Cerebral Arterial Smooth Muscle Contraction by Thromboxane A$_2$

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SUMMARY  The contractile effects of thromboxane A$_2$ (TxA$_2$), a labile arachidonic acid metabolite, were studied in arterial smooth muscle strips. TxA$_2$ was generated upon the addition of 255 mM prostaglandin cyclic endoperoxide H$_2$ to human platelet particles in the muscle bath. Using the isometric contraction produced by 40 mM K$^+$ in isotonic saline as the reference contraction, bovine middle cerebral artery strips contracted to 153 ± 14% of the reference response while bovine coronary and porcine coronary, renal and common carotid strips contracted to 47 ± 3, 26 ± 5, 43 ± 2 and 2 ± 1% of reference, respectively. The cerebral arterial response to the TxA$_2$ generating system was as great as the maximum response to prostaglandin F$_2$o and two times the maximum response to 5-hydroxytryptamine. Because TxA$_2$ is formed by brain tissue and released from aggregating platelets, it may be important in the pathogenesis of spasm associated with injured brain tissue or pathologic changes leading to platelet aggregation.

THE EXACT CAUSE of cerebral arterial spasm associated with subarachnoid hemorrhage is unknown; however, substances released from or by blood have been implicated.$^1$-$^4$ Prostaglandin F$_{2o}$ (PGF$_{2o}$) and 5-hydroxytryptamine (5HT), which are released from brain tissue and aggregating platelets, have been suggested as possible chemical mediators of spasm.$^5$-$^8$

Recent advances in prostaglandin research have suggested that arachidonic acid metabolites other than prostaglandin F$_{2o}$ may be involved in the genesis of vasospasm. Prostaglandin cyclic endoperoxides G$_2$ and H$_2$ (PGG$_2$, PGH$_2$), which are intermediates in the formation of prostaglandin E$_2$, F$_{2o}$ and D$_2$ (PGE$_2$, PGE$_{2o}$, PGD$_2$), have also been shown to be the precursors of the very labile thromboxane A$_2$ (TxA$_2$) and its stable metabolite thromboxane B$_2$ (TxB$_2$) (fig. 1).$^7$ Importantlly, the conversion of PGG$_2$, and PGH$_2$ to the thromboxanes is now known to be the preferential metabolic pathway in platelets, brain, and lung with PGF$_{2o}$, PGE$_2$, and PGD$_2$ being minor metabolic products.$^8$-$^9$ PGG$_2$, PGH$_2$, and TxA$_2$ are not only released during platelet aggregation, but can induce platelet aggregation.$^9$-$^{11}$ PGG$_2$ and PGH$_2$ have a 5 minute half-life in aqueous medium while that of TxA$_2$ is only 32 seconds.$^7$-$^8$

PGG$_2$, PGH$_2$, and TxA$_2$ have been shown to cause contraction of isolated rabbit aortic smooth muscle.$^9$-$^{11}$ Recently, we have shown that TxA$_2$ released from aggregating human platelets is capable of inducing contraction of isolated, porcine coronary artery strips.$^{12}$ The vasoactivity of platelet released TxA$_2$, coupled with the fact that TxA$_2$ is produced by brain tissue, has led us to investigate the effects of TxA$_2$ on cerebral arterial smooth muscle. It was felt that TxA$_2$ induced vasoconstriction might be relevant to the genesis of cerebral transient ischemic attacks or the vasospasm of subarachnoid hemorrhage, where platelet aggregation or brain injury has occurred.

