Adrenergic Mechanisms in Cerebral Blood Vessels: Effect of Tyramine on the Isolated Middle Cerebral Artery of the Goat

BY PEDRO R. URQUILLA, M.D., EMILIO J. MARCO, B.Pharm., GLORIA BALFAGON, AND SALVADOR LLUCH, M.D.

Abstract:
Tyramine induces dose-dependent changes in tension of the isolated middle cerebral artery of the goat. Cocaine, phentolamine and reserpine reduce the sensitivity of the tissue to tyramine by factors of 2.8, 3.7 and 3.7, respectively. The norepinephrine (NE) concentration of the arteries of the circle of Willis is 2.10 μg per gram and the corresponding value for the right atria is 1.25 μg per gram. Reserpine pretreatment (0.02 mg/kg/day for three days) reduces the NE concentration of the cerebral arteries to undetectable levels and that of the right atria to 2.4% of the control value. The relatively high concentration of NE of the cerebral arteries of the goat suggests that this tissue receives considerable sympathetic innervation. It is likely that part of the contractile response to tyramine is due to release of endogenous NE from sympathetic stores in the artery. However, some contractile response to tyramine remains after α-adrenergic blockade, reserpine pretreatment and in the presence of cocaine, suggesting that in addition to an indirect action (release of NE) tyramine also possesses a direct stimulatory effect in cerebral arteries.

Additional Key Words
- cocaine
- phentolamine
- norepinephrine
- reserpine

Methods
Goat brains were obtained from the local slaughter house within one hour of the death of the animal. The middle cerebral artery was carefully dissected out and cut into cylindrical segments of 5-mm length. The cylinder was set up for isometric recording in an organ bath according to the method described by Nielsen and Owman. The organ bath contained 3 ml of Krebs-Henseleit solution continuously bubbled with 95% oxygen and 5% carbon dioxide, pH 7.3 to 7.4, and kept at 37°C. The composition of the Krebs-Henseleit solution was (mM): NaCl, 115; KC1, 4.6; CaCl2, 2.5; KH2PO4, 1.2; MgSO4, 7H2O, 1.2; NaHCO3, 2.5; glucose, 11.1. A resting tension of 1 gm was applied to the tissue and readjusted every 15 minutes during a one-hour period of equilibration. Dose-response curves to tyramine were determined in a cumulative manner, and control and experimental responses were obtained from separate vascular preparations. Tyramine was dissolved in saline.
solution containing ascorbic acid 0.01% (w/v); the total volume added to the bath did not exceed 0.3 ml. When cocaine or phentolamine was used, these agents were added to the bath 10 minutes before tyramine and allowed to remain in contact with the tissue throughout the determination of the dose-response relationship.

Reserpine was administered i.v. in a dose of 0.02 mg/kg/day for three days. Twenty-four hours after the last dose of reserpine the animals were killed by injecting i.v. 5 ml of saturated solution of potassium chloride. The right atria and the arteries of the circle of Willis, both from control and reserpine-treated goats, were taken for the fluorometric determination of the norepinephrine tissue concentration according to the method of Shellenberger and Gordon.9 It was necessary to pool the cerebral arteries of three goats in order to have enough tissue for the fluorometric analysis. Tissue weight per pool ranged from 100 to 125 mg. Recovery of norepinephrine was 60% and the tissue values were corrected accordingly.

Some segments were taken from the vascular samples to study the contractile effects of tyramine and the remaining samples were pooled to determine norepinephrine tissue levels.

Geometric means of equipotential doses were determined in the manner described by Fleming et al.10 The 400-mg level (effective dose 400 mg) was selected for quantitative analysis because it corresponded approximately to half the maximum tension achieved with the highest concentration of tyramine used. Horizontal displacement of the dose-response curves was measured at this level by determining the ratio of ED 400 mg experimental over ED 400 mg control.

Statistical analysis was done by means of Student's t test, considering as significant a probability value of less than 5%. Drugs used were: tyramine hydrochloride (Sigma), phentolamine methanesulfonate (Ciba), reserpine (Ciba), and cocaine hydrochloride (Lab. Abello).

Results

Figure 1 illustrates the effect of cocaine 10⁻⁴M upon the response of the isolated middle cerebral artery to tyramine. The changes in tension induced by the first three doses of tyramine were significantly reduced by cocaine (P < 0.05, < 0.05, < 0.02, respectively), but the response to the highest dose of tyramine used in these experiments was not significantly modified.

