Ophthalmosonometry*
An Ultrasonic Method for Assessing Carotid Blood Flow

J. C. MAROON, M.D., D. W. PIERONI, M.D., AND R. L. CAMPBELL, M.D.
Departments of Neurological Surgery and Ophthalmology, Indiana University Medical Center, Indianapolis, Indiana

In 1966, Stegall, et al., described an ultrasonic flowmeter, based on the Doppler effect, which could continuously record arterial or venous blood flow velocity through the intact human skin.12 Vascular surgeons found application for this instrument in the localization of arterial and venous occlusions of the extremities.11,14,15 Attempts to detect sites of obstruction in the extracerebral carotid arteries, however, have thus far been disappointing.13

While using this blood velocity detector, we found that an arterial pulsation could be routinely detected with the transducer applied over the lid of the closed eye. Goldberg, et al., recently made this same observation, and after preliminary work on dogs they suggested that the use of this instrument might prove to be a practical, indirect method for assessing carotid and ophthalmic blood flow.5

The purposes of this report are to establish that it is ophthalmic artery blood flow which is detected and to illustrate potential applications of this technique. It appears that the clinical indications for determining ophthalmic artery blood flow with ultrasound are similar to those for ophthalmodynamometry (ODM). We will, for convenience, use the term "ophthalmosonometry" (OSM) for this procedure.

Principles and Methods

A transcutaneous Doppler flowmeter with an attached velocity-amplitude convertor was used.† Housed in a single handle are two D-shaped crystals which are the transmitting and receiving piezoelectric elements. The transmitting crystal generates a constant 5 mc beam of low intensity ultrasound in the range of 20–40 mw which can penetrate soft tissue and blood vessels; reflected ultrasound is detected by the receiving crystal. A frequency change occurs only when ultrasound is reflected from the moving tissue elements (blood, arterial wall); sound backscattered from motionless tissues has the same frequency as the transmitted signal and is filtered out. It is the change in frequency that occurs whenever the source of sound is changed in relation to a stationary observer that is called "the Doppler effect," after the Austrian physicist, Christian Doppler, who first described the phenomenon in 1842.6

Besides being converted to audible sound, the returning filtered signal is also processed by the velocity-amplitude convertor. This instrument yields DC voltages which are proportional to the frequency change and the amplitude of the Doppler signal. In the present studies these two components plus Lead II of the electrocardiogram were displayed on separate channels of a Honeywell Visicorder. The greater the frequency difference between the transmitted and the reflected sonic beam, the higher is the blood flow velocity. This is reflected by a greater deflection in the frequency channel and an increased pitch of the sound. It is impossible to determine accurately the absolute rate of blood flow because the frequency alteration varies markedly with changes in the angle formed by the crystals and the moving column of blood. Reproducible results, however, have been consistently obtained in the same patient over various intervals of time.

The amplitude channel indicates the amount or quantity of backscattered ultrasound. This signal is related to the size of the blood column(s) and also the focusing arrangement of the transmitting crystals. We have not found this channel useful except for gross wave form analysis.

Received for publication April 22, 1968.
* This paper was supported in part by grants from the Cerebrovascular Disease Clinical Research Center (NB 06793–01), the John A. Hartford Foundation (54–881–36), and the Heart Research Center (HE 06038).
All sonograms were obtained with the patient in the supine position. The transducer was held over the closed eyelid and Aquasonic‡ was used as the coupling agent. With little or no pressure, the transducer was moved over the eyelid until the position was found that produced the maximum auditory signal. A signal was detected with the transducer held over the medial, superior, or lateral aspect of the globe, but the maximal impulse was usually found when the transducer was placed over the medial canthus and directed toward the optic canal.

**Laboratory Studies**

To determine the source of the ocular Doppler signal experimentally, a monkey (*Macaca speciosa*) was chosen because the carotid flow and pressure characteristics in this animal are similar to those in the human. Under pentothal anesthesia, the right common, internal, and external carotid arteries were exposed in the neck. The ultrasonic transducer was then placed over the right eye and held in the position producing the maximal frequency change. Each of the exposed arteries was then alternately completely occluded and appropriate sonograms made. Following this, a right frontotemporal craniectomy was performed, and, with the aid of magnification, the internal carotid and ophthalmic arteries were clearly identified. While recording over the right eye with the Doppler instrument, the internal carotid artery immediately distal to the origin of the ophthalmic artery and the isolated ophthalmic artery were then alternately completely occluded with fine forceps.

