Local Pulse Pressure and Regression of Arterial Wall Hypertrophy During Long-Term Antihypertensive Treatment

Pierre Boutouyrie, MD, PhD; Caroline Bussy, MD; Daniel Hayoz, MD; Jurg Hengstler, MD; Nathalie Dartois, MD; Brigitte Laloux, PhD; Hans Brunner, MD; Stéphane Laurent, MD, PhD

Background—Local pulse pressure (PP) is an independent determinant of carotid artery wall thickness, stronger than mean blood pressure (BP). The present study was designed to assess whether a β-adrenoceptor antagonist–based or an ACE inhibitor–based treatment was able to reduce carotid artery wall hypertrophy through a reduction in carotid PP rather than by lowering mean BP and whether the influence of local PP reduction could also be detected at the site of a muscular artery, the radial artery.

Methods and Results—Ninety-eight essential hypertensive patients were randomized to 9 months of double-blind treatment with either celiprolol or enalapril. Arterial parameters were determined with high-resolution echo-tracking systems. PP was measured locally with applanation tonometry and independently of mean BP. After 9 months of treatment, mean BP, carotid PP, and intimal-medial thickness (IMT) decreased significantly, with no difference between the 2 groups. The reduction in carotid PP but not in mean BP was a major independent determinant of the reduction in carotid IMT. Radial artery IMT and PP decreased significantly with both treatments. However, the reduction in radial artery IMT was not related to the changes in radial artery PP.

Conclusions—The regression of carotid artery wall hypertrophy during long-term antihypertensive treatment was dependent on the reduction in local PP rather than on the lowering of mean BP. The effect of PP lowering on IMT reduction was observed at the site of an elastic artery but not at the site of a muscular artery. (Circulation. 2000;101:2601-2606.)

Key Words: blood pressure ▪ arteries ▪ hypertrophy ▪ arteriosclerosis ▪ remodeling

In hypertensive patients, increased large artery wall thickness as a consequence of medial hypertrophy contributes to the normalization of circumferential wall stress and potentiates the development of atherosclerosis at some arterial sites, such as the carotid artery. Several clinical trials have shown that a slower progression or even a reduction in intimal-medial thickness (IMT) could be obtained in response to long-term antihypertensive treatment at the site of either the carotid artery or the radial artery (RA). This effect is seldom attributed to a drug-specific mechanism of action and generally to the nonspecific lowering of mean blood pressure (MBP).

However, local pulsatile BP may play a more important role than steady MBP in the pharmacological remodeling of large arteries. Indeed, we have recently shown that carotid pulse pressure (PP) was a strong independent determinant of carotid wall thickening in essential hypertensive patients and normal subjects, whereas MBP and brachial PP were not. This finding, observed at the site of the carotid artery but not at the site of the less elastic RA, is in line with a growing body of in vitro studies showing that cyclic stretching exerts a greater influence than static load on phenotype and growth of vascular smooth muscle cells.

Antihypertensive drugs can decrease central PP by changing the amplitude and timing of reflected waves through various mechanisms, including an improvement in arterial compliance and lengthening of the distance between heart and reflection sites secondary to peripheral vasodilation. In addition, β-adrenoceptor antagonists can decrease central PP by changing the characteristics of left ventricular ejection. In the present study, celiprolol, a partial β₁-adrenoceptor agonist, was selected for its vascular β₂-adrenoceptor agonist properties, leading to vasodilation of conducting and resistive arteries and improvement in arterial compliance in hypertensive humans and rats. We hypothesized that this pharmacological profile would favor a greater reduction in central PP than that observed with classic vasodilators, such as ACE inhibitors (ACEIs), known to improve large artery compli-
ance in hypertensive patients. Among ACEIs, we selected the reference drug enalapril, which has also shown its ability to improve arterial compliance.