Dose-response curves for tyramine determined in the absence and in the presence of cocaine 10⁻⁴M. Figures in parentheses refer to number of experiments. Vertical bars represent standard errors of the means.
EFFECT OF TYRAMINE ON CEREBRAL ARTERIES

TABLE 1
Effects of Cocaine, Phentolamine and Reserpine on the ED 400 mg and Maximum Response to Tyramine in the Isolated Middle Cerebral Artery of the Goat

<table>
<thead>
<tr>
<th>Group</th>
<th>Geometric mean ED 400 mg (95% confidence limits)</th>
<th>ED 400 mg experimental</th>
<th>Maximum response*</th>
<th>No. experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.50 (0.87–2.58)</td>
<td>758 ± 78</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Cocaine</td>
<td>4.26 (2.73–6.60)†</td>
<td>2.8</td>
<td>664 ± 45</td>
<td>5</td>
</tr>
<tr>
<td>Phentolamine</td>
<td>5.63 (2.14–14.77)†</td>
<td>3.7</td>
<td>485 ± 58†</td>
<td>8</td>
</tr>
<tr>
<td>Reserpine</td>
<td>5.68 (3.67–8.82)†</td>
<td>3.7</td>
<td>660 ± 62</td>
<td>5</td>
</tr>
</tbody>
</table>

*Refers to response obtained with tyramine 2.18 × 10⁻³M.
†Different from control, P < 0.05.

(P < 0.6). The control dose-response curve for tyramine was shifted 2.8-fold to the right by cocaine (table 1).

The effect of phentolamine 10⁻⁶M on the tyramine-induced changes in tension are shown in figure 2. Phentolamine displaced the dose-response curve for tyramine 3.7-fold to the right of control, with a tendency for parallelness but with a slight decrease in slope at the latter part of the curve (see also table 1). Note that phentolamine reduced significantly the responses to all doses of tyramine (P < 0.025, < 0.05, < 0.02, < 0.02, from low to high.)

![Figure 2](http://stroke.ahajournals.org/)

**FIGURE 2**
Dose-response curves for tyramine determined in the absence and in the presence of phentolamine 10⁻⁶M. Number of experiments are indicated in parentheses. Vertical bars represent standard errors of the means.
doses, respectively). Although the maximum response to tyramine has been reduced by phentolamine, comparison of equipotent doses has been done at the 400-mg level of response because this tension change lies in the parallel portion of the curves, and for the sake of uniformity since the effects of the other treatments have been measured at this level.

Figure 3 shows the dose-response curves for tyramine determined in tissues from control and reserpine pretreated animals. The responses to the first three doses of tyramine were reduced by reserpine pretreatment (P < 0.02, < 0.005, < 0.05, respectively), whereas that due to the highest dose was not altered (P < 0.3). At the ED 400-mg level, reserpine pretreatment induced a 3.7-fold shift to the right of the control curve for tyramine (table 1).

In order to estimate the catecholamine-depleting ability of reserpine in the cardiovascular system of the goat, norepinephrine tissue levels were measured in the right atria and cerebral arteries of control and reserpine pretreated animals. In control animals, the right atria contained 1.25 μg of norepinephrine per gram of tissue, whereas the corresponding value for the cerebral vessels was 2.10 μg per gram. Reserpine reduced the norepinephrine concentrations of the cerebral arteries and of the right atria to undetectable levels and to 2.4% of control, respectively (table 2).

**Discussion**

The present study shows that the cerebral arteries of the goat possess a relatively high concentration of norepinephrine (NE). The NE concentration found in the goat cerebral vessels was greater than the corresponding values for the goat right atria (table 2), the rabbit aortic strips, or the rabbit ear artery. Since tissue levels of NE appear to be associated with the density of adrenergic innervation, it is likely that the high concentration of NE of the goat cerebral
EFFECT OF TYRAMINE ON CEREBRAL ARTERIES

TABLE 2

Effect of Reserpine Pretreatment on the Norepinephrine (NE) Tissue Concentration of the Right Atria and Cerebral Arteries of the Goat

<table>
<thead>
<tr>
<th>Group</th>
<th>NE tissue content (μg per gram ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.25 ± 0.09</td>
</tr>
<tr>
<td>Reserpine</td>
<td>0.03 ± 0.007</td>
</tr>
</tbody>
</table>

**Control**

<table>
<thead>
<tr>
<th>Group</th>
<th>NE tissue content (μg per gram ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserpine</td>
<td>Undetectable</td>
</tr>
<tr>
<td>(0.02 mg/kg/day, three days)</td>
<td>n = 5</td>
</tr>
</tbody>
</table>

*“n” refers to number of animals in the case of right atria and to number of pools (three animals per pool) in the case of cerebral arteries.
†Fluorescence of tissue sample
Fluorescence of tissue blanks < 1.0.

