AS YET THERE is no effective treatment of cerebral arterial spasm, and this may be a consequence of the event being multifactorially mediated. In a recent experimental delayed cerebral vasospasm, prostacyclin and prostaglandin F$_2\alpha$ (PGF$_2\alpha$) formation in the canine basilar artery has been significantly decreased while prostaglandin E$_2$ (PGE$_2$) synthesis has been significantly increased, suggesting that prostaglandins are involved in the pathogenesis of delayed cerebral vasospasm. In addition, a disproportionate formation of thromboxane A$_2$, main prostaglandin product of platelet, particularly its secondary aggregation, were inhibited in a dose-dependent manner by addition of chlorpromazine or amitriptyline; calmodulin antagonist. The molar concentrations at 50% inhibition by chlorpromazine or amitriptyline were 5.9 to 7.7 $\mu$M or 28 to 39 $\mu$M for the contraction of basilar artery and 57 $\mu$M or 111 $\mu$M for the secondary aggregation of platelet. The results were discussed mainly on the basis of interaction of psychotropic drugs and Ca$^{2+}$, calmodulin-dependent enzymes, particularly myosin light chain phosphorylation.

### Materials and Methods

**Relaxation Studies of Isolated Canine Basilar Artery**

Adult dogs, 10 to 18 kg in weight, were sedated with an intravenous administration of 50 mg/kg of sodium pentobarbital and sacrificed by a rapid exsanguination. The brain with the basilar artery attached was removed rapidly. A 4 mm long segment of the basilar artery was made and then mounted on rigid parallel prongs in a chamber described previously. The chamber was filled with 8 ml of modified Krebs solution of the following composition: NaCl 118.9 mM, KCl 4.7 mM, KH$_2$PO$_4$ 1.2 mM, CaCl$_2$ 1.2 mM, MgSO$_4$ 1.2 mM, NaHCO$_3$ 14.9 mM, and dextrose 5.6 mM (pH 7.4), aerated with 95% O$_2$ and 5% CO$_2$, and warmed at 37 ± 0.5°C by means of a circulating temperature bath.

Isometric tension of the arterial segment in vitro was measured with a Nihon-Koden PD transducer (Nihon-Koden Kogyo Co., Tokyo, Japan). The arterial segment was allowed to stabilize at a resting tension of 200 to 400 mg for 1 hr and then increased to a resting tension of 3 gm before the start of the experiment. Atrial contraction was made with a depolarizing solution at the beginning of each experiment to determine the condition of the arterial segment, and only those segments producing at least a 2-gm tension with the depolarizing solution were used. The depolarizing solution was composed of 76 mM K$_2$SO$_4$, 10 mM KCl, 16 mM KHCO$_3$, 2.5 mM CaCl$_2$, 1.2 mM MgCl$_2$, 1.2 mM KH$_2$PO$_4$, and 5.6 mM dextrose.

Materials used for inducing the contraction of basilar artery in vitro were PGF$_{2\alpha}$, PGE$_2$, Hb-containing solution, and serum, the concentrations of which were 10$^{-3}$ M, 10$^{-5}$ M, 1 gm/ml, and 100 $\mu$L/ml, respectively, and induced the maximal contractions. Consequently, these solutions and serum were made by the method of Toda et al. The content of Hb was assayed with a spectrophotometer (Hitachi Co., Tokyo, Japan) at a wavelength of 541 nm by the method of Van Assendelft. Methemoglobin was not detected in Hb-containing solution by the method of Van Assendelft. After in-
Reducing the contraction of basilar artery, cumulative dose-response was obtained by increasing the concentrations of chlorpromazine or amitriptyline by a factor of about 3 while the previous dose remained in contact with the basilar artery and showed a steady response. At the end of each experiment, $1 \times 10^{-4}$ M papaverine was added and the relaxation induced by papaverine was taken as 100%. Only one cumulative dose-relaxation response to chlorpromazine or amitriptyline was obtained from a single preparation. When a molar concentration at 50% relaxation was determined, the response to chlorpromazine or amitriptyline was calculated as a percentage of the maximum relaxation obtained. The molar concentration at 50% relaxation was obtained visually from a plot of percent relaxation vs. log concentration of chlorpromazine or amitriptyline.

Human Platelet Aggregation Studies

Venous blood was taken from 5 healthy adults, who had not been treated with aspirin or indomethacin for the past 3 weeks. A mixture of 9 parts human blood to 1 part 3.8% sodium citrate was centrifuged at 200 G for 10 min and platelet-rich plasma (PRP) was removed, and the remainder was processed for platelet-poor plasma (PPP) by centrifuging at 2000 G for 10 min. The aggregation of platelet was induced by 1.0 μM ADP (Sigma Chemical Co., St. Louis, Mo., U.S.A.), which is the critical concentration for the biphasic response of human platelet aggregation.