Thus, in the present study, we tested the hypotheses (1) that the decrease in IMT during long-term antihypertensive treatment would be influenced by the reduction in local PP rather than by the lowering of MBP; (2) that celiprolol would decrease central PP to a larger extent than enalapril, leading to a greater reduction in IMT; and (3) that the effect of PP reduction on IMT regression would be observed at the site of the carotid artery, a proximal elastic artery, but not at the site of the RA, a distal muscular artery.

Methods

Patients

The study was conducted in 2 centers (Paris and Lausanne). All measurements were done in both centers except carotid artery measurements, which were done in the Paris center only. This study was called CELiprolol-induced regression of Intima-Media, compared with ENalapril, in Essential hypertensives (CELMENE). Patients with an essential uncomplicated hypertension (World Health Organization stages I and II), either never treated or treated for <2 months during the previous 6 months, were considered eligible if their diastolic BP (DBP; Korotkoff phase V), measured by a mercury sphygmomanometer after 15 minutes of rest in the supine position (3 measurements), was contained between 90 and 120 mm Hg. None of the patients had atherosclerotic plaque on the common carotid artery (CCA), and only 3 patients had plaque on the carotid bifurcation or internal carotid.

After a single-blind placebo washout period that lasted 4 weeks, patients with a DBP ≥90 and ≤120 mm Hg were included, stratified per center, and randomized to receive a 9-month treatment with either celiprolol (200 mg) or enalapril (10 mg) each morning in a double-blind fashion. If DBP remained ≥90 mm Hg at any visit, drug dosage was increased according to the following design: At the 3-month visit, celiprolol dosage was increased from 200 mg BID to 200 mg TID and enalapril dosage from 20 mg OD to 20 mg BID. At the 5-month visit, hydrochlorothiazide (HCTZ) was added at a dose of 12.5 mg once daily. At the 7-month visit, the dose of HCTZ was doubled. Routine laboratory tests were obtained at inclusion. Arterial measurements were performed at inclusion and after 3 and 9 months of active treatment.

Ninety-eight patients were randomized to treatment. Forty-eight patients were included in the celiprolol group, and 50 were in the enalapril group. Ten patients in the celiprolol group and 6 in the enalapril group had previously been treated with antihypertensive drugs. No serious side effects related to treatment occurred during follow-up. Data are expressed as mean±SD unless otherwise stated. The homogeneity of the randomized groups at baseline was determined by means of unpaired Student’s t test for continuous variables and a χ² test for categorical variables. Investigation centers (Paris and Lausanne) were included in the statistical analysis of BP and arterial parameters except carotid parameters. For comparison of serial changes in BP and arterial parameters, repeated-measures ANOVA (period, group) was performed to detect treatment differences through a significant period-by-group interaction. The effects of relevant variables (baseline arterial parameters and magnitude of MBP and PP change with treatment) on the study end points were analyzed by use of a multivariate regression analysis. To determine whether there were drug-specific effects, the group (either celiprolol or enalapril) was included in this analysis as dummy variable. Statistical analysis was performed with SAS software. Statistical significance was assumed at P<0.05.

Results

Patient Characteristics, BP, and Heart Rate

The 48 and 50 patients randomized to celiprolol- and enalapril-based treatments, respectively, were similar in relation to age (51±9 versus 52±9 years, respectively), body mass index (26±3 versus 25±3), BP and heart rate before treatment (Table 1), and blood biochemistry (including total, LDL and HDL cholesterol, and fasting glycemia), but not to sex ratio (33 mol/L for 15 women versus 26 mol/L for 24 men, P<0.05), height (168±10 versus 166±8 cm, P<0.05), and weight (73±12 versus 70±12 kg, P<0.05), because of a higher number of women in the enalapril group.

