Dynamics of the Collateral Circulation in Patients with Subclavian Steal

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WHEN the proximal portion of the subclavian artery is occluded, numerous anastomotic vessels in the neck and chest wall are available to maintain the circulation to the arm. Another collateral pathway, consisting of both vertebral arteries, has recently created much interest. Contorni showed, by the use of selective arteriography, that dye passed up the right vertebral artery to its junction with the basilar artery and then down the left vertebral artery to enter the left subclavian artery distal to its site of occlusion. Reivich et al. confirmed and amplified this observation. The term "subclavian steal" was introduced by the New England Journal of Medicine and has been widely adopted, since it is succinct and euphonious. Numerous subsequent reports have described clinical, radiologic, and surgical aspects of the condition and it has also been the subject of a recent symposium.

Since the procedure of arteriography per se may result in local hemodynamic changes, the need for caution in assessing the significance of reversed vertebral flow has properly been stressed. The purpose of this study was to confirm, by the use of an alternative technic, the authenticity of the radiographic appearances that form the basis for the diagnosis of the subclavian steal.

Case Reports

Two patients were selected for study from a total of 12 in whom we have demonstrated, by selective arteriography, the occurrence of retrograde flow in a vertebral artery secondary to proximal occlusion of the ipsilateral subclavian (or innominate) artery.

Case 1

A 54-year-old man complained of the sudden onset of pain and blueness of the right foot. No pulses were palpable in the lower limbs. An abdominal aortogram showed complete occlusion below the level of the renal arteries; there was also segmental occlusion of the left superficial femoral artery with well-developed collateral vessels, and occlusion of the right anterior tibial artery. Treatment consisted of thrombectomy of the terminal aorta, both common and external iliac arteries, and both common femoral arteries; part of the left iliac system was replaced with a Dacron prosthesis. Subsequently, the circulation to both lower limbs was greatly improved, although claudication in the right calf continued.

In addition to these problems a delayed and diminished pulse in the left arm was noted, but there were no symptoms suggestive of cerebrovascular ischemia on exercise of this arm.

Special Brachiocephalic Studies

Right retrobrachial arteriography showed stenosis at the origin of the right vertebral artery, good filling of this artery, and reversed flow in the left vertebral artery (fig. 1) with subsequent filling of the distal left subclavian artery. Occlusion of the left subclavian artery at its origin was later confirmed by injecting dye into the aortic arch. There was only a slight decrease in systolic blood pressure in the brachial artery of the affected arm, but the pulse was delayed and damped (fig. 2). An indicator-dilution curve was obtained by sampling from the left brachial artery at 40 ml per minute following injection by hand into the innominate artery of 5 mg. cardio-green dye dissolved in 1 ml. of water. The indicator appeared in about 6 seconds, reached maximal concentration in about 9 seconds, and almost completely cleared prior to the onset of "recirculation" (fig. 3). This demonstration of a short circuit between the innominate and the distal left subclavian arteries confirmed the authenticity of the radiographic findings.

Case 2

A 46-year-old man complained of intermittent claudication for 4 years and of numbness of the left hand and arm. The numbness was worse during exercise of the arm and was associated with blurring of vision of the left eye and occasionally with circumoral numbness. The left arm tired easily. The
blood pressure was 145/85 mm. Hg (right arm) and 90/70 mm. Hg (left arm). The left brachial pulse was weak and delayed. Both femoral pulses were weak and bruits were heard over each. No distal pulses were felt in the left lower limb. Arteriograms showed multiple areas of stenosis in major vessels: the left common iliac artery was severely diseased; there was moderate atherosclerosis of the right common iliac artery; there were severe stenosis at the origin of the right internal carotid artery, stenosis of the left internal carotid artery, and moderately severe stenosis at the origin of the right subclavian artery; the proximal part of the left subclavian artery was occluded, and the distal part of this vessel filled by means of reversed flow down the left vertebral artery.

Special Brachiophalic Studies

An Odman-Ledin catheter, which had been advanced to the aortic arch via percutaneous puncture of the right femoral artery in order to obtain contrast films of the brachiophalic vessels, was advanced for a short distance into the left common carotid artery. A cardiac catheter was introduced to an arm vein by percutaneous puncture and placed with its tip in the low superior vena cava. A 19-gage Mayo arterial needle was placed in the left

Figure 1

Right retrobrachial arteriogram in patient (case 1) with occlusion of proximal portion of left subclavian artery. Left. Good filling of right vertebral artery, which is large. Center (2/3 second later). Reversed flow in left vertebral artery. Right (2/3 second later). Contrast medium persists in left vertebral artery.

Figure 2

Pressure pulses from aortic arch (above) and left brachial artery (below) in case 1. Note the delay and damping in the latter pulse. Calibrations for the aortic arch are on the left and for the brachial artery on the right.

