Effect of Antihypertensive Agents on Blood Pressure Variability

The Natrilix SR Versus Candesartan and Amlodipine in the Reduction of Systolic Blood Pressure in Hypertensive Patients (X-CELLENT) Study

Yi Zhang, Davide Agnoletti, Michel E. Safar, Jacques Blacher

See Editorial Commentary, pp 133–135

Abstract—To investigate the effect of different antihypertensive agents on blood pressure (BP) variability (BPV) and the underlying mechanism, we analyzed the ambulatory BP monitoring data of 577 patients before and after 3-month antihypertensive treatment, in the Natrilix SR Versus Candesartan and Amlodipine in the Reduction of Systolic Blood Pressure in Hypertensive Patients (X-CELLENT) Study, a multicenter, multinational, randomized, double-blind, placebo-controlled study with 4 parallel treatment arms (placebo, candesartan, indapamide sustained release, and amlodipine). Within-subject mean and SD of 24-hour BP, weighted by time interval between consecutive readings, were calculated in 3 time frames (daytime, nighttime, and 24 hours) to evaluate BP and BPV. The mean 24-hour heart rate (HR) and HR variability were calculated with the same algorithms. We found that the 3 antihypertensive drugs had a similar BP-lowering effect ($P<0.001$ for all), but amlodipine ($P<0.007$) and indapamide sustained release ($P<0.04$) were the only agents associated with a significantly decreased BPV after 3-month treatment. On the other hand, the major determinants of BPV at baseline were age, mean BP, and the corresponding HR variability. However, the reduction in BPV by amlodipine was significantly associated with the reduction in BP ($P<0.006$) and the reduction in HR variability ($P<0.02$), whereas the corresponding reduction by indapamide sustained release was only associated with the reduction in HR variability at night ($P=0.004$). In summary, 3-month amlodipine or indapamide sustained release treatment was associated with a significant reduction in BPV, and the mechanism of those reductions was possibly attributable to lowering BP or ameliorating the autonomic nervous system regulation or both. The combination of the 2 agents might help to optimize such properties. (Hypertension. 2011;58:155-160.)

Key Words: ambulatory blood pressure monitoring ■ calcium channel blocker ■ diuretics ■ blood pressure variability ■ heart rate variability

For many decades, the main goal of antihypertensive treatment was to lower blood pressure (BP) to a defined level. Recently, several investigators have shown that BP variability (BPV) is another critical cardiovascular risk factor, which should also be emphasized in the treatment of hypertension. Mancia et al$^1$ were the first to report a close association of BPV, assessed by 24-hour ambulatory BP monitoring (ABPM), with target-organ damage in hypertensive patients. Carotid artery damage$^4$ and increased left ventricular mass index$^5$ were, therefore, investigated in the first instance. However, the predictive value of BPV concerning cardiovascular and all-cause mortality has long been a matter of debate.$^3$–$^9$ More recently, nighttime BPV was considered to be a more pronounced risk factor than daytime BPV.$^{10,11}$ Finally, Rothwell$^{12}$ showed that visit-to-visit BPV was an independent and strong predictor of cardiovascular events, such as stroke and coronary heart disease, and calcium channel blockers and nonloop diuretics were the most effective antihypertensive agents in reducing BPV and in preventing stroke.$^{13}$

However, the unique effect of these agents in terms of BPV reduction is still unproved in the setting of randomized, double-blind, placebo-controlled study. Similar observations can be made regarding other antihypertensive agents as diuretics, $\beta$-blocking agents, and blockers of the renin-angiotensin-aldosterone system. Finally, the determinants of BPV remain unclear, and the underlying mechanism of BPV

Continuing medical education (CME) credit is available for this article. Go to http://cme.ahajournals.org to take the quiz.

Received April 8, 2011; first decision April 24, 2011; revision accepted June 9, 2011.

From the Paris Descartes University (Y.Z., D.A., M.E.S., J.B.), Assistance Publique-Hôpitaux de Paris, Diagnosis and Therapeutic Center, Hôtel-Dieu, Paris, France; Centre for Epidemiological Studies and Clinical Trials (Y.Z.), Ruijin Hospital, Shanghai Jiaotong University School of Medicine, Shanghai, China.