The reductions in brachial systolic BP (SBP), DBP, MBP, and PP were not significantly different between the celiprolol- and the enalapril-based treatments (not significant period-by-group interaction, Table 1). During the whole study period, SBP remained significantly lower in the enalapril group than in the celiprolol group, including baseline (group effect). In both groups, the decreases in SBP, DBP, and MBP were significant already after 5 months. Twenty-two and 16 patients among the celiprolol and enalapril groups, respectively (no significant difference), required addition of HCTZ to achieve the goal BP. After 9 months of treatment, SBP decreased by 16 to 20 mm Hg and DBP by 8

analyzing the radiofrequency signal (NIUS 02, SMH) that has been described, validated, and used in clinical studies. The repeatability of CCA and RA measurements has been reported previously. Mean circumferential wall stress (σr, kPa) was calculated according to Lamé’s equation as $σr=MBP\times D/2h$, where D, is mean internal diameter and h is wall thickness. Because wall thickness is influenced by variations in internal diameter, arterial mass, because of its incompressibility, is an interesting parameter for evaluating arterial remodeling. Arterial mass, m, was calculated as $m=πR_e^2L(\rho R_i^2−\rho R_e^2)$, where $\rho$ is the arterial wall density (ρ=0.06), L is the length of the arterial segment, and $R_i$ and $R_e$ are the values of mean internal and external radii, respectively, as previously described and validated. Arterial mass was normalized to the length of the arterial segment and expressed as milligrams per centimeter of length.

Cross-sectional compliance and distensibility were estimated through the variations in arterial lumen cross-sectional area and BP during systole as previously described, assuming the lumen to be circular. Local CCA and RA PPs, measured with applanation tonometry, were used in these calculations.
to 11 mm Hg. Heart rate was significantly reduced with celiprolol monotherapy but was no more different from baseline after addition of HCTZ. The changes in laboratory values (including serum potassium) were not statistically significant (data not shown).

### Carotid Artery Parameters

Table 2 shows the mean values of carotid artery parameters at baseline and during follow-up in the 40 and 42 patients of the Paris center randomized to celiprolol- and enalapril-based treatments, respectively. At baseline, mean values were not significantly different between groups. After 5 and 9 months of antihypertensive treatment, carotid PP decreased significantly and to the same extent in both groups. These changes were already significant at baseline and during follow-up. At baseline, mean values did not differ significantly between groups. After 5 and 9 months of antihypertensive treatment, carotid PP decreased significantly and to the same extent in both groups.

During both antihypertensive treatments, significant decreases in internal diameter, IMT, arterial mass, and circumferential wall stress and a significant increase in distensibility were observed (period effect). No significant period-by-group interaction was observed, indicating that these changes occurred to the same extent in both groups. These changes were already significant after 5 months. After 9 months, the changes in IMT were on average −39 and −24 μm in the celiprolol and enalapril groups, respectively, despite the decrease in internal diameter. Thus, the corresponding changes in carotid artery mass were −11.3% and −9.2% in the celiprolol and enalapril groups, respectively. After 9 months, distensibility changes were about 12% (1.8 kPa⁻¹×10⁻³) and +17% (2.4 kPa⁻¹×10⁻³) in the celiprolol and enalapril groups, respectively. There was a tendency (P=0.08) for an increase in carotid compliance (period effect).

### RA Parameters

Table 3 shows the RA parameters for both treatment groups at baseline and during follow-up. At baseline, mean values were not significantly different between groups. Baseline
values of radial IMT were significantly \((P<0.01)\) related to baseline values of carotid IMT. After 9 months of antihypertensive treatment, the RA exhibited significant decreases in PP and IMT and significant increases in diameter, distensibility, and compliance (period effect). These changes occurred to the same extent in both treatment groups. Arterial mass decreased to a greater extent in the enalapril than celiprolol group \((-11.0\% \text{ versus } -3.5\%, P<0.05)\). Circumferential wall stress did not change significantly.

**PP and Arterial Remodeling**

In a multivariate regression analysis among the entire population, the decrease in carotid artery IMT after 9 months of treatment was significantly related to the reduction in PP (explaining 11\% of the variance), independent of baseline IMT, and not related to treatment and changes in MBP (Table 4). In contrast, the decrease in RA IMT after 9 months of treatment was not related to the reduction in radial PP but was significantly related to treatment (enalapril-based treatment showing a higher efficacy than celiprolol-based treatment), independent of baseline IMT (Table 4). Similarly, a predominant influence of carotid PP over radial PP was observed when carotid mass and RA mass were studied instead of IMT or when final values of carotid and RA IMT and mass (at 9 months) were introduced into the multivariate model instead of the changes between baseline and month 9 (data not shown).