Methods

Fresh bovine and porcine tissue from a local slaughter house was transported in 4°C Krebs-Ringer bicarbonate solution.$^{10}$ The arteries used were taken from the following anatomic locations: 1) the left coronary artery and proximal two thirds of the left anterior descending artery, 2) the distal renal artery and its first intra-renal branches, 3) the distal one-half of the common carotid, and 4) the middle cerebral. Arteries were isolated and spiral cut to produce strips approximately 2 cm long and 1.5 mm wide. The strips were then placed in 3 ml baths containing 37°C Krebs-Ringer bicarbonate buffer saturated with 95% O$_2$ - 5% CO$_2$ and containing 8 µM indomethacin, which inhibited endogenous prostaglandin synthesis. After 3 hours of equilibration, changes in isometric tension were measured in strips which had been pre-loaded with 1.25–1.50 grams of tension. Before the experiment, all arteries were tested with 5-HT or norepinephrine to insure normal drug reactivity. Experimental contractile responses are expressed relative to the maximum tension developed by 40 mM K$^+$ substituted for an equivalent concentration of Na$^+$ in Krebs-Ringer bicarbonate solution. After obtaining dose response curves for 5-HT, the artery strips were treated with the 5-HT antagonist methysergide (2.83 µM) and tested with 5-HT (5.7 nM) to insure completeness of blockade. This was done to prevent action of any 5-HT released from platelet particles used in the TxA$_2$ generating system. A concentrated stock solution of PGF$_{2o}$ tromethamine salt (Upjohn Co.) was made by dissolving PGF$_{2o}$ in ethanol. Care was taken that the concentration of ethanol in the artery baths was less than 1 µl per ml.

Prostaglandin cyclic endoperoxide G$_2$ and H$_2$ were synthesized from sheep seminal vesicular gland microsomes, isolated and structurally confirmed as reported by Hamberg et al.$^{11}$ We used the particulate fraction from human platelets to convert cyclic endoperoxides into TxA$_2$. Blood was drawn from normal volunteers who had not had aspirin or other drugs for at least one week. Washed platelets were prepared$^{11}$ and subsequently frozen and thawed 3 times, homogenized and centrifuged at 2,000 x g for 15 minutes. The 2000 x g supernatant fluid was then spun at 100,000 x g for 1 hour, and the resulting pellet resuspended in a volume of Krebs-Ringer bicarbonate equivalent to one-fifth the washed platelet volume. Aliquots (0.1 ml) of the suspension of platelet particles were added to 2.9 mls of medium and preincubated at 37°C for 3 minutes before being transferred to the artery baths. The TxA$_2$ generating system was started by the addition of 25.5 or 255 mM PGH$_2$ to the baths containing the platelet particles. We have previously shown that this system generates TxA$_2$ by measuring the formation of its stable metabolite, TxB$_2$, in the artery baths.$^{14}$

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Attempts to generate greater concentrations of TxA₂ by using more cyclic endoperoxide substrate or platelet particle enzymes were technically unsuccessful for two reasons. First, higher substrate concentrations have a substantial effect on the vascular smooth muscle. Cyclic endoperoxide itself induces contraction of porcine arterial strips and so can PGE₂ which is spontaneously formed by isomerization of cyclic endoperoxide. Secondly, oxygen bubbling in the baths, which is needed to insure mixing as well as oxygenation, causes foaming when higher concentrations of platelet protein are added. Future studies are being directed toward isolating TxA₂ and purifying the enzyme necessary for conversion of cyclic endoperoxide to TxA₂.

\[\text{Addition of PGH}_2\text{ to the platelets in the bath reached a maximum in} \ 0.9 \text{ to} \ 1.5 \text{ minutes.}\]

Because the cerebral artery response to TxA₂ was particularly strong, we compared the cerebral artery response to TxA₂ with that of PGF₉α and 5-HT, which have been suggested to be mediators of cerebral vasospasm. The cerebral contraction produced by the TxA₂ generating system, consisting of platelet particles plus 255 nM PGH₂, was twice that produced by 255 nM PGF₉α or 5-HT and six times that produced by 255 nM PGH₂ alone (fig. 3). TxA₂ generated by adding 255 nM PGH₂ to platelet particles, induced a contraction which was almost twice as great as the maximum attainable 5-HT (2.5μM) contraction and was as great as the maximum PGF₉α (2.5μM) induced contraction (fig. 4).

