Bilateral Simultaneous Sphygmomanometry

A New Diagnostic Test for Subclavian Steal Syndrome

By JAMES F. TOOLE, M.D., AND E. FRANK TULLOCH

SINCE its first description in 1961,1,2 the subclavian steal syndrome has been documented in more than 200 patients.3 In this condition flow through one and rarely through both vertebral arteries proceeds from the brain to the arm which at times causes symptoms of cerebral vascular insufficiency. When brachial blood pressures are unequal and the arrival of the pulse wave in the two radial arteries is asynchronous, one should strongly suspect unilateral reversed vertebral flow. Therefore, the diagnosis of subclavian steal can usually be made by physical examination. At times, however, when blood pressure inequality is equivocal, palpation of the two radial pulses can be misleading. The purpose of this communication is to describe a simple new office test which is extremely useful in these situations.

Method

A series of 30 normal controls and four patients with angiographically proved subclavian steal syndrome were studied with a standardized exercise test. The patients were studied both before and after operation.

An electronic sphygmomanometer* was devised in our laboratories to enable us to measure blood pressure simultaneously in both arms (fig 1). This instrument consists of two aneroid sphygmomanometers so designed that sound transmitted to a battery-powered microphone, placed over the brachial artery, causes a light to flash. The two pressure cuffs are interconnected with a Y tube so that they inflate and deflate together. After inflation, the first Korotkoff sound initiates a flash of the light; with each subsequent pulse, the light flashes until diastolic pressure is reached at which time the blinking ceases. This avoids the use of a stethoscope and makes it possible for a single observer to measure blood pressure simultaneously in the two arms by watching the lights. Our apparatus was periodically standardized against a mercury sphygmomanometer and was found to be accurate within ±5 mm Hg.

In our tests, bilateral blood pressures were measured with the subjects in the recumbent and sitting positions with the arms in various positions until it was ascertained after a series of determinations that the position of greatest accuracy was with the patient sitting with his arms relaxed at his side.4

Thenceforth, blood pressure was measured in this position following which one arm at a time and then both arms together were exercised by lifting a 5-pound weight 30 times as rapidly as possible. It was found that only normal test subjects could perform this test within 60 to 90 seconds. Many subjects had difficulty completing the test, but patients with subclavian steal were particularly quick to fatigue. Therefore, 30 lifts per 60 to 90 seconds was used as the standard rate of exercise. The weight was lifted from the knee to the chest and extended above the head, at which time the patient was asked to squeeze the barbell as hard as he could; the weight was then brought back to the chest, then to the knee. This sequence was repeated immediately.

*Pupet Type TB, Toshiba Nucleonics Co., Japan.

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for a total of 30 times. In this fashion muscles about the shoulder girdle, the upper and lower arm, and the intrinsic muscles of the hand were all exercised repetitively producing maximum stimulation of blood flow. It has been known since 1909 that exercise of an arm can increase its blood flow from a resting state of less than 3 to more than 30 ml per 100 ml of tissue per minute. This exercise hyperemia is sustained as long as muscle contraction is continued. Other factors can also affect flow to the upper limb, such as environmental temperature, exercise of other extremities, and body posture. In this series of experiments every person studied was in a resting state in an air-conditioned hospital, but possible thermal and emotional effects could not be studied.

**Results**

**Normal Subjects***

Simultaneous determination of blood pressure and the standard exercise test were performed on the 30 normal subjects, 16 men and 14 women, ranging in age from 14 to 65 years. None had a difference of more than 10 mm Hg systolic, 4 mm Hg diastolic, or 10 mm Hg in the mean pressure in the resting state. In only one subject in this group did exercise of one arm with 5 pounds or both arms simultaneously (2% pounds each) produce any significant change in blood pressure between the two sides. In the one exception, base-line pressures were 140/70 mm Hg in the right arm and 130/70 in the left arm. Exercise of each arm separately did not produce any significant difference in systolic or mean pressures. Exercise of both arms together produced a difference of 18 mm Hg systolic (7 mm Hg mean). In the others, no consistent change in blood pressure followed this exercise.

**Subclavian Steal**

Simultaneous blood pressures of four patients with reversed vertebral artery flow, demonstrated angiographically, were studied in similar fashion. Short case histories follow.

**Case 1 (NCBH 39-47-42).**

A 59-year-old man complained of 1 to 3-minute attacks of dizziness, blurred vision, and light-headedness of 3 months’ duration, with progression in frequency to two to three attacks per day at the time of admission. These episodes occurred while the patient was working in a textile mill which required that he stand all day and use his arms strenuously.