Correspondence to Michel E. Safar, Centre de Diagnostic et de Thérapeutique, Hôtel-Dieu, 1, Place du Parvis Notre-Dame, 75181 Paris Cedex 04, France. E-mail michel.safar@htd.aphp.fr

© 2011 American Heart Association, Inc.

Hypertension is available at http://hyper.ahajournals.org

DOI: 10.1161/HYPTENSIONAHA.111.174383
reduction has never been elucidated precisely in subjects with hypertension.

We analyzed the ABPM data of 577 patients before and after 3-month antihypertensive treatment, in a multicenter, multinational, randomized, double-blind, placebo-controlled study with 4 parallel treatment arms (the Natrilix SR Versus Candesartan and Amlodipine in the Reduction of Systolic Blood Pressure in Hypertensive Patients [X-CELLENT] Study), to investigate the effect of different antihypertensive agents on BPV and the underlying mechanism.

**Methods**

**Study Design**

The X-CELLENT Study was conducted in 2370 outpatients (aged between 40 and 80 years) with essential hypertension. The inclusion criteria included 150 mm Hg ≤ systolic BP < 180 mm Hg and 95 mm Hg ≤ diastolic BP < 110 mm Hg or 160 mm Hg ≤ systolic BP < 180 mm Hg and diastolic BP < 90 mm Hg. The exclusion criteria were a history of coronary artery disease, heart failure, stroke or transient ischemic attack, left ventricular hypertrophy, diabetes mellitus (type 1 or type 2), and renal failure. A total of 608 subjects were excluded from the study because of BP criteria not met (n=341), medical reasons (n=197), and nonmedical reasons (n=70). After a 4-week selection and run-in placebo period, 1762 subjects were randomized to receive placebo, indapamide (1.5 mg) sustained release (SR), candesartan (8.0 mg), or amlodipine (5.0 mg), all given once daily in the morning for a treatment period of 12 weeks. Further information concerning the study design can be found in a previous publication.\textsuperscript{14} The study protocol was approved by the ethics committees of each country involved, and written informed consent was obtained from each study participant.

**Ambulatory BP Monitoring**

A total of 577 patients participated in an ABPM ancillary study, and 496 of them underwent repeat ABPM after 3-month antihypertensive treatment. The ABPM was performed with SpaceLabs 90202 or 90207 (SpaceLabs, Redmond, WA), 4±3 days before the week 0 and week 12 visits and according to the European Society of Hypertension recommendations.\textsuperscript{15} Reproducibility of the ABPM measurements had been reported before.\textsuperscript{16} The frequency of the ABPM was every 15 minutes throughout the whole day, and the sleep and wake-up times were recorded by participants and recorded for further calculations. Daytime and nighttime were defined as from wake-up to sleep time and from sleep to wake-up time, respectively, for each participant.

**Calculation of BP and Heart Rate Variability**

To minimize the effects of recording errors during the 24-hour ABPM, we used the within-subject mean and SD, weighted for the time interval between consecutive validated readings, to evaluate BP and HRV. Considering nighttime dipping, mean and SD were calculated for the times awake and asleep, as daytime mean, daytime SD, nighttime mean, and nighttime SD. The overall mean and SD, as daily mean and daily SD, were assessed using the following 2 formulas: (1) daily mean=(daytime mean×AT+nighttime mean×ST)/(AT+ST) and (2) daily SD=(daytime SD×AT+nighttime SD×ST)/(AT+ST), where AT and ST stand for awake time and sleeping time in hours.

Another parameter, read-to-read average real variability (ARV), recently proposed by other investigators,\textsuperscript{9} was also used to evaluate BPV, as calculated by the following formula:

\[
ARV = \frac{1}{n} \sum_{k=1}^{n} w \times |BP_k - BP_{k-1}|
\]

where \(k\) ranges from 1 to N, \(w\) is the time interval between \(BP_{k-1}\) and \(BP_k\), and \(n\) is the number of BP readings in 24 hours.

The mean value of 24-hour heart rate (HR) and HRV were assessed with the same algorithms as the BP.

**Statistical Analysis**

Quantitative and qualitative parameters were presented as mean±SD and absolute number with percentage in parentheses, respectively. We used the ANOVA to compare the mean and variability of BP, as well as biochemical variables, between subjects with different antihypertensive treatments at baseline, and applied the Student’s t test
and the generalized linear regression to compared BPV between treatment and placebo groups, before and after adjustment for corresponding BP reduction. Multivariate linear regression analysis was used to investigate determinants of BPV and the reduction in BPV by indapamide SR and amlodipine, separately. Statistical analysis was performed using SAS software, version 9.1 (SAS Institute, Cary, NC). P<0.05 was considered as statistically significant.