Addition of only platelet particles to the artery baths did not cause an increase in artery tension. TxB₂, the stable metabolite of TxA₂, was also tested on the cerebral strips. Unpurified TxB₂, formed by allowing platelet particles to react with 255 nM PGH₂ for 3 minutes, produced no cerebral artery contraction. However, TxB₂ extracted from this generating system and purified by high performance liquid chromatography induced a small, slowly developed increase in cerebral artery tension.

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Discussion

Numerous studies of the physiology and pharmacology of the cerebral vasculature have been reported, yet controversy continues over factors which control normal and pathologic brain blood flow. It is likely that several chemical factors from blood and neural tissue, including 5-HT, prostaglandins and others, act together to control pathologic cerebral vascular smooth muscle tension. Our data show that thromboxane A2 should be added to the list of potential chemical mediators of spasm associated with subarachnoid hemorrhage and brain injury.

While 5-HT can cause contraction of cerebral vascular smooth muscle both in vitro and in vivo, it is of particular interest since it is released by aggregating platelets. White et al. have shown 5-HT to cause cerebral vasospasm when injected intracisternally in relatively low doses. Our data show that at low doses bovine cerebral artery strips are more sensitive to 5-HT than PGF2α. Similarly, Allen et al. have shown human cerebral strips to be more responsive to low concentrations of 5-HT than equimolar concentrations of PGF2α. Also, this study demonstrates that the maximum bovine cerebral artery response to PGF2α is two times stronger than the maximum response to 5-HT. Somewhat analogously, White et al. have reported that intracisternal injections of PGF2α induced a more prolonged and more severe cerebral vasospasm than equimolar doses of 5-HT.

Our results show TxA2 is an effective contractor of vascular smooth muscle from several major organs in different animal species. While it is effective on coronary and renal arteries, the extraordinarily powerful cerebral response make it of particular interest since TxA2 is released from aggregating platelets and TxB2 is the most abundant arachidonic acid metabolite synthesized by the brain. Continuous formation of TxA2 might induce a prolonged spasm whereas acute TxA2 formation and severe vasoconstriction could lead to intravascular thrombosis.

Our comparison of the cerebral response to TxA2, PGF2α, and 5-HT is somewhat hampered by the fact that the effective TxA2 concentration existing in the artery baths at any particular time is unknown. While we use 25.5 or 255 nM cyclic endoperoxide as the substrate for the platelet particles, only a small fraction of the added cyclic endoperoxide is converted to and exists as TxA2 at any particular instant. Therefore, less than 25.5 or 255 nM TxA2 exists in the bath at any time, and, on a molar basis, TxA2 is at least 10 times more powerful than 5-HT or PGF2α in our test system.

We conclude that TxA2 can contract cerebral arterial smooth muscle in vitro. These findings provide the basis for the following hypothesis: brain trauma or platelet aggregation in areas of damaged endothelium can release TxA2 and thus cause constriction of cerebral arteries. This hypothesis may merit testing in conditions where cerebral spasm is known or postulated such as in subarachnoid hemorrhage and transient ischemic attacks.

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References

Recent publications suggested that disease, demonstrated angiographically normal carotid arteries in 22% of patients with amaurosis fugax (with or without hemispheric transient ischemic attacks). Since these data were originally collected when the importance of the non-stenotic but ulcerative lesion of the carotid artery had not yet been recognized, we felt that the reported incidence of normal angiographic findings in these patients might be erroneously high.

There was no significant difference in the incidence or types of ulcerations between those patients with amaurosis fugax and those with hemispheric transient ischemic attacks. Eighty-eight percent of arteries examined in this series were amenable to surgical reconstruction. Amaurosis fugax and hemispheric transient ischemic attacks were of equal value in predicting the possibility of a surgically treatable lesion at the carotid bifurcation.

**Methods**

From August 1974 to August 1976, 123 patients underwent carotid angiography at the San Francisco Veterans Administration Hospital for evaluation of hemispheric transient ischemic attacks (93) or amaurosis fugax (with or without hemispheric transient ischemic attacks) (30). Fifteen of 123 had bilateral symptoms, bringing the total number of individual carotid arteries for study to 138.
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