For 3 weeks prior to admission he had had intermittent headaches. He noted no weakness or claudication of the extremities and had never been unconscious. Aside from minimal signs of cerebellar impairment, he was neurologically intact.

The patient had brachial blood pressures of 180/100 mm Hg in his right arm and 130/100 in his left arm. There was a grade II systolic bruit over the right carotid artery and a grade III systolic vertebral bruit heard in the right occipital area. Palpation of radial pulses revealed a weak left radial pulse, with a definite delay in arrival as compared with normal right radial pulse (pulse delay). Digital plethysmographic studies revealed good flow in both extremities, which was about equal bilaterally. On the left, the pulse contour was rounded, and there was a 0.05-second delay in the pulse compared to arrival of the right radial pulse. A right retrograde brachial arteriogram showed obstruction of the proximal portion of the left subclavian artery with normal direction of flow in the right vertebral and both carotid arteries but reversed flow in the left vertebral artery which supplied the left arm.

The artery was repaired with a patch graft. One week and again 6 months after surgery, blood pressures in the two arms were equal at 180/100 mm Hg, and the patient had no symptoms.

**Case 2 (NCBH 37-35-77).**

A 55-year-old minister had dizzy spells and a hissing noise in his ears of 3 months’ duration. His attacks occurred several times weekly, with and without exertion, and were most frequent while he was preaching. With arm exercise he became weak and dizzy and had a feeling of falling forward, but he did not have any claudication of his arms.

Blood pressures were 130/100 mm Hg in the right and 180/110 mm Hg in his left arm. A grade II systolic bruit was audible at the base of the right carotid artery and in the right supraclavicular area. There was a palpable pulse delay on the right. Neurological evaluation was normal.

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*The voluminous data obtained on these subjects are available on request but are not considered sufficiently enlightening for inclusion in this report.

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Plethysmographic studies revealed good flow in both extremities, better on the right. The pulse contour on the right was rounded with a definite pulse delay. Film and cineangiographic evaluation of the aortic arch and great vessels revealed a plaque partially obstructing the origin of the right subclavian artery and reversal of right vertebral artery flow. Right subclavian endarterectomy was done. Postoperatively, the blood pressure in the right arm was 130/100 and in the left arm was 130/96.

Case 3 (NCBH 38-46-84).

In January 1964, a 67-year-old man developed a sudden sharp pain in his left arm. His physician found his arm to be cold and pulseless. Thereafter, the patient complained of recurrent severe occipital headaches, more prominent on the left, intermittent slurring of speech, drop attacks, and marked weakness of the left arm. Coordination was poor and a tremor, evident on motion, was most prominent in the left arm. He complained also of a throbbing roar in his left ear and a ringing in his right ear.

In July 1964, neurovascular examination revealed simultaneous blood pressures of 160/80 mm Hg in his right arm and 110/80 in his left arm. The left pulse was weak and delayed. A grade II systolic bruit was audible in the left supraclavicular area.

Plethysmographic studies revealed low blood flow, abnormal pulse contour, and marked pulse delay on the left. A right retrograde brachial arteriogram revealed occlusion of the left subclavian artery just distal to its origin and reversal of blood flow in the left vertebral artery. Thromboendarterectomy was done. Twenty-four hours after operation, blood pressure was 136/80 in the right arm, and 110/80 in the left. Within 1 week the pressures were 158/90 mm Hg bilaterally with no return of symptoms. Follow-up study 1 year later, including angiography, revealed no return of symptoms, equal blood pressures at rest and no arteriographic evidence of reversed vertebral artery flow.

Case 4 (NCBH 08-68-66).

A 46-year-old man reported episodes of diplopia, dysequilibrium, light-headedness, and easy fatigability of 10 months' duration. Attacks usually occurred while he was exercising or walking. He also noted short bouts of intermittent shooting pain in the left side of his head and complained of some weakness of his left arm, but there was no claudication of his extremities or unconsciousness.

Brachial blood pressures were 130/70 mm Hg in his right arm and 112/70 in his left. A grade III to IV systolic bruit, audible in the left supraclavicular area, radiated up the left vertebral artery. There was a grade II systolic bruit over the left carotid artery at the base of the skull. A pulse delay was not palpated by the examiner, but special tests elicited this sign.

Plethysmographic studies revealed equal flow in both arms. The left pulse contour was somewhat damped, and there was a pulse delay on the left. Aortic arch arteriogram with serigraphic film and cineangiographic studies revealed stenosis of the left subclavian artery proximal to the origin of the vertebral artery and stenosis of the left common carotid artery at its bifurcation. Reversal of blood flow was not demonstrated at rest, but with exercise the reversal phenomenon was seen. Ligation of the left vertebral artery was done and a patch graft was applied to the left common carotid and internal carotid arteries. Studies 3 days and 1 year later revealed unequal blood pressures but good flow in both extremities and no pulse delay. The patient had had no return of symptoms.

