Effect of Reducing Elevated Blood Pressure on Cerebral Circulation

RAY W. GIFFORD, JR., M.D.

SUMMARY Circulation to the brain is protected not only by autoregulation, which maintains cerebral blood flow (CBF) in spite of a decrease in mean arterial pressure, but also by baroreflexes that tend to prevent or minimize hypotension. Hypertensive patients have impaired cerebral autoregulation and depressed baroreflex sensitivity, suggesting that the brain might be vulnerable to a reduction in blood pressure. Nevertheless, in clinical experience, studies of cerebral blood flow during drug-induced reduction of elevated blood pressure have shown that control of hypertension can usually be achieved without jeopardizing cerebral blood flow or inducing signs and symptoms of cerebral ischemia, even in patients with cerebrovascular disease. Indeed, control of hypertension reduces both the risk of stroke and the recurrence rate for second strokes.

(Hypertension 5 (supp III): III-17-III-20, 1983)

KEY WORDS • cerebral autoregulation • stroke prevention • hypertension • antihypertensive therapy • cerebral blood flow

SINCE potent antihypertensive agents first became available over 30 years ago, there has been concern about the possible adverse effects of reducing blood pressure on perfusion of vital organs, especially the brain. Indeed, one of the earliest recognized adverse effects of some of the adrenergic inhibiting agents was orthostatic faintness or syncope. Theoretically, it would seem that hypertensive patients with atherosclerotic cerebrovascular disease might be especially vulnerable to reduction of blood pressure.

The purpose of this paper is to examine the mechanisms that control cerebral blood flow (CBF), and how they are affected by hypertension and antihypertensive therapy, in an effort to answer the question: Is it safe to reduce blood pressure for patients who have clinical evidence of cerebrovascular disease and, if so, how low?

Results of the Hypertension Detection and Follow-up (HDFP) study suggest that one of the reasons the mortality rate was 16.9% lower in the Stepped Care (SC) group than in the Referral Care (RC) group was because a goal diastolic blood pressure was ardently pursued in the SC group. This goal diastolic blood pressure was 90 mm Hg or less for patients whose initial diastolic blood pressure was 100 mm Hg or more, or at least a 10 mm Hg decrement for patients whose initial diastolic blood pressure was 90 to 99 mm Hg. Indeed, at the end of the 5-year study, the average diastolic blood pressure for patients in SC was 84 mm Hg, compared to 89 mm Hg in RC.

The 5-year incidence of stroke was 34% lower in SC than RC (1.9/100 persons in SC vs 2.9 in RC). This would strongly suggest that treatment of hypertension is beneficial, not detrimental, to the cerebral circulation. Other controlled treatment trials have also demonstrated that antihypertensive therapy reduces the risk of stroke.

However, only 2.5% of the participants in the HDFP study had a history of stroke at the time of enrollment and the effect of antihypertensive therapy on cerebrovascular complications in this key subgroup was not specifically reported.

Cerebral Autoregulation

Cerebral blood flow (CBF) is maintained within narrow limits over a wide range of blood pressure levels, a phenomenon known as autoregulation. When blood pressure falls, cerebral vasodilatation occurs, and when blood pressure rises, cerebral vasoconstriction occurs, so that, in normal individuals, the CBF remains constant during fluctuations in mean arterial pressures (MAP) from 60 or 70 mm Hg to well over 150 mm Hg. When MAP drops below the lower limit of autoregulation, the brain extracts more oxygen from the blood to compensate for the reduced CBF. Consequently, clinical manifestations of cerebral ischemia do not occur until this mechanism fails, at which
Cerebral Hemodynamics During Induced Hypotension

<table>
<thead>
<tr>
<th>Group and age</th>
<th>MAP C</th>
<th>E</th>
<th>CBF C</th>
<th>E</th>
<th>CVR C</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normotensive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-46 yr (n = 7)</td>
<td>84</td>
<td>35*</td>
<td>45.6</td>
<td>31.3*</td>
<td>1.9</td>
<td>1.2*</td>
</tr>
<tr>
<td>59-93 yr (n = 10)</td>
<td>79</td>
<td>29*</td>
<td>48.3</td>
<td>29.0*</td>
<td>1.7</td>
<td>1.1*</td>
</tr>
<tr>
<td>Hypertensive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53-72 yr (n = 8)</td>
<td>113</td>
<td>47*</td>
<td>47.9</td>
<td>29.1*</td>
<td>2.4</td>
<td>1.6*</td>
</tr>
<tr>
<td>Malignant hypertensives</td>
<td>33-47 yr (n = 7)</td>
<td>179</td>
<td>89*</td>
<td>60.3</td>
<td>35.1*</td>
<td>3.0</td>
</tr>
</tbody>
</table>

MAP = mean arterial pressure (mm Hg); CBF = cerebral blood flow (cc/min/100 g brain); CVR = cerebral vascular resistance (mm Hg/cc blood/min/100 g brain); C = control; E = during induced hypotension at time of symptomatic cerebral ischemia.