Occlusion of the common carotid artery resulted in a dramatic decrease in the amplitude and frequency as recorded on the sonogram (Fig. 1). The impaired flow recorded after complete occlusion of the internal carotid in the neck was significant, but not as striking as that following common carotid ligation. This finding was not unexpected,

‡ Parker Laboratories, Irvington, New Jersey.

![Fig. 1](attachment:image.png)

Fig. 1. Continuous recording of the electrocardiogram (ECG), mean amplitude (AMP) and frequency (FREQ) of the ophthalmic Doppler signal in the monkey. A. Marked decrease in amplitude and frequency with occlusion (first arrow) of the common carotid. B. No change with external carotid occlusion. C. A significant decrease with internal carotid occlusion. D. Abrupt disappearance of a detectable signal with ophthalmic artery occlusion. (In this and all subsequent sonograms, the amplitude and frequency deflections are in millivolts.)
since Hedges, et al., had demonstrated in the monkey that the damping effect of common carotid artery occlusion on the ophthalmic artery pressure can be greater than that from internal carotid occlusion alone. Occlusion of the ophthalmic artery under direct visualization caused the amplitude and frequency channels to return to the baseline (Fig. 1). There was no change found either with occlusion of the external carotid or the internal carotid distal to the ophthalmic artery.

In laboratory studies conducted to establish the safety of the technique, no pathological changes were found in the eyes of animals subjected to 75 to 100 times the usual clinical exposure.

**Case Reports**

The following cases illustrate conditions in which ophthalmosonometry may be of practical clinical significance.

**Case 1.** This 67-year-old white man with hypertensive cardiovascular disease was referred to the neurosurgical service because of bilateral carotid bruits and transient loss of vision and lightheadedness. Bilateral carotid arteriography demonstrated almost complete occlusion of the left internal carotid (Fig. 2) and moderate stenosis at the bifurcation of the right common carotid artery. Ophthalmodynamometry (ODM) revealed a pressure of 150+/110 and 150+/96 in the right and left eyes respectively (a 12.5% difference). The blood pressure at the time was 210/110 mm Hg in both arms. Sonograms, however, showed a striking decrease in the amplitude and frequency signals from the left ophthalmic circulation, compared to a normal flow pattern from the right (Fig. 2). At the time of surgery 3 days later, the left internal carotid artery was found to be completely occluded, but an excellent backflow was obtained following thromboendarterectomy. After the operation, a dramatic improvement in the flow was recorded by ophthalmosonometry of the ophthalmic Doppler signal on the side with marked stenosis. Recordings after left carotid endarterectomy show a return to a normal flow pattern on the left (C), and no change on the right (D).
(OSM) (Fig. 2), and the pressure recordings with ODM were 150+/120 bilaterally with a corresponding blood pressure of 205/110 mm Hg.

Comment. In this patient with bilateral carotid occlusive disease, OSM demonstrated a marked impairment of flow on the more severely affected side, whereas ODM demonstrated only an equivocal difference in pressure. After surgery, the sonogram revealed comparable flow patterns bilaterally.

Case 2. This 58-year-old white man had an aneurysm of the left middle cerebral artery treated by left common carotid artery ligation in October, 1967. The internal carotid systolic pressure decreased from 130 to 60 mm Hg with temporary occlusion at the time of surgery. The artery was then gradually occluded over the next 7 days with a Crutchfield clamp. There was progressive clearing of a pre-existing aphasia and right-sided weakness, and the patient returned to his former occupation as an automobile mechanic. OSM performed 3 months following surgery showed a decrease in amplitude and frequency of the Doppler signal on the left (Fig. 3). ODM performed concomitantly with OSM revealed pressures of 140/80 and 75/50 in the right and left eyes.

Comment. OSM can be readily adapted to the pre- and postoperative evaluation of patients with carotid artery ligation. In the three patients whom we have studied, velocity determinations compared favorably with the results of ODM. OSM has an additional advantage in that it can be used when ODM is contraindicated or impossible to perform.

