The Use of Ultrasound to Determine Cerebral Arterial Reserve*

GLENN W. KINDT, M.D., †JULIAN R. YOUUMANS, M.D., AND LOUIS W. CONWAY, M.D.

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

A test to detect individuals likely to develop an ischemic cerebrovascular accident would have wide applicability. The majority of victims of cerebrovascular disease already have a neurological deficit when first seen by a physician. Such deficits are often permanent, the brain tolerating ischemia poorly. Some patients seek medical attention prior to a major stroke because of transient ischemic attacks. If these patients have a correctable ischemic attacks, surgical results are favorable. Results of vascular surgery following a completed stroke have been discouraging. Consequently, some have considered such surgery primarily prophylactic. Also, medical therapy would likely have its best results when applied prophylactically. In order to apply appropriate preventive measures, the stroke-prone individual must first be identified.

The patient with vascular disease such as a carotid occlusion may have a normal cerebral blood flow. Such a patient, however, has been shown to have diminished cerebral arterial reserve. For example, he is less able to maintain adequate cerebral blood flow in the face of hypotension, and to increase cerebral blood flow in response to stimulus such as carbon dioxide inhalation.

We suggest that a useful method for identifying the stroke-prone individual could be based on the concept of cerebrovascular reserve. We have evaluated the effect of carbon dioxide inhalation on common carotid blood flow as an indication of cerebral arterial reserve.

Received for publication December 9, 1968.
Revision received April 24, 1969.
* Supported by U.S. Public Health Service, National Institutes of Health Grant NB 08013-01.
† Present address: Section of Neurosurgery, University of Michigan Medical Center, Ann Arbor, Michigan.

Materials and Methods

Common carotid blood flow was measured by the Doppler transcutaneous technique. This technique is based on the principle described by Doppler in 1842. A flowmeter using the Doppler principle was first developed for air currents and fluid flow and more recently the technique has been popularized for blood flow measurements. A velocity-amplitude converter was attached to the flowmeter; this produced DC voltages which are proportional to the velocity of blood flow. The converter signal was monitored on a Mark 220 Brush Recorder.

Initial studies of the accuracy and sensitivity of the instrument were performed on the abdominal aortas of three dogs. A 5-in. segment of the aorta of each animal was isolated, and all side branches of the vessel were ligated and divided. After heparinization, a ¾-in. teflon tube was inserted via an arteriotomy into the distal end of the aorta, and the aorta was ligated distal to the arteriotomy. A screw clamp was placed around the tube to allow blood to exit from the aorta at a controlled rate. The distal end of the tubing was placed in a calibrated 1000 ml reservoir. A rotary pump returned blood to the animal via the right iliac vein. The ultrasound transducer was placed on the prepared segment of the abdominal aorta at an angle of 45° and held in place with screw clamps on a ring stand. Blood flow was measured by removing the teflon tube from the reservoir and obtaining timed volume measurements in a 100 ml graduated.

Systemic blood pressure was monitored via a catheter in the right subclavian artery. Calibrations were performed only when the

† Smith-Kline Instrument Company, Philadelphia.
§ Clevite Corporation, Cleveland.
blood pressure was stable. The screw clamp on the tube leading from the arteriotomy was opened by increments to obtain several different flow velocities within the abdominal aorta. With each increment of change in flow rate, the outside diameter of the abdominal aorta was measured, and the inner diameter of the vessel estimated by making an allowance for the thickness of the arterial wall. From the inner diameter of the artery and the blood flow rate in milliliters per minute, the blood velocity could be calculated. This velocity was then plotted against the voltage output of the Doppler flowmeter (Fig. 1).

Common carotid blood flow was measured transcutaneously on 25 patients using the same blood flow detector. Each patient was supine on a firm stretcher. No premedication was given as the test proved painless and was not fatiguing. The patient was instructed to rest comfortably but remain motionless. A disposable mask was placed on his face for administration of gases. The transducer of the blood flow detector was placed over one common carotid artery at an angle of 45° until a stable and reproducible signal was obtained.

Two examiners performed each test. One held the transducer steady while 100% O₂ was administered to the patient for a 3 minute period. Without notifying the patient or the examiner holding the transducer, the gas was changed to 5% CO₂ in oxygen. In some cases, 7% CO₂ in oxygen was also used. Systemic blood pressures were recorded at intervals during the test. Each test was performed until reproducible results were obtained. The percentage change in flow veloc-}

ity between the inhalation of pure oxygen and the inhalation of the oxygen-carbon dioxide mixture was calculated for each observation.

**Results**

When the transcutaneous technique was used, the millivolt output from the converter proved to be less than might be expected for the calculated velocity in the human common carotid. This decreased output from the converter was presumed to be due to the distance between the artery and the transducer. Because of this attenuation of the signal during the transcutaneous technique, no attempt was made to convert the data to absolute values. Instead, the results were expressed in terms of the percent increase in voltage produced by the introduction of 5% CO₂ into the inhaled oxygen. Since a linear relationship between voltage and flow was demonstrated in the animal studies, it was assumed that this linear relationship persisted during the transcutaneous studies. However, it would be a mistake to try to be quantitative about a technique which does not yield quantitative data.

It was difficult to obtain a steady, reproducible signal from the human carotid. Any change in the relationship between the artery and the probe would influence the strength of the signal. The examiner had to be careful not to change the pressure against the neck or the angle of the probe. It was necessary to obtain a clear arterial signal, free of interference from the jugular vein before recordings were taken. The patient had to be cautioned not to move his neck or swallow.

Despite the difficulties, with practice, a steady recording of voltage output related to carotid flow velocity could be obtained for several minutes. Manipulation in the region of the patient's mask could not be made without the risk of producing some motion of the patient or of the examiner in control of the probe. Two examiners were necessary, one to control the gases and one in control of the probe. To avoid bias of the result, the examiner in control of the probe was not informed when the inspiratory gas was changed. Also, the examiner in charge of the probe did not look at the recorder during the test, but concentrated only on the position of the probe.

![Image](image.png)

**Fig. 1.** Calibration curve. Average of readings on the aortas of three dogs. A linear relationship existed between voltage output and velocities of over 7 cm/sec.