Results

Table 1 shows the characteristics of subjects at baseline according to randomized antihypertensive therapy. There was no significant difference between groups. After 3-month antihypertensive treatment, 496 subjects underwent a second ABPM, and there was no significant difference in characteristics between subjects with (n=497) or without the repeat ABPM (n=82).

In Table 2, compared with placebo, all 3 of the antihypertensive agents significantly decreased systolic BP in the 3 time frames, daytime, nighttime, and 24 hours (P<0.001 for all), whereas amlodipine and indapamide SR were the only antihypertensive agents to significantly decrease systolic BPV. Specifically, amlodipine significantly decreased systolic BPV in the 3 time frames (P<0.008 for all), and indapamide SR significantly decreased systolic BPV in the daytime (P=0.03) and 24 hours (P=0.03). However, candesartan did not reduce systolic BPV in any time frame. The similar findings are presented in the Figure. In addition, although no significant difference in systolic BPV was observed in the 24-hour read-to-read ARV mode after 3-month different antihypertensive treatments (P=0.08), the reduction in ARV by amlodipine also reached statistical significance (P=0.007). Furthermore, even after adjustment for the corresponding mean BP reduction, the present findings remained unaltered, except that the reduction in daily BPV by indapamide lost its previous significance (P=0.06).

When subjects at baseline were investigated, the determinants of systolic BPV were studied in different modes, such as daytime, nighttime, and 24 hours (P<0.001 for all), whereas amlodipine and indapamide SR were the only antihypertensive agents to significantly decrease systolic BPV. Specifically, amlodipine significantly decreased systolic BPV in the 3 time frames (P<0.008 for all), and indapamide SR significantly decreased systolic BPV in the daytime (P=0.03) and 24 hours (P=0.03). However, candesartan did not reduce systolic BPV in any time frame. The similar findings are presented in the Figure. In addition, although no significant difference in systolic BPV was observed in the 24-hour read-to-read ARV mode after 3-month different antihypertensive treatments (P=0.08), the reduction in ARV by amlodipine also reached statistical significance (P=0.007). Furthermore, even after adjustment for the corresponding mean BP reduction, the present findings remained unaltered, except that the reduction in daily BPV by indapamide lost its previous significance (P=0.06).

When subjects at baseline were investigated, the determinants of systolic BPV were studied in different modes, such as daytime, nighttime, and 24 hours (P<0.001 for all), whereas amlodipine and indapamide SR were the only antihypertensive agents to significantly decrease systolic BPV. Specifically, amlodipine significantly decreased systolic BPV in the 3 time frames (P<0.008 for all), and indapamide SR significantly decreased systolic BPV in the daytime (P=0.03) and 24 hours (P=0.03). However, candesartan did not reduce systolic BPV in any time frame. The similar findings are presented in the Figure. In addition, although no significant difference in systolic BPV was observed in the 24-hour read-to-read ARV mode after 3-month different antihypertensive treatments (P=0.08), the reduction in ARV by amlodipine also reached statistical significance (P=0.007). Furthermore, even after adjustment for the corresponding mean BP reduction, the present findings remained unaltered, except that the reduction in daily BPV by indapamide lost its previous significance (P=0.06).

When subjects at baseline were investigated, the determinants of systolic BPV were studied in different modes, such as daytime, nighttime, and 24 hours (P<0.001 for all), whereas amlodipine and indapamide SR were the only antihypertensive agents to significantly decrease systolic BPV. Specifically, amlodipine significantly decreased systolic BPV in the 3 time frames (P<0.008 for all), and indapamide SR significantly decreased systolic BPV in the daytime (P=0.03) and 24 hours (P=0.03). However, candesartan did not reduce systolic BPV in any time frame. The similar findings are presented in the Figure. In addition, although no significant difference in systolic BPV was observed in the 24-hour read-to-read ARV mode after 3-month different antihypertensive treatments (P=0.08), the reduction in ARV by amlodipine also reached statistical significance (P=0.007). Furthermore, even after adjustment for the corresponding mean BP reduction, the present findings remained unaltered, except that the reduction in daily BPV by indapamide lost its previous significance (P=0.06).