**TABLE 3. Changes in RA Parameters During Treatment**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Treatment</th>
<th>Baseline</th>
<th>At 5 mo</th>
<th>At 9 mo</th>
<th>P, ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Group</td>
<td>Effect</td>
<td>Period</td>
<td>Interaction</td>
</tr>
<tr>
<td>Tonometric PP, mm Hg</td>
<td>Celiprolol</td>
<td>63±17</td>
<td>60±17</td>
<td>57±13</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>59±12</td>
<td>53±14</td>
<td>51±12</td>
<td>NS</td>
</tr>
<tr>
<td>Internal diameter, mm</td>
<td>Celiprolol</td>
<td>2.22±0.47</td>
<td>2.36±0.47</td>
<td>2.30±0.47</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>2.23±0.43</td>
<td>2.25±0.48</td>
<td>2.24±0.50</td>
<td>NS</td>
</tr>
<tr>
<td>IMT, μm</td>
<td>Celiprolol</td>
<td>270±58</td>
<td>255±53</td>
<td>255±51</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>271±48</td>
<td>243±44</td>
<td>239±48</td>
<td>NS</td>
</tr>
<tr>
<td>Arterial mass, mg/cm</td>
<td>Celiprolol</td>
<td>22.8±8.6</td>
<td>22.5±7.0</td>
<td>22.0±8.2</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>22.8±6.7</td>
<td>20.6±6.5</td>
<td>20.3±7.0</td>
<td>NS</td>
</tr>
<tr>
<td>Circumferential wall stress, kPa</td>
<td>Celiprolol</td>
<td>67.6±13.7</td>
<td>70.0±15.2</td>
<td>66.2±19.3</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>65.5±14.4</td>
<td>67.2±15.7</td>
<td>65.5±15.2</td>
<td>NS</td>
</tr>
<tr>
<td>CS compliance, m²·kPa⁻¹·10⁻¹⁷</td>
<td>Celiprolol</td>
<td>1.6±1.1</td>
<td>2.2±1.4</td>
<td>1.8±1.2</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>1.5±0.8</td>
<td>1.7±1.2</td>
<td>1.8±1.1</td>
<td>NS</td>
</tr>
<tr>
<td>CS distensibility, kPa⁻¹·10⁻³</td>
<td>Celiprolol</td>
<td>3.9±2.3</td>
<td>4.8±2.6</td>
<td>4.1±1.9</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Enalapril</td>
<td>3.8±1.7</td>
<td>4.3±2.3</td>
<td>4.7±2.7</td>
<td>NS</td>
</tr>
</tbody>
</table>

CS indicates cross-sectional. Values are mean±SD. Celiprolol, n=48; enalapril, n=50.

**TABLE 4. Multiple Stepwise Robust Regression Analysis of the Determinants of Changes in CCA and RA IMT After 9 Months of Antihypertensive Treatment**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Parameter</th>
<th>In</th>
<th>r</th>
<th>R² Increment</th>
<th>β-Coefficient</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in common carotid artery IMT</td>
<td>(baseline to month 9), μm</td>
<td>Yes</td>
<td>0.71</td>
<td>0.35</td>
<td>0.55±0.08</td>
<td>6.40</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Carotid IMT at baseline</td>
<td></td>
<td>Yes</td>
<td>0.40</td>
<td>0.11</td>
<td>1.32±0.35</td>
<td>3.70</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ΔCarotid P, mm Hg</td>
<td></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔMBP, mm Hg</td>
<td></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment (1=enalapril, 2=celiprolol)</td>
<td></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total variance explained R²=0.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Change in radial artery IMT (baseline to month 9), μm</th>
<th>Parameter</th>
<th>In</th>
<th>r</th>
<th>R² Increment</th>
<th>β-Coefficient</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial IMT at baseline</td>
<td>Yes</td>
<td>0.53</td>
<td>0.27</td>
<td>0.44±0.08</td>
<td>5.70</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Treatment (1=enalapril, 2=celiprolol)</td>
<td>Yes</td>
<td>−0.27</td>
<td>0.07</td>
<td>−23±8</td>
<td>−2.9</td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ΔRadial P, mm Hg</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔMBP, mm Hg</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total variance explained R²=0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are mean±SD. In indicates that the variable is significantly included in the model.
The decrease in carotid artery internal diameter after 9 months of treatment was significantly \( (P < 0.001) \) related to the reduction in PP (explaining 10\% of the variance), independent of baseline diameter, reduction in MBP (6\% of the variance, \( P < 0.05 \)), and treatment (7\% of the variance, \( P < 0.01 \), with celiprolol-based treatment showing a higher efficacy than enalapril-based treatment). In contrast, RA PP did not influence the changes in RA internal diameter. Similarly, a predominant influence of carotid PP over radial PP was observed when final values of carotid and radial IMT diameter (at month 9) were introduced into the multivariate model instead of the changes between baseline and month 9 (data not shown).

