrophy and longer duration of hypertension, both of which are factors possibly correlated to a reduction in coronary reserve and to the presence of microvascular disease.

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**KEY WORDS** ischemia • dipyridamole • echocardiography • essential hypertension
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