Case 3. This 55-year-old white woman had a right common carotid artery ligation in August, 1967, because of advanced symptoms and signs from a right carotid-cavernous sinus fistula confirmed by angiography (Fig. 4). Although the patient experienced a decrease in the roaring sounds in her head, 4 months after surgery she still was symptomatic. On examination the bruit could still be easily heard, and proptosis and conjunctival injection persisted. OSM at that time demonstrated a striking sustained increase in both the frequency and amplitude of the Doppler signal (Fig. 4), and the audible output was heard as a continuous, high-pitched roar analogous to the sound previously recorded from arteriovenous fistulae in the extremities.13

Comment. Ophthalmosonometry appears to offer a simple, reliable and harmless tool for further study of a carotid-cavernous sinus fistula.

Case 4. This 60-year-old white woman was admitted to the hospital in October, 1967, for evaluation of the sudden onset of proptosis of the right eye associated with subconjunctival hemorrhage, severe orbital pain, and periorbital edema. Physical examination revealed no bruit or thrill. The Hertel measurements were 23 mm on the right and 18 mm on the left. There was limitation of gaze in all directions and advanced papilledema on the right.

Angiography demonstrated what was at first believed to be a carotid-cavernous sinus fistula (Fig. 5). Although an increase in blood flow through the right eye compared to the left was suggested by an increase in both amplitude and frequency of the Doppler signal, the recording did not have the characteristics of a fistula (Fig. 5). Selective carotid angiography was then performed, and a vascular tumor of the orbit supplied primarily by the right external carotid artery was outlined. The orbit was explored through a right frontotemporal craniotomy and after much difficulty in controlling bleeding from an extremely vascular orbital roof, an intraorbital hemangioma and an old hematoma were removed. The patient had an excellent return of function and a remission of symptoms;
the postoperative sonogram was virtually unchanged.

Comment. Although a more prominent sonogram was obtained over the side with the orbital tumor, the primary value of OSM in this case was to cast doubt on the diagnosis of a carotid-cavernous sinus fistula.

Case 5. This 73-year-old white man had lost all vision in both eyes over a 3-month period. The ophthalmoscopic picture of the left eye was that of central retinal artery occlusion and that of the right was ischemic optic neuritis. A temporal artery biopsy confirmed the suspected diagnosis of temporal arteritis. The fluorescein appearance time was 10 sec for the right eye, but the dye was never seen to enter the constricted retinal arteries of the left eye. A left carotid angiogram showed normal filling of the carotid artery, but the ophthalmic branch was not visualized even with the subtraction technique. OSM was normal on the right, but no flow pattern could be recorded from the left eye (Fig. 6).

Comment. The results of ophthalmosonometry in this patient with ophthalmic artery occlusion indicate that OSM can be a valuable adjunctive diagnostic tool in those patients in whom vascular obstruction is suspected but cannot be confirmed because of impediments to ophthalmoscopy.

Case 6. This 54-year-old white man was referred to the neurosurgical service in January, 1962, for evaluation of intermittent, severe left supraorbital headaches and a progressive right-sided weakness. Interestingly, the exacerbations of the headache coincided with difficulty in using the right
Ophthalmosonometry

FIG. 5. Photographs: Right carotid arteriogram suggestive of a carotid cavernous sinus fistula later found to be an intraorbital hemangioma. Tracings: The sonogram from the right eye (B), although slightly increased in both amplitude and frequency, compared to the left eye (A), has none of the features of the fistula seen in Case 3.

arm. Arteriography demonstrated complete occlusion of the left internal carotid, but excellent collateral circulation reached the ophthalmic and intracranial vasculature via dilated superficial temporal and supraorbital arteries (Fig. 7). The right internal carotid was also diseased, with over 50% narrowing. Although a thromboendarterectomy was successful on the right, flow could not be re-established in the left internal carotid artery.

Because of persistent left supraorbital headaches and a bothersome cranial bruit, arteriography was repeated in May, 1967, and again demonstrated occlusion of the left internal carotid artery and well-developed

FIG. 6. Case 5. There is no detectable Doppler signal on the side of the occluded ophthalmic artery (A). The sonogram from the opposite eye is normal (B).
collateral circulation. Sonograms obtained in March, 1968, revealed excellent, pulsatile, arterial flow patterns bilaterally. However, the left ophthalmic recording could be completely obliterated with compression over the left supraorbital ridge (the location of his headaches), or by occluding the superficial temporal artery (Fig. 7). Concurrent ODM measurements were 120/70 and 60/35 in the right and left eyes.

