Arterial Clamp for More Gradual Blood Flow Reduction

Technical Note

GLENN W. KINDT, M.D.

Department of Neurosurgery, University of California School of Medicine, Davis, California

Gradual occlusion of the common or the internal carotid artery is an accepted method of therapy for certain patients with intracranial aneurysms. The goal of the gradual occlusion is to allow progressive development of a collateral circulation during the occlusion. A common procedure is to tighten the occluding clamp one turn, or part of a turn, daily until the artery is totally occluded. Occasionally, there are no symptoms until the last turn of the clamp, following which a sudden and severe neurological deficit develops.

The reason for the precipitous neurological deficit is the sudden decrease in blood flow rate during the last increment of arterial occlusion. As noted by Mann, et al., in 1938, there is little or no change in blood flow through an artery until a marked and critical level of stenosis is reached. Thereafter, further reduction in lumen size rapidly reduces blood flow and distal blood pressure. Tindall, et al., have shown that there is no reduction in common carotid artery flow or distal blood pressure until the area of the lumen of the vessel is decreased by 90.5% or until the last turn of a Crutchfield clamp. Thus, if the clamp is turned gradually each day, there is no stimulus for development of collateral circulation until the last turn is made, and the situation is the same as it would have been had the artery been occluded acutely.

Surgeons, who have recognized that it is only the last turn of the clamp which is important, have turned the clamp down more rapidly during the initial stage and used only small fractions of a turn during the late stage of occlusion. With this method of occlusion there remains the difficulty of estimating by turning the clamp when arterial flow first reaches zero. Zero flow cannot be easily estimated since it is reached at an indefinite point before resistance is felt as the clamp is tightened.

The problem of the sudden drop in blood flow produced by the presently available clamps was studied with the goal of developing a method for more gradual reduction in blood flow.

Materials and Method

Sixteen dogs were anesthetized with phenobarbital, and their abdominal aortas were exposed. The branches of the abdominal aorta between the renal arteries and the aortic bifurcation were ligated and divided. An electromagnetic flow probe was placed around the aorta immediately distal to the renal arteries. Systemic blood pressure was recorded by cannulating the right subclavian artery. Pressure below the stricture was measured through a cannula in the right femoral artery. The arterial pressures and blood flow were recorded with a Honeywell Visicorder.

Arterial clamps were then placed around the aorta and slowly tightened by measured increments while the systemic and distal arterial pressures and aortic blood flow were measured. Clamps described by Crutchfield, Silverstone and White, and some specially constructed clamps (Fig. 1) were used. The effect on blood flow and distal arterial pressure was determined during increments of occlusion using the various clamps.

Results

No significant decrease in blood flow occurred using the Crutchfield or the Silverstone clamp until the area of the arterial lumen was decreased by an average of 94.25%. Further encroachment of the lumen area resulted in a rapid decrease in blood flow. The solid line in Fig. 2 demonstrates the effect on flow of a gradual reduction of lumen area. The dotted line represents the equivalent diameter reduction which was calculated from the curve for area.

When clamps shown in Fig. 1 were used, the flow again did not decrease until the lumen area approached 95% reduction.
However, a marked difference in the flow pattern occurred as the clamp was turned. When the Crutchfield clamp was used, the last 5.75% reduction in area which reduced flow from 100% to 0% was brought about by one-half turn of the clamp. When the clamps shown in Fig. 1 were used, the flow reduction occurred over more than two complete turns of the clamp. Thus, there was a more gradual reduction in flow as the clamp was tightened.

**Discussion**

The arterial clamps presently in common use will reduce the cross-sectional area of the lumen of an artery linearly as the clamp is tightened. When the artery is of sufficient size to fill the clamp, the arterial lumen is forced by the clamp into essentially a rectangular shape. The linear reduction of one dimension of a rectangle is a linear reduction in area. Thus, each turn of the clamp produces an equal reduction in lumen area.

The difficulty with a clamp which produces a linear reduction in area is that there is no reduction in flow during most of the turns of the clamp but then a marked reduction in flow during the last turn of the clamp. The solid line in Fig. 2 represents the flow pattern during a linear area reduction. With no reduction in flow or distal arterial pressure until the last one-half turn, this clamp is often ineffective in producing the collateral circulation which is the goal of gradual arterial occlusion.

A clamp designed to vary the diameter or the circumference of an artery linearly with each turn of the clamp is more satisfactory than linear reduction of area for gradual arterial occlusion. The dotted line of Fig. 2 is the pattern of reduction of flow with linear diameter reduction. The area of the lumen of an artery varies as the square of its diameter. Assuming that there are 10 turns of a clamp which reduces the diameter linearly, the first turn, which reduces the diameter 10% would reduce the area: $1^2 - 0.9^2 = 0.19 = 19\%$. The last turn of such a clamp, 

![Fig. 1. Arterial clamps which reduce the equivalent diameter of the lumen linearly with each turn of the clamp.](image)

![Fig. 2. A composite graph of the data obtained during gradual occlusion of the aortas of dogs. The flow rate for a clamp which reduces the area linearly follows the solid line, and the flow rate when using a clamp which reduces the diameter linearly follows the dotted line.](image)
which would obliterate the last 10% of the diameter, would obliterate only $0.1^2 - 0^2 = 0.01 = 1\%$ of the area. Thus, the latter part of the occlusion is more gradual than the earlier part. This is exactly what is required during arterial occlusion, since because of fluid flow characteristics, it is only during the last part of the occlusion that flow is affected.

Several types of clamps can be made which reduce the diameter or the circumference linearly. The clamps shown in Fig. 1 are examples which do occlude the equivalent diameter linearly. These clamps were tested and the flow pattern for occlusion was proven to be similar to the dotted line in Fig. 2. A linear circumference reduction can be produced by using the principle of the simple radiator hose clamp. Further refining of the clamps shown in Fig. 1 has been done to make a safe clamp available for human use.

**Summary**

When the area of an arterial lumen is decreased linearly, there is no change in blood flow until the lumen is markedly constricted. Any further reduction in area beyond this critical level of stenosis produces a precipitous fall in blood flow.

The clamps currently used for gradual arterial occlusion work on the principle of linear area reduction. Because flow is reduced only during the last turn of the clamp, there is often no stimulus for development of collateral blood flow and there is the danger of producing a neurological deficit.

Clamps have been developed during this study which reduce the diameter linearly instead of the area. These clamps when tested produced a more gradual flow reduction.

**Acknowledgments**

The author wishes to acknowledge the technical assistance of Robert Drew and Paul Willard of the Department of Engineering, University of California, Davis, who constructed the clamps used for this project.

**References**