Inhibition of Thromboxane A2 Production Does Not Improve Post-Ischemic Brain Hypoperfusion in the Dog

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SUMMARY In a canine model of global brain ischemia, six dogs received a selective thromboxane A2 synthetase inhibitor, UK 38,485 (dazmagrel) before the ischemic event; six received a saline placebo. Cerebral blood flow (CBF), systolic and diastolic arterial pressure, cardiac output, pH, PaCO2, PaO2, and arterial and jugular-vein thromboxane B2 (a stable metabolite of thromboxane A2) and 6-keto PGF1α (a stable metabolite of prostacyclin) were measured at baseline, after release of aortic and venae caval occlusion and at intervals up to 120 min thereafter. Treated animals showed nearly complete post-ischemic inhibition of thromboxane B2 production; control animals showed increases in jugular venous thromboxane B2. Arterial and jugular venous levels of 6-keto PGF1α were significantly higher in treated animals at most post-ischemic intervals. CBF in both groups was similar to baseline values at time 0, then declined similarly in both groups by 30 min to ≈35% of baseline values where it remained thereafter. There were no significant differences in other variables at any interval. We conclude that inhibition of thromboxane A2 production does not alter post-ischemic brain hypoperfusion.

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A right femoral arterial catheter was placed percutaneously and connected, via a Statham P-23Db transducer, to a Grass model 79D oscillograph. A 7.5 Fr pulmonary artery catheter was pass percutaneously through the right external jugular vein using the Seldinger technique. A left external jugular catheter was passed in a retrograde direction (i.e., cephalad) until resistance was encountered, at which time the catheter was withdrawn 2.0 mm and secured. The animal was then placed in the left lateral decubitus position and a thoracotomy performed in the fifth interspace. The azygos vein was isolated and ligated. The superior and inferior venae cavae were dissected free and snares were passed circumferentially and loosely secured. The pericardium was incised and umbilical tape was passed circumferentially around the aorta at a point immediately proximal to the origin of the brachiocephalic artery. The thoracotomy wound was loosely approximated and the animal was turned to the prone sphinx position. The temporalis muscles were dissected from the cranium using a periosteal elevator. A cadmium telluride gamma detector was placed over each posterior parietal area.

Data Collected
The following data were collected at intervals to be specified below: cerebral blood flow (CBF), PaCO₂, systolic and diastolic arterial pressure, cardiac output, pH, PaCO₂, PaO₂, central venous pressure, and heart rate. Blood samples were collected from the jugular vein and the systemic arterial catheter for radioimmunoassay of TxB₂ and 6-keto PGF₁α, the stable metabolites of TxA₂ and PGI₁, respectively.

Sampling Intervals
Baseline data were collected after the animal had been surgically prepared and halothane had been discontinued for 30 min, during which time the animal was ventilated with a 60:40 mixture of nitrous oxide and oxygen. Immediately after collection of baseline systemic hemodynamic and CBF data, the animal was then assigned to 1 of 2 groups: control animals (n = 6) received 5.0 ml of saline intravenously; treated animals (n = 6) received 1.5 ml/kg of UK 38,485 intravenously through a peripheral catheter. No other resuscitative drugs were administered. Follow- ing occlusion, ventilation was varied to maintain PaCO₂ between 35 and 45 mm Hg and PaO₂ greater than 80 mm Hg; pH was permitted to vary, i.e., no further NaHCO₃ was administered. Hemodynamic and CBF data were collected at time 0 (immediately after release of occlusion) and at times 30, 60, 90, and 120 min following release of occlusion. Blood samples were obtained for determination of TxB₂ and 6-keto PGF₁α at time 0 and at times 10, 30, and 60 min.

Cerebral Blood Flow Measurements
All CBF measurements were performed using ¹³⁷Xe- nон, dissolved in sterile saline and injected rapidly intravenously in a dose of 5.0 mCi. CBF was calculated from the clearance curve recorded by each gamma detector using the initial slope index method.¹⁹ The CBF data were displayed on a portable CBF computer with a colorgraphic display during accumulation to eliminate atypical Xenon clearance curves. Data were stored in a Vax 730 computer for later analysis.