### Table 1

<table>
<thead>
<tr>
<th>Agents</th>
<th>Conc. (M)</th>
<th>Reduced tension (mg) of basilar artery contracted by</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$PGF_{2\alpha}$ (7)</td>
<td>$PGE_2$ (8)</td>
<td>Hb (8)</td>
</tr>
<tr>
<td>Before</td>
<td>$1 \times 10^{-6}$</td>
<td>2054 ± 499</td>
<td>1587 ± 346</td>
<td>2132 ± 406</td>
</tr>
<tr>
<td>chlorpromazine</td>
<td>$3 \times 10^{-6}$</td>
<td>168 ± 82</td>
<td>276 ± 103</td>
<td>285 ± 108</td>
</tr>
<tr>
<td>Papaverine</td>
<td>$1 \times 10^{-5}$</td>
<td>899 ± 193</td>
<td>748 ± 132</td>
<td>799 ± 252</td>
</tr>
<tr>
<td></td>
<td>$3 \times 10^{-5}$</td>
<td>1441 ± 281</td>
<td>1128 ± 246</td>
<td>1416 ± 320</td>
</tr>
<tr>
<td>amitriptyline</td>
<td>$3 \times 10^{-5}$</td>
<td>1782 ± 362</td>
<td>1323 ± 286</td>
<td>1665 ± 393</td>
</tr>
<tr>
<td></td>
<td>$1 \times 10^{-4}$</td>
<td>2021 ± 418</td>
<td>1622 ± 336</td>
<td>2033 ± 458</td>
</tr>
</tbody>
</table>

After the addition of ADP to PRP at 37°C, the increase in light transmission was monitored by a Bryston aggregometer (Bryston Manufacturing Ltd., Rexdale, Ontario, Canada). Chlorpromazine or amitriptyline was added to PRP 1 min before the addition of ADP to examine its anti-aggregation activity.

Chlorpromazine and papaverine were supplied from Sigma Chemical Co. and Wako Chemical Co., Ltd., Osaka, Japan, respectively. $PGF_{2\alpha}$ and $PGE_2$ as well as amitriptyline were generously supplied by Ono Pharmaceutical Co., Ltd., Osaka and Nippon Merck Banyu Pharmaceutical Co., Ltd., Tokyo, Japan, respectively.

**Results**

Relaxation Studies of Isolated Canine Basilar Artery

The addition of $PGF_{2\alpha}$, $PGE_2$, Hb, or serum induced a prompt contraction of canine basilar artery, which attained maximum plateau within 15 min and was sustained at least for 2 hrs, and the mean values of the maximum tensions were 2045 ± 414, 1625 ± 349, 2116 ± 464, and 1856 ± 377 mg, respectively. The sustained contraction thus induced showed a dose-dependent relaxation by addition of $1 \times 10^{-6}$ to $1 \times 10^{-4}$ M chlorpromazine or amitriptyline, and tensions reduced by chlorpromazine, amitriptyline, or $1 \times 10^{-4}$ M papaverine, although variable from specimen to specimen, are shown in table 1. The relaxation of basilar artery produced by chlorpromazine or amitriptyline was not affected by pretreatment with $5 \times 10^{-5}$ M propranolol and $10 \times 10^{-6}$ M atropine. The molar concentra-
CHLORPROMAZINE AND AMITRIPTYLINE

Human Platelet Aggregation Studies

The platelet aggregation in response to 1.0 μM ADP was variable from person to person. A typical tracing of ADP-induced platelet aggregation when chlorpromazine or amitriptyline was given, is shown in figure 1. Chlorpromazine and amitriptyline were effective in a dose-dependent manner for the inhibition of platelet aggregation induced by 1.0 μM ADP, as exhibited in table 2, in which the aggregation rates at 1 and 5 min after the addition of ADP are shown if the transmission of PPP is taken as 100% and percent inhibitions are calculated from the aggregation rates induced by ADP alone and by chlorpromazine or amitriptyline plus ADP. If the platelet aggregations at 1 and 5 min after the addition of ADP indicated the primary and the secondary aggregations of platelet, respectively, the inhibition of the primary aggregation by chlorpromazine or amitriptyline was weaker than that of the secondary, and more amount of chlorpromazine or amitriptyline was needed to inhibit the primary aggregation. The molar concentrations at 50% inhibition of secondary aggregation by chlorpromazine and amitriptyline were (5.7 ± 2.3) × 10^-6 M and (11.1 ± 5.1) × 10^-5 M, respectively, as shown in table 2. Amitriptyline was less potent in inhibiting human platelet aggregation than chlorpromazine.