Base-Line Blood Pressure

Blood pressures were determined on these four patients over a period of several days at various times during the day. Blood pressures were found to fluctuate markedly in the two arms even at rest. At times, the degree of change seemed to be less in the involved than in the normal arm. The most extreme example of this is shown in figure 2.

In addition to the inequality of blood pressures, all four had visible pulse delay; that is, when the blood pressures were determined

![Figure 2](http://circ.ahajournals.org/)

Preoperative and postoperative blood pressures. See text for explanation.
simultaneously the lights were not synchronous, the one for the normal side flashing earlier than the one for the abnormal. This indicated that the pulse arrived earlier on the normal than on the involved side.

**Exercise Test**

After the patient had been studied in the base-line state for varying lengths of time, the standardized exercise test was used. The patients were not given any indication in advance as to what to expect. Two were unable to complete the test because of claudication in the abnormal arm. They were questioned and examined as soon as the test was completed. None had symptoms or signs suggesting ischemia of the brainstem or cervical cord. It must be reemphasized that these patients were in a hospital and sitting down, so that their cardiovascular system was not functioning under stress. The results obtained on these four patients are charted in table 1.

After exercise of the arm without subclavian stenosis, blood pressures were not significantly altered. On the other hand, exercise of the involved arm caused pulse pressure to decrease or become undetectable while simultaneous exercise of the two arms also resulted in a fall or undetectable pulse pressure, presumably due to exercise of the involved extremity. One patient (no. 2) became fatigued and exercise of both arms was not done.

**Discussion**

The importance of determining blood pressure in the two arms has been emphasized to medical students for many years. The main reason for this has been the occasional patient with unequal brachial blood pressures. These patients usually have been considered to have lesions in the subclavian, axillary, or brachial arteries, but no further importance has been attached to this difference in blood pressures. Only with the advent of our understanding of the effects which these differences may have on the pressure gradient between the vertebral-basilar and the brachial

### Table 1

<table>
<thead>
<tr>
<th>Case no., age &amp; sex, &amp; angiographic diagnosis</th>
<th>Arm</th>
<th>Sitting at rest</th>
<th>Blood pressures, mm Hg</th>
<th>Exercise of arms</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (NCHB 39-47-42), 50 M.</td>
<td>Right</td>
<td>180/80</td>
<td>180/90</td>
<td>180/80</td>
<td>180/80</td>
</tr>
<tr>
<td>Stenosis of L subclavian artery; reversal of flow in L vertebral artery</td>
<td>Left</td>
<td>100/80</td>
<td>(88)</td>
<td>100/90</td>
<td>90/78</td>
</tr>
<tr>
<td>2 (NCHB 37-35-77), 55 M.</td>
<td>Right</td>
<td>130/100</td>
<td>100/90</td>
<td>130/90</td>
<td></td>
</tr>
<tr>
<td>Stenosis of R subclavian artery at origin; reversal of flow in R vertebral artery</td>
<td>Left</td>
<td>180/110</td>
<td>(138)</td>
<td>180/110</td>
<td>(138)</td>
</tr>
<tr>
<td>3 (NCHB 35-46-84), 67 M.</td>
<td>Right</td>
<td>160/80</td>
<td>170/85</td>
<td>170/90</td>
<td>160/90</td>
</tr>
<tr>
<td>Occlusion of L subclavian artery just distal to origin; reversal of flow in L vertebral artery</td>
<td>Left</td>
<td>110/80</td>
<td>(92)</td>
<td>108/80</td>
<td>(84)</td>
</tr>
<tr>
<td>4 (NCHB 08-68-66), 46 M.</td>
<td>Right</td>
<td>136/80</td>
<td>126/80</td>
<td>120/80</td>
<td>140/80</td>
</tr>
<tr>
<td>Stenosis of L subclavian artery just proximal to origin of vertebral artery; slightly reversed flow in L vertebral, markedly increased by exercise of L arm</td>
<td>Left</td>
<td>110/80</td>
<td>(92)</td>
<td>0†</td>
<td>0</td>
</tr>
</tbody>
</table>

*Mean.
†Barely palpable pulse which was markedly delayed.

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circulations has the importance of this determination been realized.

By the standards used in the past, a difference in blood pressure of 10 to 15 mm Hg systolic has been considered to be within normal limits of variability. While the cuff is being transferred from one to the other arm before making the second measurement, numerous factors can alter the blood pressure. The most important is probably anxiety on the part of the patient when he realizes that his blood pressure is being taken a second time.