Radioimmunoassay Techniques
Simultaneous 4.0-ml samples of blood were withdrawn from the aortic and jugular-vein catheters into sterile disposable syringes and immediately transferred to test tubes containing 0.5% EDTA and indomethacin (25 µg/ml whole blood) and maintained on ice at 4°C until centrifuged at 1500 g for 15 min. The plasma was aspirated and placed in polypropylene test tubes, which were then labelled and stored at -20°C. Immunoreactive TxB₂ and immunoreactive 6-keto PGF₁α were assayed directly in plasma by standard double-antibody radioimmunoassay techniques.²⁰, ²¹ Cross reactivities and sensitivity limits of these antibodies and reagent sources have been described.²⁰

Statistical Methods
All data were analyzed by the SAS statistical program using analysis of variance of repeated measures. Individual differences between groups for the primary variables TxB₂, 6-keto PGF₁α and CBF were confirmed using the Student's t-test: One-tailed tests were applied to comparisons of TxB₂ levels between groups; all other tests were two-tailed.

Results
In control animals, immunoreactive TxB₂, measured in jugular venous blood was increased following release of aortocaval occlusion and was still increased at time 60 min post-ischemia (fig. 1). In contrast, treated animals had no increase in immunoreactive TxB₂ levels in jugular venous blood, and the difference between jugular venous TxB₂ levels in the two groups was significant at all intervals following occlusion. Arterial levels of TxB₂ tended to be lower than jugular venous levels in control animals at all time intervals (table 1). In contrast, arterial levels of TxB₂ in treated animals were similar to baseline at time 0 and progressively decreased thereafter. At no interval were arterial levels significantly different from jugular venous levels in treated animals.

Immunoreactive 6-keto PGF₁α levels in jugular venous blood increased in control animals following release of aortic occlusion (fig. 2). In treated animals, levels were higher than in control animals at times 0, 10, 30, and 60 min post-ischemia, and those differences attained statistical significance at times 0 and 10 min. Arterial levels of immunoreactive 6-keto PGF₁α were significantly higher in treated animals than in control animals at all intervals following release of occlusion. There were no significant differences between arterial
and jugular venous levels of 6-keto PGF₁α within either group at any time interval.

Systolic and diastolic blood pressure, PaCO₂, cardiac output, central venous pressure, and heart rate were similar in both groups of animals at all intervals before and after release of occlusion. Systolic and diastolic blood pressures quickly returned to control levels in all animals, usually within 60 sec following release of the aortocaval occlusion. PaO₂ was similar in both groups at all intervals and consistently exceeded 80 mm Hg in all animals. pH ranged from 7.20 to 7.42 following occlusion and was similar between groups.

CBF (fig. 3) was similar to baseline in both groups immediately after release of occlusion; it then decreased to levels approximately 35% of baseline values at times 30, 60, and 120 min. There were no significant differences between the groups.

**Discussion**

The canine model of global cerebral ischemia has been used extensively to test the ability of pharmacologic agents to modify post-ischemic hypoperfusion and to protect against post-ischemic neuronal damage. The model used in this study differs in several respects from previously reported models in other studies. First, we ligated the azygos vein before reversibly occluding the superior and inferior venae cavae and aorta. Second, by using pulmonary artery pressure measurements to adjust filling of the cardiopulmonary circuit during the period of systemic ischemia, we avoided excessive cardiac dilatation during the course of the occlusion and presumably preserved stable coronary artery filling pressures by maintaining adequate preload. Third, we measured CBF by measuring the clearance of 133Xenon. Since measurement of CBF by this technique requires at least 10 min of data collection, we did not detect the transient post-ischemic hyperemia that had been reported by other investigators.