Discussion

Blaumanis and Grady reported that a topical application of 10^-7 to 10^-4 M chlorpromazine led to a prompt relaxation of the spastic cerebral artery segment induced by electrical, mechanical, or chemical stimuli or by subarachnoid hemorrhage. The sustained contraction of the canine basilar artery induced by PGF, PGE, Hb, or serum in the present study was relaxed in a dose-dependent manner by chlorpromazine or amitriptyline. Alpha-adrenergic, serotoninergic and histaminergic H1 mechanisms were not involved in the contractile responses of the canine basilar artery to PGF, and PGE. In addition, alpha-adrenergic, histaminergic H1 and angiotensin-related mechanisms were not involved in the contractile responses to Hb and serum. Finally, the relaxation induced by chlor-
promozine or amitriptyline was not affected by treatment with adrenergic or cholinergic blocking agents such as propranolol and atropine, suggesting that chlorpromazine or amitriptyline does not work through various receptors described above.

Recent studies of smooth muscle cells have suggested that contraction is regulated by a light chain kinase, which is activated by calmodulin in the presence of Ca^{2+} and that activation of the kinase enhances the activity of actomyosin ATPase and the contraction of the myosin system.\cite{10,12} Hidaka et al.\cite{14,15,16} reported that naphthalenesulfonamide derivatives or psychotropic drugs such as chlorpromazine and amitriptyline induced relaxation of rabbit aortic strips contracted by various agonists such as KCl, CaCl_{2}, norepinephrine, histamine and PGF_{2a} and inhibited the superprecipitation of aorta smooth muscle actomyosin by addition of ATP. The psychotropic drugs such as chlorpromazine and amitriptyline showed a high-affinity, Ca^{2+}-specific binding to calmodulin, forming a calmodulin-calcium-psychotropic complex which cannot activate the calmodulin-sensitive form of enzymes.\cite{17,18,19}

A Scatchard analysis of the binding of chlorpromazine to calmodulin revealed two sets of binding sites; one set of high-affinity sites (K_d = 5 \mu M, N = 3 sites per molecules) and a second set of low-affinity site (K_d = 130 \mu M, N = about 17 sites per molecules), and the high-affinity binding was dependent on the presence of calcium and the low-affinity sites were calcium independent.\cite{19} The degree to which psychotropic drugs bind to calmodulin is directly related to their ability to inhibit the activation of phosphodiesterase.\cite{19} I_{50} values for the inhibition of activated phosphodiesterase by chlorpromazine and amitriptyline were 42 and 130 \mu M, respectively.\cite{17,20} I_{50} value for phosphodiesterase inhibition by trifluoperazine was about 10 times greater than K_d value for specific binding of trifluoperazine to calmodulin.\cite{18} The molar concentrations at 50% relaxation by chlorpromazine or amitriptyline were 5.9 to 7.7 \mu M or 28 to 39 \mu M for isolated canine basilar artery, and low as compared to the I_{50} values for the inhibition of activated phosphodiesterase by chlorpromazine and amitriptyline\cite{17,20} or to ED_{50} values of chlorpromazine and amitriptyline for the relaxation of rabbit aorta contracted by 0.5 \times 10^{-6} M PGF_{2a}\cite{19} possibly due to the difference of species or to the characteristic of cerebral artery.

Hogaboam and Fedan\cite{20} reported that calmodulin in the canine tracheal smooth muscle directly stimulated the activity of a microsomal Ca^{2+}-transport ATPase and that in addition to the initiation of contraction, Ca^{2+}-calmodulin interactions might regulate the rate and degree of smooth muscle relaxation by stimulating the removal of Ca^{2+} from the myoplasm and facilitating the dissociation of Ca^{2+} from the contractile proteins. However, if chlorpromazine or amitriptyline inhibits the transmembrane Ca^{2+}-influx, it is likely that the relaxing action of these drugs is dependent on the extracellular calcium concentration and that this relaxation would be abolished by extracellular calcium in excess amount. Kanamori et al.\cite{21} showed that 1 \times 10^{-6} and 3 \times 10^{-6} M chlorpromazine shifted the dose-response curve of rabbit aortic strips for CaCl_{2} to the right, indicating that Ca^{2+}-induced contraction was inhibited in a competitive fashion. Since the effect of chlorpromazine on phospholipid, Ca^{2+}-dependent protein kinase was partially responsible for its pharmacological actions,\cite{21} chlorpromazine would be an effective Ca^{2+}-influx inhibitor. The pharmacological action of amitriptyline for Ca^{2+}-flux is unknown, but chlorpromazine might induce the relaxation of the canine basilar artery by acting as calmodulin antagonist and Ca^{2+}-influx inhibitor.