When subjects at baseline were investigated, the determinants of systolic BPV were studied in different modes, such as daytime, nighttime, and 24 hours (P<0.001 for all), whereas amlodipine and indapamide SR were the only antihypertensive agents to significantly decrease systolic BPV. Specifically, amlodipine significantly decreased systolic BPV in the 3 time frames (P<0.008 for all), and indapamide SR significantly decreased systolic BPV in the daytime (P=0.03) and 24 hours (P=0.03). However, candesartan did not reduce systolic BPV in any time frame. The similar findings are presented in the Figure. In addition, although no significant difference in systolic BPV was observed in the 24-hour read-to-read ARV mode after 3-month different antihypertensive treatments (P=0.08), the reduction in ARV by amlodipine also reached statistical significance (P=0.007). Furthermore, even after adjustment for the corresponding mean BP reduction, the present findings remained unaltered, except that the reduction in daily BPV by indapamide lost its previous significance (P=0.06).
Variables calcium channel blockers significantly reduce BPV, as as-
Table 4. Determinants of the Reduction of Systolic Blood Pressure Variability by Amlodipine and Indapamide Sustained Release

<table>
<thead>
<tr>
<th>Variables</th>
<th>Daytime SD Reduction</th>
<th>Nighttime SD Reduction</th>
<th>Daily SD Reduction</th>
<th>ARV Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>Partial R²</td>
<td>P</td>
<td>β</td>
</tr>
<tr>
<td>Subjects taking amlodipine (n=123)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean SBP reduction, mm Hg</td>
<td>0.08</td>
<td>0.06</td>
<td>0.005</td>
<td>0.02</td>
</tr>
<tr>
<td>HR SD reduction, bpm</td>
<td>0.19</td>
<td>0.04</td>
<td>0.02</td>
<td>0.46</td>
</tr>
<tr>
<td>Subjects taking indapamide SR (n=133)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean SBP reduction, mm Hg</td>
<td>0.04</td>
<td>0.02</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>HR SD reduction, bpm</td>
<td>0.01</td>
<td>0.01</td>
<td>0.89</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Age, sex, body mass index, as well as systolic blood pressure reduction and the reduction of heart rate variability calculated with the same algorithm in the same period as blood pressure variability, were considered in the linear regression models. Reduction indicates the after-treatment value minus the corresponding value at baseline. SBP indicates systolic blood pressure; HR, heart rate; ARV, the read-to-read average real variability, which was calculated by the formula mentioned in the Methods. Daytime SD=time-weighted SD of 24-h systolic blood pressure readings during awake time; nighttime SD=time-weighted SD of 24-h systolic blood pressure readings during sleeping time; daily SD=(daytime SD×awake time+nighttime SD×sleeping time)/(awake time+sleeping time).

After 3-month treatment, we had sufficient statistical power to confirm our findings.

Perspectives

In this study, we have shown that age, BP, and HRV were the major determinants of BPV. Amlodipine and indapamide SR were the only effective antihypertensive agents in decreasing BPV by lowering BP or ameliorating the ANS regulation or both. Their combination might help to optimize such properties. However, the mechanism underlying the reduction in BPV has yet to be clarified, especially its potential interaction with arterial stiffness and/or reflection waves. Given the increasing importance of BPV in the prevention of stroke, as well as other target-organ damage, further studies are undoubtedly warranted.

Acknowledgments

We thank all of the investigators and patients who participated in this study. We are grateful to the monitors and the staff of Institut de Recherches Internationales Servier, France (Dr Luc Feldmann, Dr Martine de Champvallins, Dr Benoît Tallot, Corentin Le Camus, and Elsa Merkling).

Sources of Funding

The X-CELLENT study was supported by Servier.

Disclosures

D.A. received a grant from Servier. J.B. and M.E.S. received grants and honoraria from Servier.

References

4. Bjorklund K, Lind L, Zethelius B, Berglund L, Lithell H. Prognostic significance of 24-h ambulatory blood pressure characteristics for cardio-


Yi Zhang, Davide Agnoletti, Michel E. Safar and Jacques Blacher

Hypertension. 2011;58:155-160; originally published online July 11, 2011;
doi: 10.1161/HYPERTENSIONAHA.111.174383

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/58/2/155

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/