No significant differences in baseline characteristics (including RA and carotid artery parameters) and responses to treatment were observed between patients who remained under monotherapy and patients who required combination therapy.

**Discussion**

The present study is the first controlled, blinded study showing that the reduction in local PP by antihypertensive treatment is involved in the reduction of large artery IMT.

**PP and Pharmacological Remodeling**

In the present study, both \( \beta \)-adrenoceptor antagonist- and ACEI-based treatments reduced carotid and RA IMT and PP in middle-aged patients with essential hypertension. Because baseline carotid IMT and RA IMT were similar to those already published for untreated middle-aged hypertensives,\(^6,7^\) the decrease in carotid and RA IMT that we observed in the present study can be considered a regression of arterial wall hypertrophy. The reduction in carotid PP was likely due, at least in part, to the improvement in large artery elastic properties by celiprolol and enalapril, which have also demonstrated this effect in previous studies.\(^13,15^\)

The major finding of the present study is that antihypertensive treatment reduced carotid wall thickness through the lowering of local PP rather than MBP. Interestingly, the effects of PP lowering on IMT reduction were not observed at the site of the RA. These results are in line with previous findings that carotid PP is a strong independent determinant of carotid wall thickening in essential hypertensive patients and normal subjects, whereas MBP and brachial PP are not.\(^7^\) We also previously showed that local PP was related to carotid IMT but not to radial IMT, suggesting that the amplitude of stroke change in diameter, 10-fold higher at the site of the carotid artery than at the site of the RA,\(^7^\) could be a mechanism by which PP influenced IMT.

These findings are in line with a growing body of in vitro studies showing the greater influence of pulsatile than static load on phenotype and growth of vascular smooth muscle cells.\(^8–10^\) For instance, DNA synthesis, rate of growth, migration, alignment, and smooth muscle myosin expression are greater in vascular smooth muscle cells in tissue culture that are subjected to cyclic stretching than in cells that are grown under static conditions.\(^8–10^\) Thus, the present study extends the concept of the prominent influence of pulsatile load on arterial remodeling to the pharmacological regression of arterial wall hypertrophy.

This applies also to the reduction in carotid internal diameter (inward remodeling) under long-term treatment, which was independently related to the decrease in carotid PP but not with the decrease in MBP. Indeed, internal carotid diameter decreased to a larger extent than expected from the decrease in MBP. Again, this finding is in line with our previous observation that carotid PP is a strong independent determinant of carotid internal diameter in essential hypertensive patients and normal subjects, whereas MBP and brachial PP are not.\(^7^\) The reduction in carotid internal diameter may explain why circumferential wall stress significantly decreased under treatment despite the reduction in wall thickness. A clinical implication of this finding for the treatment of arterial diseases complicated by arterial dilation, like ascending aorta dilation in Marfan syndrome,\(^16^\) is that a primary therapeutic goal should aim at reducing the amplitude of central PP rather than decreasing mean BP.