We measured jugular venous levels of immunoreactive arachidonate metabolites rather than levels in the sagittal sinus or at the confluence of the sagittal and lateral sinuses because we found in preliminary experi-

**Table 1 Changes in Hemodynamic Variables and Arterial Levels of TxB₂ and 6-keto PGF₁α (means ± SEM)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Baseline</th>
<th>0 min</th>
<th>10 min</th>
<th>30 min</th>
<th>60 min</th>
<th>120 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial TxB₂ (ng/ml plasma)</td>
<td>1 0.62±0.10</td>
<td>1.42±0.48</td>
<td>1.60±0.20*</td>
<td>2.71±0.83†</td>
<td>2.14±0.49†</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>2 1.32±0.65</td>
<td>1.50±0.64</td>
<td>0.35±0.13</td>
<td>0.30±0.08</td>
<td>0.27±0.13</td>
<td>—</td>
</tr>
<tr>
<td>Arterial 6-keto PGF₁α (ng/ml plasma)</td>
<td>1 0.10±0.02</td>
<td>0.68±0.05</td>
<td>0.54±0.11</td>
<td>0.30±0.09</td>
<td>0.16±0.05</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>2 0.18±0.04</td>
<td>1.04±0.09†</td>
<td>0.84±0.11†</td>
<td>0.66±0.14†</td>
<td>0.49±0.16†</td>
<td>—</td>
</tr>
<tr>
<td>Systolic BP (mm Hg)</td>
<td>1 125±12</td>
<td>127±10.0</td>
<td>—</td>
<td>109±6.7</td>
<td>119±7.3</td>
<td>133±13.9</td>
</tr>
<tr>
<td></td>
<td>2 133±9.0</td>
<td>127±10.0</td>
<td>—</td>
<td>117±6.7</td>
<td>129±6.8</td>
<td>154±11.0</td>
</tr>
<tr>
<td>Diastolic BP (mm Hg)</td>
<td>1 75±9.6</td>
<td>79±5.4</td>
<td>—</td>
<td>70±3.7</td>
<td>76±4.8</td>
<td>97±10.1</td>
</tr>
<tr>
<td></td>
<td>2 84±7.7</td>
<td>84±6.5</td>
<td>—</td>
<td>71±5.5</td>
<td>83±5.4</td>
<td>96±4.7</td>
</tr>
<tr>
<td>PaCO₂ (mm Hg)</td>
<td>1 39.8±1.7</td>
<td>49.3±3.1</td>
<td>—</td>
<td>38.4±1.9</td>
<td>43.5±1.6</td>
<td>36.0±2.0</td>
</tr>
<tr>
<td></td>
<td>2 37.2±3.1</td>
<td>40.1±3.9</td>
<td>—</td>
<td>38.8±4.2</td>
<td>39.8±3.6</td>
<td>44.0±6.6</td>
</tr>
<tr>
<td>Cardiac output (L/min)</td>
<td>1 2.6±0.3</td>
<td>2.4±0.3</td>
<td>—</td>
<td>1.8±0.2</td>
<td>1.9±0.2</td>
<td>2.1±0.1</td>
</tr>
<tr>
<td></td>
<td>2 2.3±0.2</td>
<td>2.0±0.1</td>
<td>—</td>
<td>1.7±0.1</td>
<td>2.0±0.2</td>
<td>1.9±0.5</td>
</tr>
<tr>
<td>CVP (mm Hg)</td>
<td>1 10.5±4.9</td>
<td>9.5±3.8</td>
<td>—</td>
<td>5.7±1.3</td>
<td>4.5±1.0</td>
<td>8.0±2.1</td>
</tr>
<tr>
<td></td>
<td>2 6.7±1.4</td>
<td>9.7±2.4</td>
<td>—</td>
<td>3.7±0.6</td>
<td>6.3±1.1</td>
<td>10.2±3.5</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>1 144±9.1</td>
<td>134±13.9</td>
<td>—</td>
<td>151±16.1</td>
<td>145±13.8</td>
<td>160±17.2</td>
</tr>
<tr>
<td></td>
<td>2 150±17.3</td>
<td>140±9.5</td>
<td>—</td>
<td>140±14.1</td>
<td>149±10.7</td>
<td>127±19.8</td>
</tr>
</tbody>
</table>

Group 1 = control; Group 2 = UK 38,485. *p < 0.001; †p < 0.05; ‡p < 0.01, all Group 1 versus Group 2.
ments that the combination of heparin, used to prevent clotting in the sagittal sinus, and UK 38,485 produced uncontrollable bleeding from the cranial dissection site. Consequently, although the majority of canine CBF drains through the external jugular vein, there may have been extracerebral contamination of our jugular venous samples. In addition, the baseline levels of TxB2 were somewhat elevated, probably reflecting the release of TxA2, that accompanies vascular catheterization. We have no explanation for the small differences between groups in baseline levels of TxB2 and 6-keto PGF1α, although we speculate that variability may have reflected catheter-induced activation.