The response of the cerebral arteries to tyramine is apparently mediated to some extent by the release of adrenergic transmitter. The evidence for this is that reserpine pretreatment, which reduced endogenous NE to undetectable levels, reduced the response to tyramine. However, in spite of the absence of NE in the vascular tissues obtained from animals pretreated with reserpine, tyramine still produced a contractile effect. The dose-response curve for tyramine was only 3.7-fold to the right of the control. These results raise the possibility that the effects of tyramine on the cerebral vasculature of the goat include, in addition to its well-known indirect mechanism of action mediated through the release of NE, another component which appears to be independent of the endogenous stores of adrenergic transmitter. This interpretation is supported by the results obtained with cocaine, an agent generally considered to interfere with the neuronal uptake of amines and which, therefore, would prevent the access of tyramine to the storage sites of endogenous norepinephrine. In the present study, cocaine was used in a concentration ten times higher than that shown to block the uptake of labeled norepinephrine in rabbit aortic strips and it produced a 2.8-fold shift to the right of the tyramine control curve. The reduction of the response to tyramine induced by cocaine was comparable to the reduction produced by reserpine, and the ED 400 mg of tyramine under both procedures was not significantly different (P < 0.1). Based on this evidence, tyramine seems to possess a mechanism of action which is independent of the availability of adrenergic neurotransmitter. These results differ from those obtained by Nielsen et al. on the isolated middle cerebral artery of the cat. Those authors showed that reserpine pretreatment or removal of the superior cervical ganglion virtually eliminated the responses to tyramine. However, it is interesting to note in their study that two weeks after denervation the response to tyramine returned to control levels. Nielsen et al. explain this finding in terms of the development of supersensitivity to the remaining direct effect of tyramine, thus implying a mixed mechanism of action of tyramine in the cat cerebral vessels.

Phentolamine 10⁻⁴ M, a concentration which reduces the sensitivity of rabbit aortic strips to norepinephrine to one-tenth of normal, produced approximately the same degree of displacement of the tyramine control curve as does reserpine or cocaine (table 1). These data indicate that norepinephrine released by tyramine induces contractile effects through the activation of alpha adrenergic receptors. The present results also suggest that the potency of phentolamine is lower in the goat cerebral arteries than in the rabbit aortic strips. This may be due to differences in the density of adrenergic innervation in the two arteries as inferred from their respective norepinephrine concentration (present study table 2; ref. 11). The density and spatial distribution of the nerve endings in rabbit aortic strips seem to influence the potency of phentolamine against endogenously released norepinephrine. A further indication of this study is that the direct component of the effect of tyramine does not appear to involve alpha adrenergic receptors because if this were the case one would expect that phentolamine exerted a greater blockade compounded by antagonism to the action of the released mediator (NE) and to the action of the releasing agent (tyramine). Possibly, another type of receptor system mediates the direct effect of tyramine in this preparation, as it has been suggested for other tissues. At high doses of tyramine, however, some degree of activation of alpha adrenergic receptors begins to appear since phentolamine significantly reduced the response to 2.18 × 10⁻⁴ M (fig. 2 and table 1). Thus, the effects of tyramine on the isolated middle cerebral artery of the goat involve, conceivably, the release of endogenous norepinephrine present in the artery wall, plus another mechanism of action which is likely to be nonadrenergic in nature.

In summary, the presence of the adrenergic neurotransmitter in the cerebral arteries of the goat, the catecholamine-depleting ability of reserpine and the indirect component of action of tyramine in these blood vessels are experimental facts which lend support to the proposal of Lluch et al. pointing toward the possible role of the sympathetic nervous system in the regulation of cerebral blood flow of the goat. D'Alecy and Feigl have made a similar proposal for the sympathetic nervous control of the cerebral blood flow of the dog.
References

11. Maxwell RA, Eckhardt SB, Wastila WB: Concerning the distribution of endogenous norepinephrine in the adventitial and media-intimal layers of the rabbit aorta and the capacity of these layers to bind tritiated norepinephrine. J Pharmacol Exp Ther 161:34-39, 1968
Adrenergic Mechanisms in Cerebral Blood Vessels: Effect of Tyramine on the Isolated Middle Cerebral Artery of the Goat
PEDRO R. URQUILLA, EMILIO J. MARCO, GLORIA BALEFAGON and SALVADOR LLUCH

Stroke. 1974;5:447-452
doi: 10.1161/01.STR.5.4.447

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/5/4/447

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Stroke 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 Stroke is online at:
http://stroke.ahajournals.org/subscriptions/