Figure 3

Indicator-dilution curve obtained from left brachial artery after injection of cardio-green dye into the innominate artery (injection time marked by arrow). The rapid appearance time (6 seconds) and peak concentration (9 seconds) were due to shunting of the dye via the collateral vertebral circulation shown in figure 1.
Figure 4

Indicator-dilution curves obtained from the left brachial artery in case 2 following injection into the superior vena cava (A), the left carotid artery (B), and the left carotid artery (C) during a period of intense reactive hyperemia in the left arm.

The brachial artery. Indicator-dilution curves were obtained by sampling from the left brachial artery at 15 ml per minute.

Following injection of 5 mg of cardio-green dye into the superior vena cava, dye appeared at the brachial artery in 12 seconds (fig. 4A). Following injection into the left carotid artery, dye appeared in 22 seconds (fig. 4B). The difference of 10 seconds in these appearance times must have been due to the transit from the carotid artery through the brain and back via the jugular veins to the superior vena cava. A sphygmomanometer cuff was then placed around the left arm, and pressure was maintained at 200 mm Hg for 10 minutes. Simultaneously with its sudden release dye was again injected into the left carotid artery and a dilution curve was recorded (fig. 4C). A fraction of the dye now appeared in 6 seconds, i.e., 16 seconds faster than on the previous occasion, whereas the remainder began to appear 17 seconds after injection.

Discussion

The hitherto unsuspected fact that, in certain circumstances, the arm may deprive the brain of part of its blood supply,28 has been responsible for the unusual interest in the subclavian steal syndrome. The belief that such diversion of blood may occur is based mainly on radiographic observations, which have now been amply documented.1-23

Caution in Interpreting Angiograms

There is a need for caution, however, in the interpretation of the direction of flow in blood vessels demonstrated by selective angiography. Artifacts may occur, due either to the mechanics of the injection or to the chemical properties of the radiopaque dye. Contrast dyes are often injected in large volumes and under high pressures into relatively small blood vessels; further, since they are hypertonic solutions,29 they are highly vasoactive.30 Therefore, the angiographic demonstration of dispersal of contrast medium in a certain direction does not invariably guarantee that blood flows thus in normal circumstances. For example, Gonzalez and his associates25 and Shockman26 have recently shown that dye injected into one vertebral artery may pass up to the basilar artery and down the opposite vertebral artery in patients who are ultimately shown to have no abnormality whatsoever of the brachiocephalic circulation. Curry and Howland27 pointed out that "... overzealous efforts to identify this newly recognized entity may have resulted in the reporting of some cases which are not true subclavian steals ... this is particularly true when the entity is established by roentgenologic studies limited to a unilateral retrograde brachial arterial study."

The present investigation was therefore undertaken in order to confirm, by a different method, that blood may flow in a retrograde fashion down the vertebral artery to perfuse the subclavian artery distal to its site of obstruction.

Use of Indicator-Dilution Curves (Case 1)

The injection for the indicator-dilution curve shown in figure 3 differed from that for the angiograms in that it was made by hand, the total volume was 1 ml, the solution was aqueous, and cardio-green dye has no vasoactive properties. Therefore the possibility of artifactual appearances due to mechanical or chemical effects of the injection could be excluded. Figure 3 demonstrated conclusively that an arterial short circuit must exist in case 1 between the innominate and left brachial
arteries even when the left arm is at rest, since dye appeared in the left brachial artery 6 seconds after its injection into the innominate artery. In a person with a normal brachiocephalic circulation, dye could not have appeared until it had circulated through the brain (or right arm), returned to the right side of the heart, circulated through the lungs, and then passed via the aorta to the brachial artery. This would take 20 to 30 seconds. Thus, the dilution curve confirmed the authenticity of the angiograms.

Stimuli Increasing the Demand of the Upper Limb for Blood

Since in most persons there is a potential communication via the circle of Willis between the cerebral and the vertebral-basilar circulations, it appeared possible that, in the presence of an unusual demand by the affected arm, blood might be drained backwards from the carotid as well as from the vertebral circulation. To test this hypothesis, circumstances were sought in which retrograde perfusion of an affected subclavian artery was likely to be maximal.

The requirement of the resting upper limb for blood is small, the total arterial flow (100 to 200 ml. per minute) being only a small fraction of the cephalic blood flow. Moderate exercise, however, increases the blood flow through skeletal muscle by 10-fold or more. Therefore, when a normal arm is exercised, its arterial inflow can very readily exceed the total cephalic blood flow. During reactive hyperemia induced by sudden release of a blood pressure cuff previously inflated around the upper arm to 200 mm. Hg for 10 minutes, the blood flow through the limb for several seconds is even greater than that during exercise. This is a simple and reproducible procedure, and we used it in our studies in case 2 in order to provide the situation in which retrograde flow was most likely to be demonstrable.