These data suggest that TxA2 and PGF1α are released in large quantities following global cerebral ischemia, and that the release of TxA2 may be greater from the cerebral than from the systemic circulation. However, they do not examine the question of the origin, i.e., blood vessel or brain tissue, of the increased plasma levels of TxB2 and 6-keto PGF1α. We speculate that the origin is the vessel wall or intraluminal cellular elements. Thus, plasma measurements of the circulating vasoactive compounds may be more pertinent to a study of the hypoperfusion state than would be tissue levels.

Further, these data suggest that inhibiting the conversion of cyclic endoperoxides to TxA2 increases the synthesis of PGF1α in post-ischemic blood vessels. These findings are consistent with those in the study of Maguire and Wallis in rats, but in our study inhibition of the synthesis of TxA2 did not modify the state of cerebral hypoperfusion seen following global ischemia. Failure of thromboxane synthetase inhibition to improve perfusion is consistent with data in cats treated with UK 38,485 before and after an acute focal cerebral ischemic lesion, and with those in a rabbit model of global cerebral ischemia. Logically, inhibiting the production of a potent cerebral vasoconstrictor in conjunction with increasing synthesis of a potent cerebral vasodilator should improve cerebral blood flow in the post-ischemic period.

On first examination, the failure of thromboxane synthetase inhibition to improve CBF in this model suggests 1) that TxA2 is not an important factor in the production of the global hypoperfusion seen after global cerebral ischemia, and 2) that further increases in physiologic levels of prostacyclin produced by the inhibition of thromboxane synthetase are insufficient to dilate the cerebral vessels. These data appear to contradict those from the study of Hallenbeck et al. in which the administration of indomethacin (which would inhibit production of both TxA2 and PGF1α) in conjunction with the intravenous infusion of PGF1α ameliorated post-ischemic cerebral hypoperfusion. It is possible that the pharmacologic doses of prostacyclin used in that study produced levels in the cerebral vessels that were greater than those produced in our study.

However, cyclo-oxygenase inhibition would also decrease other potential vasoconstricting products of the cyclo-oxygenase pathway. In fact, a possible explanation for the failure of thromboxane synthetase inhibition to ameliorate post-ischemic hypoperfusion may be that inhibition of thromboxane synthesis not only redirects arachidonate metabolism toward the production of PGF1α but also increases the amount of substrate available for metabolism to other eicosanoids. The substrata for thromboxane synthetase, the cyclic prostaglandin endoperoxides, also cause vasocostriction and platelet aggregation. Accumulation of cyclic endoperoxides may explain the surprisingly limited effect of thromboxane synthetase in this as in other studies. Antagonists of thromboxane and cyclic endoperoxide receptors may produce more useful pharmacologic effects than inhibitors of thromboxane synthesis. In addition, just as the quantity of the prostacyclin metabolite present in jugular venous blood increased following inhibition of thromboxane synthetase, it is possible that lipoxigenase products were similarly increased. The role, if any, of lipoxigenase-derived metabolites of arachidonate has not been well characterized in the post-ischemic state.

Another possible explanation for the failure of thromboxane synthetase inhibition to ameliorate post-ischemic cerebral vasoconstriction may be that increased levels of TxA2 are not an etiologic component of post-ischemic cerebral hypoperfusion. Further studies are necessary to determine whether other interventions, such as nimodipine, which clearly increase CBF following global cerebral ischemia, are associated with decreased cerebral venous release of TxB2. The release of TxB2 and 6-keto PGF1α may serve as useful markers of the extent of vascular injury following global cerebral ischemia.

In summary, inhibiting the production of TxA2 failed to alter the marked reduction in CBF that followed a 10-min period of global cerebral ischemia in dogs. Cerebral blood flow remained low despite evidence of markedly decreased production of TxA2 and reciprocally increased production of PGF1α.

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References

FIGURE 3. Cerebral blood flow in dogs after 10 minutes of aortocaval occlusion.
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