Comment. OSM is a potentially useful method for studying collateral circulation in the presence of carotid occlusive disease. It should be mentioned, however, that well-developed collateral circulation, particularly from vessels which are inaccessible to ultrasonic evaluation, such as the internal maxillary artery, may limit the reliability of the technique.

Discussion

Due to the increased awareness of the significance of extracranial carotid occlusive disease and the inherent dangers of carotid angiography, \(^3,4,6\) a myriad of techniques have been developed for the indirect assessment of carotid blood flow. The more common of these include ophthalmodynamometry, retinal fluorescein-appearance times, tonography combined with carotid artery compression, thermography, isotope flow patterns, and studies with electromagnetic flowmeters.\(^8\) Ophthalmosonometry appears to have a high degree of safety, simplicity, reliability and convenience, compared to these other methods. At present, we are using OSM in the pre- and postoperative period in patients undergoing carotid artery surgery and also in patients suspected of having the following conditions: carotid occlusive disease; carotid-cavernous sinus fistulae or arteriovenous malformations; and intraorbital tumors. There have been no complications and no significant discomfort in any of the 95 pa-

Fig. 7. Case 6. Photographs: Right carotid arteriogram showing complete occlusion of the internal carotid artery (circle). The intracranial vessels fill through the ophthalmic circulation supplied partially by the superficial temporal artery (arrows). Tracings: With compression of the left superficial temporal artery (arrow) the Doppler signal is markedly decreased (A); normal right ophthalmic sonogram (B).
tients thus far examined. A normal auditory acuity and the experience which accrues from examining several patients are the only criteria demanded of an examiner.

Since the instrument is small, lightweight, and readily portable, it can easily be carried from the office to the patient’s bedside. It can also be used at the time of surgery to assess the patency of a graft or the circulation distal to the site of an occlusion.15

Because ultrasound can penetrate light-opaque structures, OSM is of value when a funduscopic examination is impossible because of decreased transparency of the ocular media. It can also be used instead of ODM when any of the contraindications to the latter exist, such as central retinal artery occlusion, or when conditions such as previous ocular surgery, glaucoma, or an uncooperative patient precludes accurate ODM measurements.

It was of interest to compare the results of OSM and ODM obtained from the same patients. Usually they were in agreement. In a few patients, however, especially in those with chronic carotid occlusive disease, a marked discrepancy between the two measurements was evident. In Case 1, for example, the pressure difference between the eyes was not in the range considered significant;1 OSM, however, demonstrated a marked impairment in flow, consistent with the angiographic findings. In Case 6, there was an appropriate pressure differential in the presence of a carotid occlusion, but OSM was considered normal until the extensive collateral flow via the superficial temporal artery was demonstrated.

As with any diagnostic technique, results must be interpreted in the light of inherent limitation. With present instrumentation, the absolute volume flow rate cannot be determined nor can the direction of blood flow. Thus, in the presence of a carotid occlusion with well-developed ophthalmic collaterals (Case 6), reversed flow can give asymmetrical sonograms which may be erroneously interpreted. Since the Doppler signal is dependent upon the angle and the alignment of the transducer with respect to the ophthalmic artery complex, careful positioning of the transducer is essential. Furthermore, it is necessary to examine several normal patients, not only to obtain the necessary experience with one’s own equipment, but also to establish a general frame of reference concerning the variations which may be encountered among a normal population. Even then, however, it is strongly emphasized that, as with ophthalmodynamometry, results are best interpreted by comparing differences between the eyes of the same individual.

Summary

An ultrasonic method based on the Doppler effect has been described for assessing carotid and ophthalmic artery blood flow. Experimental and clinical data have been presented that demonstrate the value of the procedure. The current applications and limitations of the technique have been discussed.

References

10. MAROON, J. C., PIERONI, D. W., and CAMPBELL, R. L. Ocular effects of limited exposure
of the rabbit eye to low intensity ultrasound. Expl Eye Res. (Submitted for publication.)