*p < 0.01. Adapted from: Finnerty et al. J Clin Invest 1959; 33:1227, with permission.

Cerebral Hemodynamics During Induced Hypotension

The results of the study show that the lower limit of autoregulation occurred at 45 mm Hg in the normotensive group (table 2). Strandgaard found that the lower limit of autoregulation occurred at an average MAP of 113 mm Hg in 13 untreated hypertensive patients compared to 73 mm Hg in 10 normotensive patients. The average lowest tolerated MAP was 65 mm Hg in the hypertensive group compared to 43 mm Hg in the normotensive group (table 2). Hypertensive patients on treatment had values that were midway between the normotensive group and the untreated hypertensives, suggesting that hypotensive therapy tends to restore autoregulation towards normal.

It is interesting that the percentage of resting MAP at which CBF begins to decline remains remarkably constant when comparing normotensives to hypertensives (table 2). The same was true for the lowest tolerated MAP. Thus, it is possible to predict that the CBF will start to decrease when MAP is reduced to approximately 75% of the resting control, and symptoms of cerebral ischemia will appear when MAP is reduced to approximately 45% of resting MAP (table 2).

Finnerty and colleagues found that hypertensive patients developed symptoms of cerebral ischemia at a higher MAP than did normotensive subjects, even though CBF was not greatly different between the two groups at the time symptoms appeared. This represents a failure of cerebrovascular resistance to decrease appropriately when blood pressure is reduced acutely in hypertensive patients (table 1).

Studies in rats have shown that autoregulation of CBF is impaired in spontaneously hypertensive rats (SHR) compared to Wistar-Kyoto (WKY) controls. Old SHR have a greater reduction in CBF when blood pressure is reduced acutely than do younger SHR, demonstrating that both age and hypertension impair cerebral autoregulation.15 Antihypertensive therapy improved cerebral autoregulation in aged SHR.16

Baroreflexes

Circulation to the brain is protected not only by autoregulation, which maintains CBF in spite of a de-

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean arterial blood pressure (mm Hg)</th>
<th>% of Rest MABP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Lower limit of autoreg.</td>
</tr>
<tr>
<td>Normotensive (n = 10)</td>
<td>98 ± 10</td>
<td>73 ± 9</td>
</tr>
<tr>
<td>Hypertensives (n = 13)</td>
<td>145 ± 17</td>
<td>113 ± 17*†</td>
</tr>
<tr>
<td>Controlled hypertensives (n = 9)</td>
<td>116 ± 18</td>
<td>96 ± 17</td>
</tr>
</tbody>
</table>

Values given as means ± sd. MABP = mean arterial blood pressure. (Adapted from: Strandgaard S. Circulation 1976;53:720, with permission.)

* p < 0.01 for difference between normotensives and hypertensives.
†p < 0.01 for difference between controlled and uncontrolled hypertensives.
increase in MAP, but also by baroreflexes, which tend to prevent or minimize hypotension. Gribbin et al.\textsuperscript{15} have shown that increasing age and increasing arterial blood pressure act independently to reduce baroreflex sensitivity, thus making elderly and hypertensive patients more vulnerable to hypotension, drug-induced or otherwise.

Baroreflexes were found to be absent in 15 of 18 patients with acute cerebrovascular disease and in 32 of 112 patients with remote cerebrovascular events.\textsuperscript{16} Patients over 40 years of age had less active baroreflexes than younger patients even in the absence of cerebrovascular disease.\textsuperscript{16}

**Clinical Implications**

Even though hypertensive patients have impaired cerebral autoregulation and depressed baroreflex sensitivity, conditions that should place the brain in jeopardy when blood pressure is reduced, clinical experience has shown that antihypertensive therapy rarely leads to irreversible ischemic events in the brain. Indeed, most controlled therapeutic trials have demonstrated that the incidence of stroke is sharply reduced by effective antihypertensive therapy.\textsuperscript{2,4}

Perhaps this is because treating hypertension seems to improve cerebral autoregulation,\textsuperscript{6,14} although the mechanism for this has not been elucidated. It seems to occur too rapidly to be explained by a structural change in medial hypertrophy, but too slowly to be a direct drug effect. Furthermore the improvement is noted when blood pressure is reduced by adrenergic inhibiting drugs which are not thought to have any effect on the tone of cerebral arteries and arterioles.