Use of Indicator-Dilution Curves (Case 2)

When the injection was made into the left carotid artery with the left arm at rest, dye was not detected in the left brachial artery until 22 seconds had elapsed. Thus, no short circuit existed between the carotid and the distal subclavian artery. The injection was then repeated simultaneously with the release of an arterial occlusion cuff around the left arm. A fraction of the injected dye now appeared in the left brachial artery within 6 seconds; the remainder appeared about 17 seconds after the injection. The initial fraction of the dye, and hence a fraction of the carotid blood flow, must have reached the left brachial artery by means of a short circuit. The most likely route was via the internal carotid and the posterior communicating arteries and then, by further reversal of flow, the basilar and left vertebral arteries. The possibility cannot be excluded, however, that the circuit was extracranial, for example, via anastomoses between the occipital and vertebral arteries.

These observations confirm the clinical suspicion that the amount of retrograde flow in the left vertebral artery may be increased during exercise of the left arm. Whether or not symptoms of cerebral ischemia are induced by such exercise depends upon the state of the other cerebral blood vessels. In case 2, in addition to the occlusion of the left subclavian artery, severe narrowing involved the right and left internal carotid arteries and the origin of the right subclavian artery. In other patients, in whom involvement of the other arteries is mild or absent and the reserve of the cerebral circulation is greater, adequate compensation occurs for the increased vertebral run-off, and symptoms do not occur.

Importance of Anatomic Variations

Variations in the anatomy of the brachiocephalic vessels are numerous. In another case recently studied by us, an anomalous left subclavian artery coexisted with coarctation of the aorta, and resulted in a delayed and damped left radial pulse (fig. 5) similar to that in case 1 (fig. 2). A right retrobrachial angiogram showed late filling of the left subclavian artery via reversed flow in the left internal mammary and other arteries, but not
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the left vertebral artery. The explanation for this was that the left vertebral artery arose as a separate vessel from the aorta proximal to the site of coarctation.

We have subsequently encountered the reverse situation in a girl aged 15 years who for 18 months before operation had symptoms and signs of a mild left-sided hemiparesis. Her left subclavian artery arose normally proximal to the coarctation, while the origin of the left vertebral artery was distal to it. In this situation reversed flow in the left subclavian artery contributed to the perfusion of the descending thoracic aorta.

Massumi\textsuperscript{16} has demonstrated the occurrence of subclavian steal in a patient with congenital atresia of the intrathoracic portion of the left subclavian artery, to which the vertebral artery was normally connected. As that author pointed out, patients with reversed vertebral flow due to congenital vascular anomalies or secondary to ligation of the innominate artery in the Blalock-Taussig operation are likely to be asymptomatic, since they have normal cerebral vessels.

The magnitude of the reversed flow is clearly dependent on numerous factors, such as the duration of the block in the subclavian artery, the size of the vertebral arteries, and the extent of development of other collateral channels. The term “subclavian snitch”\textsuperscript{33} has jocularly been applied to a small steal, while an unusually large steal has recently been designated “vertebral grand larceny.”\textsuperscript{34} For instances, such as our case 2, in which the reversal of flow can be shown to compromise not only the vertebral-basilar but also the carotid circulation, we feel that “the brain drain” or “the great brain robbery” would be appropriate.

Summary

The occurrence of retrograde blood flow in the ipsilateral vertebral artery of patients with proximal occlusion of the subclavian or innominate artery has been amply demonstrated by selective angiography. However, since flow artifacts may be induced by the physical or chemical effects of injections of contrast media, it was thought desirable to employ a different method for physiologic demonstration of the reversed flow.

In the first case, cardio-green dye was injected into the innominate artery and a dilution curve was recorded from the left brachial artery. The early appearance of the dye (6 seconds) proved that a short circuit existed between the arterial injection and sampling sites, and confirmed the authenticity of the reversed vertebral flow shown in previous angiograms.

In the second patient, who had symptoms of cerebral ischemia during exercise of the left (affected) arm, dye injected into the left carotid artery did not appear early in the brachial artery of the resting left arm. When it was injected during a period of intense hypoxemia of the left arm, a fraction of the dye did appear early. This confirmed that, when the demand of the arm increased, blood was shunted to it not only from the vertebral-basilar system but also from the carotid system.

The importance of anatomic factors was evident in another case in which absence of the anticipated retrograde flow was explained by the fact that the vertebral artery arose directly from the aorta and did not communicate with the affected subclavian artery.

These observations illustrate how radiographic and hemodynamic technics may usefully be combined to assess the effects of acquired diseases of the major blood vessels.
References

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Circulation. 1965;31:249-254
doi: 10.1161/01.CIR.31.2.249

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