Influence of Multiple Vessel Impairment on Carotid Blood Flow in the Monkey*

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One important factor when considering a patient for carotid endarterectomy is the percentage of constriction as determined by arteriography. Mann, et al., reported in 1938 that it is necessary to reduce the diameter of the lumen of an artery by 70% or the cross-sectional area by 90% before a 50% reduction in blood flow occurs. Tindall, et al., demonstrated that a 90.5% reduction in the cross-sectional area of the human common carotid was necessary before a significant reduction of flow or blood pressure occurred.

In our experience, patients have shown transient ischemic attacks with less than 70% reduction in diameter of the internal carotid artery. These attacks could have been caused by emboli arising from the atheromatous plaque as has been suggested by De Bakey. Another factor that may have influenced the onset of the attacks was the presence of lesions in more than one neck vessel. Gurdjian and Thomas have stressed the importance of multiple vessel disease in patients with cerebral ischemia. We noted lesions in more than one neck vessel in some patients who had less than 70% occlusion of the appropriate vessel. To compare the effect of a carotid constriction when the collateral arteries are open with that when they are compromised, we performed the following experiment.

Method

Ten large stump-tail macaque monkeys were used for this study. The animals were tranquilized with Sernylan† and then given intravenous sodium pentobarbital. A tracheostomy was performed and breathing was controlled with a Bird respirator. The femoral artery was cannulated, and constant blood pressure recordings were made using a Statham strain gauge. Through a midline incision, both carotid and both vertebral arteries were clearly exposed (Fig. 1). A Medicor flow probe was placed around the left carotid artery, and the carotid flow and blood pressure measurements were recorded using a Honeywell Visicorder. After obtaining the flow base line, the left carotid was occluded in measured increments with a modified Crutchfield clamp. In each animal several recordings of the flow rate with gradual occlusion of the artery were made (Fig. 2 left).

In the next phase of the study, the opposite carotid and both vertebral arteries were occluded with nontraumatic clamps. The remaining artery was then occluded by the same increments while its blood flow was

![Fig. 1. Operative exposure used in this experiment. Both carotid and both vertebral arteries are available for study.](image-url)
measured (Fig. 2 right). The carotid blood flow rates with the collateral vessels occluded were compared to the flow rates when the collateral vessels were patent. More than 90 observations were made on the 10 monkeys, and the results were averaged and plotted (Fig. 3). Further studies were obtained with the collateral arteries partially occluded instead of completely occluded. Thus, comparison was made between the effect of a carotid constriction when the collateral arteries were open and when they were totally or partially occluded.

**Results**

The average flow rate in the common carotid artery before constriction was 38 ml per min. The flow in the left carotid artery increased as the opposite carotid and each vertebral artery were occluded in succession. The average increase was to a level of 160% of the value with the collaterals open.
With the collaterals open, it was necessary to constrict the diameter by 70% or the cross-sectional area by 90% before a significant reduction in blood flow occurred (Fig. 3). After the opposite carotid and both vertebral arteries were occluded, reduction of the diameter of the left carotid by only 60% produced a significant reduction in blood flow to the brain. There was a greater flow rate in the remaining carotid at all degrees of constriction (Fig. 3). At the higher levels of constriction, however, the percentage of reduction in flow rate was usually greater when the collaterals were occluded than when they were patent. As the last artery approached total occlusion, the brain became hypoxic and there was a consistent rise in systemic blood pressure (Fig. 2 right). The blood pressure rise probably influenced the blood flow at these late stages of the occlusion.

Discussion

It is difficult to forecast by arteriography the effect of a carotid stricture on blood flow. A good method to determine the effect of the constriction is to measure carefully the pressure drop across the constriction. Another method is to measure the blood flow before and after removal of the stricture. Both methods require exposure of the carotid artery and cannot be used in evaluating a patient preoperatively. The amount of constriction seen on arteriography remains one of the most important practical preoperative tests when considering a patient for endarterectomy.

There is general agreement that the lumen diameter reduction must be 70%, or the area reduction at least 90%, before a significant flow reduction occurs.\textsuperscript{1,4,6,7,8} The diameter reduction of 70% is essentially equivalent to an area reduction of 90% because the area varies as the square of the radius. Constricting the collateral circulation results in an immediate compensatory increase in flow in the remaining patent vessel in both animals and man.\textsuperscript{5,8} This increase in flow is secondary to the drop in pressure in the distal arteriolar and capillary bed, causing a greater difference between the systemic blood pressure and the capillary bed pressure. As demonstrated in Fig. 3, at the higher levels of constriction there is a greater percentage reduction in flow rate with the collaterals occluded than with the collaterals open. One reason why a stricture is more significant with an increased flow rate is because the energy lost due to turbulence increases rapidly as the flow rate increases. It is also important to note that occlusion of the collaterals results in a reduction in total blood flow to the brain, whereas the flow reduction with the collaterals open concerns only one of the four cervical arteries.

As mentioned by Shipley and Gregg,\textsuperscript{7} the length of the stricture is also of great importance when considering the effect on blood flow. Since flow through a vessel of any length varies as the radius to the fourth power, a reduction in arterial size to one-half would reduce flow through the artery to one-sixteenth of the previous flow. Thus, a stricture of great length would have a more profound effect on the blood flow than a short one.

The results of this study have influenced our evaluation of patients for carotid endarterectomy. The patient must have appropriate neurological symptoms; however, when interpreting the arteriogram we do not believe that it is always necessary to have a reduction in diameter of 70% as a criterion for operation. We now give added weight to the presence of disease in the collateral vessels and to the length of the plaque. In some instances we operate when there is less than a 70% constriction, provided the patient has the appropriate symptoms and other conditions are present, such as disease of the collateral vessels or an unusually long plaque.

Summary

The effect of carotid constriction on blood flow in monkeys with and without compromising the collateral arteries was studied. It appeared that a given amount of constriction had a greater effect on the blood flow when the collateral vessels were compromised than when they were patent.

References