Meyer et al.\textsuperscript{17} used methyldopa to treat 13 hypertensive patients with cerebral vascular disease (cerebral infarction and/or transient ischemic attacks). Average CBF for the group was low initially (table 3). At the end of the 2-week treatment period, MAP and cerebrovascular resistance were both significantly reduced and CBF was significantly increased. Since methyldopa is an inhibitor of the sympathetic nervous system, it is unlikely that it had a direct effect to reduce cerebrovascular resistance, hence the reduction must be related to autoregulation.

Harmsen et al.\textsuperscript{18} produced symptoms of cerebral ischemia by reducing MAP acutely with intravenous infusions of pentolinium during upright tilt in 47 patients. The infusion and upright tilt were promptly discontinued when symptoms of cerebral ischemia supervened. Although MAP was reduced by an average of 55%, no patient developed focal neurologic symp-
reducing cardiac output or total peripheral resistance. A reduction in cardiac output would have a detrimental effect on CBF without an autoregulatory decrease in cerebrovascular resistance.

A decrease in total peripheral resistance, not shared by the cerebral circulation or compensated for by an increase in cardiac output, would lead to a diversion of blood away from the brain if it weren't for autoregulation of the cerebral circulation. Some of the adrenergic blocking agents, such as guanethidine, Bethanidine, and hexamethonium, reduce both cardiac output (especially in the upright position) and total peripheral resistance without having any dilating effect on the cerebrovasculature. This could obviously be devastating to the CBF if it weren't for the autoregulatory mechanism. Indeed, it is these drugs which are most often responsible for orthostatic faintness and syncope when inappropriate doses are administered. Fortunately, irreversible ischemic events rarely ensue even in patients who have cerebrovascular disease.

Hemodynamically, the ideal antihypertensive drugs for patients with cerebrovascular disease would maintain cardiac output and reduce total peripheral resistance, including cerebrovascular resistance. A direct vasodilator, such as hydralazine, minoxidil, or one of the calcium channel entry blockers would fit this description, although the effect of these drugs on cerebrovascular resistance hasn't been extensively studied. It is important to note that the measurement of total CBF can be misleading and mask perfusion deficits in localized areas of the brain. Future studies of the effect of antihypertensive agents on CBF should include measurements of regional CBF in an effort to identify areas that might actually be deprived of adequate flow by a steal mechanism.

Conclusions

In spite of the fact that hypertensive patients have impaired cerebral autoregulation and baroreflex function, clinical studies have clearly shown benefit from antihypertensive therapy in the primary and secondary prevention of stroke.

Cerebral autoregulation tends to improve as elevated blood pressure is reduced. The goal blood pressure for hypertensive patients with evidence of cerebrovascular disease should be the same as it is for hypertensive patients without evidence of cerebrovascular disease: ≤90 mm Hg if the initial diastolic blood pressure is ≥100 mm Hg and at least a 10 mm Hg decrement when the initial diastolic blood pressure is 90–99 mm Hg.

For patients who have had an acute atherothrombotic stroke, it has been my practice not to initiate antihypertensive therapy until the neurologic deficit has been stable for 2 to 3 weeks and the patient has begun to ambulate, unless the diastolic blood pressure is ≥110 mm Hg. During this initial period following cerebral infarction a decrease in blood pressure might endanger the ischemic zone surrounding the infarcted area because of deficient autoregulation and/or impaired or absent baroreflexes. Thereafter, blood pressure should be reduced gradually over a period of several weeks, avoiding, if possible, agents that might cause abrupt orthostatic hypotension (guanethidine, Bethanidine, ganglion blocking agents, and prazosin).

References

1. Hypertension Detection and Follow-up Program: Five-year findings of the hypertension detection and follow-up program. I. Reduction in mortality of persons with high blood pressure, including mild hypertension. JAMA 242: 2562, 1979
Effect of reducing elevated blood pressure on cerebral circulation.
R W Gifford, Jr

Hypertension. 1983;5:III17
doi: 10.1161/01.HYP.5.5_Pt_2.III17

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1983 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

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/5/5_Pt_2/III17

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/