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 Fα (PGFα) and 5-hydroxytryptamine (5HT), which are released from brain tissue and aggregating platelets, have been suggested as possible chemical mediators of spasm.4

Recent advances in prostaglandin research have suggested that arachidonic acid metabolites other than prostaglandin Fα may be involved in the genesis of vasospasm. Prostaglandin cyclic endoperoxides G2 and H2 (PGG2, PGH2), which are intermediates in the formation of prostaglandin E2, Fα and D2 (PGE2, PGFα, PGD2), have also been shown to be the precursors of the very labile thromboxane A2 (TXA2) and its stable metabolite thromboxane B2 (TXB2) (fig. 1). Important, the conversion of PGG2 and PGH2 to the thromboxanes is now known to be the preferential metabolic pathway in platelets, brain, and lung with PGF2α, PGE2 and PGD2 being minor metabolic products.8-10 PGG2, PGH2 and TXA2 are not only released during platelet aggregation, but can induce platelet aggregation.11 

PGG2, PGH2 and TXA2 have been shown to cause contraction of isolated rabbit aortic smooth muscle.5, 11, 12 Recently, we have shown that TXA2 released from aggregating human platelets is capable of inducing contraction of isolated, porcine coronary artery strips.13 The vasoactivity of platelet released TXA2, coupled with the fact that TXA2 is produced by brain tissue, has led us to investigate the effects of TXA2 on cerebral arterial smooth muscle. It was felt that TXA2 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.14 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 spirally 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% O2 - 5% CO2 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 µM) to insure completeness of blockade. This was done to prevent action of any 5-HT released from platelet particles used in the TXA2 generating system. A concentrated stock solution of PGF2α, tromethamine salt (Upjohn Co.) was made by dissolving PGF2α in ethanol. Care was taken that the concentration of ethanol in the artery baths was less than 1 µl per ml. 

Prostaglandin cyclic endoperoxide G2 and H2 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 TXA2. Blood was drawn from normal volunteers who had not had aspirin or other drugs for at least one week. Washed platelets were prepared11 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 TXA2 generating system was started by the addition of 25.5 or 255 mM PGH2 to the baths containing the platelet particles. We have previously shown that this system generates TXA2 by measuring the formation of its stable metabolite, TXB2, in the artery baths.14
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.

Results

Initial studies on vascular smooth muscle showed that contraction of the bovine middle cerebral artery strip produced by the TxA₂ generating system (platelet particles plus 255 nM PGH₂) was at least three times stronger than that of bovine coronary or porcine coronary, renal, or common carotid artery (fig. 2). The contraction produced upon addition of PGH₂ to the platelets in the bath reached a maximum in 9 to 1.5 minutes.

Because the cerebral artery response to TxA₂ was particularly strong, we compared the cerebral artery response to TxA₂ with that of PGF₂α 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 two times that produced by 255 nM PGF₂α 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 PGF₂α (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.
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,14,17 it is of particular interest since it is released by aggregating platelets. White et al.18 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.19 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.18 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 platelets2 and TxB2 is the most abundant arachidonic acid metabolite synthesized by the brain.10 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.

Acknowledgments

This work was supported in part by grant GM-15431 from The National Institutes of Health. Prostaglandins and sheep seminal vesicles were generously provided by J. Pike of The Upjohn Company. Methysergide maleate was provided by Sandoz Pharmaceutical Company.

References

Relationship of Transient Ischemic Attacks and Angiographically Demonstrable Lesions of Carotid Artery

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SUMMARY Eighty-eight percent of arteries in patients with amaurosis fugax or hemispheric transient ischemic attacks had angiographically demonstrable lesions in the carotid bifurcation. Eighty-one percent had stenoses or occlusions at the carotid bifurcation; 7 percent had ulcerative lesions without stenoses at this site. Forty-nine percent of arteries in these patients demonstrated ulcerative lesions with or without stenosis at the carotid bifurcation. 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.

HEMISPHERIC TRANSIENT ischemic attacks and amaurosis fugax have been related to ulcerative and occlusive lesions of both the extracranial and intracranial carotid arterial systems. Recent publications suggested that there is a relatively high occurrence of normal findings on arteriography in patients with well-documented transient ischemic attacks. Lemak and Fields, reviewing the data from the cooperative study on extracranial arterial occlusive disease, demonstrated angiographically normal carotid arteries in 22% of patients with amaurosis fugax (with or without hemispheric transient ischemic attacks) and in 43% of patients with hemispheric transient ischemic attacks alone. 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.

The purpose of this communication is to review our series of patients with hemispheric transient ischemic attacks and amaurosis fugax with regard to (a) the incidence and types of arteriographically-identifiable lesions of the appropriate carotid artery and, as a corollary, (b) the incidence of lesions potentially correctable by surgical intervention.

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.


6. White RP, Morgan H, Robertson JT: Cerebrovascular effects of ulcers and ulcerative lesions of the carotid artery and, as a corollary, (b) the incidence of lesions potentially correctable by surgical intervention.


Cerebral arterial smooth muscle contraction by thromboxane A2.
E F Ellis, A S Nies and J A Oates

Stroke. 1977;8:480-483
doi: 10.1161/01.STR.8.4.480

Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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