We have determined that when the subclavian artery is stenosed or occluded, a blood pressure difference in excess of 20 mm Hg systolic or a mean arterial blood pressure difference of about 10 mm Hg must exist before reversal of blood flow through the vertebral system occurs. This gradient can be increased by arm exercise which dilates the vascular bed of the skeletal muscle by as much as 100%. Therefore, arm exercise is an especially important test in patients with equivocal blood pressure differences between the two arms at rest. After exercise a striking difference may be found. It has also been suggested that this difference is greater when the patient is raised on a tilt table. Presumably normal vasomotor reflexes affect the vascular beds of the two arms unequally and cause change in blood pressures.

Blood pressure difference between the two arms at rest is greater when the subclavian artery is occluded acutely, and as time goes by, the gradient tends to become less, probably because collateral channels develop and other compensatory mechanisms begin to act. Change in systemic blood pressure, fluctuations in environmental temperature which may dilate or constrict the peripheral vascular beds, and exercise of the lower extremity are all known to affect blood flow through the normal upper extremities. What their effects may be upon patients with stenosis or occlusion of the proximal portion of the subclavian artery of one or both sides has not been studied.

A simple bedside method for simultaneous determination of the blood pressures in both arms has been devised. Differences in blood pressure in excess of 20 mm Hg systolic accompanied by a pulse delay which can be palpated or be easily seen by the asynchronous flashing lights are reliable criteria for detecting subclavian steal clinically, so that anyone who knows how to determine blood pressures can suspect the diagnosis. Diastolic levels may frequently be the same or minimally different. We have seen one patient with stenosis of the left subclavian artery distal to the origin of the left vertebral artery who had no reversed flow and no pulse delay, but who had a difference of 30 to 40 mm Hg in blood pressure in the two arms with exercise.

We have suspected in the past that the degree of reversal of blood flow may vary from time to time as the blood pressure difference in the two arms changes as a result of various systemic stresses. The exercise test described herein was designed to clarify this situation. Of particular significance in this respect is case 4, in which intermittent reversal of vertebral artery blood flow was demonstrated angiographically. Subclavian steal had been strongly suspected from the preoperative exercise test, pulse delay, and plethysmographic studies but when this patient was studied in the recumbent position under basal anesthesia, no reversal was seen on angiogram until he exercised his arm.

It must be emphasized that the rate of exercise must be kept standard. In several normal subjects studied initially who were asked to exercise their arm maximally, a much greater difference in blood pressure was observed than when the exercise rate was held to 30 lifts per 60 to 90 seconds. This is probably due to many factors, the main ones being dilatation of the muscle vascular bed with shunting of blood from the brachial artery to this dilated vascular network.

Bilateral subclavian steal has been described but has not been found by us. Therefore, we have no data on this subject. Theoretically, at least, blood pressures in the two arms might be equal and no delay in the radial artery pulse found, but a delay in pulse
arrival between the carotid and the subclavian arteries would occur. This points to the necessity for simultaneous measurement of pulse arrival times in the subclavian, the carotid, and the ophthalmic arteries or their branches. These studies are currently being carried out at this institution and will be the subject of a subsequent report.

Postoperative follow-up on the patients who have had angiographically demonstrated subclavian steal has shown complete disappearance of symptoms and no recurrence of blood pressure inequalities. The patient who has been studied longest (12 months) is able to complete his exercise without difficulty and demonstrates no pulse delay (table 2).

**Summary**

A series of 30 normal persons and four patients with proved subclavian steal were studied by use of a standard exercise test and an instrument devised by us for measuring blood pressure in the two arms simultaneously. No significant differences were found in the blood pressures in the arms of the normal persons in the base-line or exercise state, but in the patients with subclavian steal, exercise of the involved limb produced rapid fatigue and always reduced the blood pressure on the involved side. In one case, pulse pressure was lost completely so that there was no detectable blood pressure. In these four cases the radial pulse which had been palpable before the exercise test was either absent or barely palpable, and a definite pulse delay was detected on the involved side. The exercise test may serve to accentuate borderline differences in blood pressure and substantiate a clinical diagnosis of subclavian steal.

**References**


**Table 2**

<table>
<thead>
<tr>
<th></th>
<th>Sitting at rest</th>
<th>Exercise of arms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Preoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>160/80</td>
<td>170/85</td>
</tr>
<tr>
<td>Left</td>
<td>110/80</td>
<td>108/80</td>
</tr>
<tr>
<td>Postoperative (1 yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>160/90</td>
<td>180/100</td>
</tr>
<tr>
<td>Left</td>
<td>160/90</td>
<td>180/100</td>
</tr>
</tbody>
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