The inhibitory effects of chlorpromazine and amitriptyline on platelets have already been well studied.\cite{39,40} Irreversible ADP-induced platelet aggregation shifted promptly from primary to secondary aggregation, and platelet release reaction initiated simultaneously with the beginning of the secondary aggregation.\cite{41} The secondary aggregation of platelet was inhibited in a dose-dependent manner by the addition of chlorpromazine or amitriptyline in the present study. Serotonin uptake by platelets was inhibited by chlorpromazine,\cite{40} and single phase reversible aggregation triggered by serotonin in PRP was prevented by trifluoperazine.\cite{10} However, serotonin uptake was also inhibited by ouabain,\cite{41} which did not prevent secretion-associated aggregation,\cite{40} and, in general, the abil-

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**Table 2 Effect of Chlorpromazine or Amitriptyline on Human Platelet Aggregation Induced by 1.0 \mu M ADP**

<table>
<thead>
<tr>
<th>Agents</th>
<th>Conc. (M)</th>
<th>Aggregation rate</th>
<th>% inhibition</th>
<th>1 min (%)</th>
<th>5 min (%)</th>
<th>% inhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorpromazine</td>
<td>control</td>
<td>60.4±10.7</td>
<td></td>
<td>73.8±7.9</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 \times 10^{-6}</td>
<td>58.2±8.7</td>
<td>4</td>
<td>71.2±6.9</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 \times 10^{-5}</td>
<td>55.0±10.4</td>
<td>9</td>
<td>63.6±15.5</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 \times 10^{-5}</td>
<td>57.6±10.4</td>
<td>5</td>
<td>58.4±16.4</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 \times 10^{-4}</td>
<td>49.2±12.5</td>
<td>19</td>
<td>15.6±13.0</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Amitriptyline</td>
<td>control</td>
<td>49.8±7.9</td>
<td></td>
<td>72.6±11.3</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 \times 10^{-5}</td>
<td>45.4±7.9</td>
<td>9</td>
<td>69.0±13.6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 \times 10^{-5}</td>
<td>44.6±9.0</td>
<td>10</td>
<td>67.8±16.0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 \times 10^{-4}</td>
<td>39.8±7.9</td>
<td>20</td>
<td>38.6±21.4</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 \times 10^{-4}</td>
<td>29.0±8.1</td>
<td>42</td>
<td>5.4±3.9</td>
<td>93</td>
<td></td>
</tr>
</tbody>
</table>

Aggregation rates and their percent inhibitions at 1 and 5 min after the addition of ADP are shown.
ity of drugs to block serotonin uptake did not parallel their ability to block platelet aggregation. It is unlikely, therefore, that the inhibitory activity of chlorpromazine and possibly amitriptyline on platelets involves prevention of serotonin uptake. Chlorpromazine was bound preferentially to phosphatidylycerine and phosphatidylsorosine in the inner bilayer of the platelet membrane, and produced its inhibitory effect on the platelet function in part by changing the organization of the membrane bilayer.

Platelet myosin light chain kinase has been identified as a Ca\(^{2+}\)-dependent enzyme that requires calmodulin for its activity. A calmodulin-mediated system, such as Ca\(^{2+}\)-dependent phosphorylation plays an important role in the release reaction of platelet. Calmodulin antagonists such as trifluoperazine and naphtalen sulphonamide derivatives inhibited secondary aggregation and release reaction of platelet.

In addition, chlorpromazine affected ATP-dependent calcium transport by a microsomal fraction from human platelets. Platelet phospholipase A\(_2\), which is involved in the release of arachidonic acid from certain phospholipids, has also been reported to be stimulated by calmodulin in membrane preparations, and inhibition of arachidonic acid mobilization by trifluoperazine has recently been reported. If chlorpromazine and amitriptyline have an inhibitory effect on arachidonic acid mobilization, similar to that by trifluoperazine, the decreased formation of thromboxane A\(_2\) might prevent platelet aggregation and contraction of cerebral artery. The pharmacological effects of chlorpromazine and amitriptyline on platelets may result from a combination of several types of molecular interactions and cannot be explained by a single mechanism.

References

4. Fukumori T, Tani E: Unpublished observation
30. Van Rossum JN: Cumulative dose-response curves. II. Techniques


50. Grinstein S, Furuya W: Calmodulin binding to platelet plasma membranes, Biochim Biophys Acta 668: 55–64, 1982


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A Sukenaga, E Tani, T Fukumori and Y Maeda

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