Carotid PP was reduced to the same extent after celiprolol- and enalapril-based treatments, in contrast to what was theoretically expected from the pharmacological profile of celiprolol.\(^12–14^\) Aortic peak flow, which influences PP, was not measured in the present study. Celiprolol, because of its partial agonism, and ACEI did not change aortic peak flow in hypertensive patients,\(^12,19^\) in contrast to the \( \beta \)-blocker metoprolol.\(^12^\) Thus, it is unlikely that celiprolol and enalapril have major differential effects on aortic peak flow.

Carotid artery diameter decreased to a greater extent after celiprolol- than enalapril-based treatment. In addition, ANOVA (Table 3) and multivariate analysis (Table 4) show that RA mass decreased to a greater extent after enalapril- than after celiprolol-based treatment. These results, which suggest direct effects of celiprolol and enalapril on the carotid and RA walls, respectively, occurring independently of the changes in mechanical load, should be confirmed in a larger number of patients. For instance, enalapril can decrease IMT by reducing the various cellular mechanisms involved in the growth-stimulating properties of angiotensin II, including direct stimulation of AT\(_1\) receptors on smooth muscle cells (leading to cellular hypertrophy and extracellular matrix production), and indirect effects through aldosterone secretion and sympathetic activation.\(^20^\) Whether celiprolol and other \( \beta \)-blockers, which reduce the activity of both sympathetic and renin-angiotensin systems,\(^21^\) are more or less effective than ACEI for normalizing cardiovascular hypertrophy for an equal antihypertensive effect in humans\(^20^\) is still a matter of debate.

**Methodological Issues**

Because the present study is not a placebo-controlled study, for obvious ethical reasons, one may question whether antihypertensive treatment truly reduced arterial IMT. However, several findings strongly suggest that a “time” effect is very unlikely.\(^18^\) A major argument is that in a multiple regression analysis, the final value of carotid IMT (at 9 months) was not only related to the baseline value, but also to the in-treatment decrease in local PP. Similarly, the reduction in radial IMT (or the final radial IMT) was related not only to
the baseline value but also to treatment, with enalapril showing a greater efficacy than celiprolol. In addition, the reductions in carotid and RA mass observed under treatment in the present study are close in relative value to those obtained in various long-term studies showing a reduction in carotid IMT\(^4\) or left ventricular mass.\(^{20,21}\) Finally, there was a significant relationship between baseline values of carotid IMT and radial IMT (\(P<0.01\)), although measurements were done with 2 different apparatuses. Therefore, our conclusion that the reduction in arterial mass represents a true regression of arterial wall hypertrophy seems well founded.

A major characteristic of the study is that local PP and MBP were measured independently with 2 different apparatuses. Thus, changes in PP and MBP could be introduced into the same multivariate model without introducing statistical bias.

Ultrasound imaging cannot discriminate between the intimal layer and the medial layer of the vessel wall to distinguish true arteriosclerosis, ie, the adaptive response of the medial layer to changes in tensile stress such as during hypertension, from atherosclerosis, viewed as a disorder restricted to the intimal layer.\(^4\) However, the CCA is usually spared atherosclerosis, in contrast to the carotid bifurcation and proximal internal carotid artery.\(^4\)

In conclusion, in middle-aged essential hypertensive patients, carotid and RA IMT and PP were significantly reduced after 9 months of a celiprolol- or enalapril-based treatment. Carotid PP and IMT were reduced to the same extent by both regimens. The reduction in carotid PP but not in mean BP was a major independent determinant of the reduction in carotid IMT. The effect of lowering PP on IMT reduction was observed at the site of the CCA, a proximal elastic artery, but not at the site of the RA, a distal muscular artery.

Acknowledgments

This study was supported by grants from the Institut National de la Santé et de la Recherche Médicale (INSERM grant 35 494014) and Laboratoires Bellon-Rhône-Poulenc Rorer.

References

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Circulation. 2000;101:2601-2606
doi: 10.1161/01.CIR.101.22.2601

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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