Ultrasonic echoes from an artery, registered on an oscilloscope screen as vertical deflections from a horizontal baseline, exhibit pulse-synchronous displacements on the x-axis as well as variations in amplitude. The visualization of these echo movements can constitute the basis for an evaluation of arterial conditions comparable to palpation of the pulse but has the advantage of being applicable to arteries that cannot be palpated. The method has been applied to the internal carotid artery in 325 patients, and an evaluation of the method is given on the basis of a comparison with 166 angiograms of the artery. The method has proven to be a valuable diagnostic aid in studying patients suspected of having carotid artery disease.

Key Words · ultrasound · pulse · carotid artery · cerebrovascular disease

A preliminary report of the clinical usefulness of this method of direct observation of echo movements has previously been reported in a small series of patients suspected of having carotid artery disease. We now report and discuss the use of the method in 325 patients.

Method

When an ultrasonic beam is directed toward an artery, the echoes corresponding to the artery are seen to move synchronously with the arterial pulse (Fig. 1). The demonstration of pulsations in single intracranial arteries by means of ultrasound has been reported by Freund, who photographed the changes of amplitude of the echoes from arteries in search, and by Kristensen, who used direct observation of the movements and photographed the x-axis displacement.

A preliminary report of the clinical usefulness of this method of direct observation of echo movements has previously been reported in a small series of patients suspected of having carotid artery disease. We now report and discuss the use of the method in 325 patients.

Method

When an ultrasonic beam is directed toward an artery, the echoes corresponding to the artery are seen to move synchronously with the arterial pulse (Fig. 1). The demonstration of pulsations in single intracranial arteries by means of ultrasound has been reported by Freund, who photographed the changes of amplitude of the echoes from arteries in search, and by Kristensen, who used direct observation of the movements and photographed the x-axis displacement.

A preliminary report of the clinical usefulness of this method of direct observation of echo movements has previously been reported in a small series of patients suspected of having carotid artery disease. We now report and discuss the use of the method in 325 patients.
Ultrasonic evaluation of carotid artery

changes in the orientation of the echo-giving structures, and thus the amplitude of the echoes will vary.

These pulsesynchronous "echomovements" were first observed on the extremities, and when found valuable in estimating the pulsation in single arteries in the extremities, this "visual pulse palpation" was applied to the carotid and vertebral arteries.

When examining the carotid arteries, the transducer is placed just anterior to and above the external meatus of the ear (Fig. 2). It is directed toward the bulb of the opposite eye, and thus the ultrasonic beam will hit the internal carotid artery in its bone canal at a depth of 4 to 6 cm. On the oscilloscope screen the echoes corresponding to the artery will be seen to move synchronously with the pulse, the direction of the transducer being changed slightly until the echo movements are maximal. Normal variation in amplitude amounts to 1 or 2 cm (the time base adjusted to 1 cm tissue per division) but this varies individually depending on the thickness of the skull and the setting of the sensitivity of the apparatus. The displacement on the x-axis only amounts to 1 or 2 mm. The movements are observed as a fast and sudden change of amplitude and a slower return to the starting position of the echoes.

Thus, the visual impression of the speed and to a lesser extent the range of variation of amplitude of the echoes are the fundamentals of ultrasonic estimation of arterial pulsations comparable to the tactile impression of peripheral arterial pulsations. Just as the tactile impression can be classified, the visual impression can also be classified into normal pulsations, slightly reduced, moderately reduced, and severely reduced pulsations, or no pulsations at all. To a certain extent the pulsations of one side should be compared to those of the other side, but since often there will be pathological conditions on both sides, one should not rely too much on such a comparison.

A Physionic TM-2 somascope and a Hewlett-Packard diagnostic sounder were used for the examinations. The frequency of the transducer was 2.25 mc. A non-focused transducer was used at first, but later a transducer with a focal length of 10 cm (built for another purpose) was found to be more suitable. Probably a focal length of 5 cm would be even better.

Fig. 1. Diagram illustrating the principle of ultrasonic pulse detection. A. Echo from the skin surface. B. Echo from the artery, moving synchronously with the pulse. C. Echo from bone.

Fig. 2. Photograph of patient showing the placement of the transducer for examination of the carotid arteries.
TABLE 1
Angiographic findings compared to echographic findings in 166 internal carotid arteries

<table>
<thead>
<tr>
<th>Angiographic Findings</th>
<th>Echographic Pulsations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>occlusion</td>
<td>8</td>
</tr>
<tr>
<td>severe stenosis</td>
<td>3</td>
</tr>
<tr>
<td>slight stenosis</td>
<td>3</td>
</tr>
<tr>
<td>severe atherosclerosis</td>
<td>1</td>
</tr>
<tr>
<td>slight atherosclerosis</td>
<td>1</td>
</tr>
<tr>
<td>kinking</td>
<td></td>
</tr>
<tr>
<td>normal</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

Clinical Material

The method has been used for more than 2 years on 325 patients with suspected permanent or transient cerebrovascular episodes. Most of the tests were done by the same examiner. In the majority of cases, the ultrasonic examination was done before angiography.

In six cases the examination had to be given up because the patients could not keep their heads still. With angiography used as the basis for the evaluation of the method, 196 patients have been excluded either because they did not have angiography or because the angiography failed to give a satisfactory outline of the internal carotid artery. In the remaining 123 patients, 166 angiograms of internal carotid arteries were made; 41 patients had aortocervical angiography, and some of these and the rest of the patients had peripheral carotid angiography.

The angiographic evaluation of internal carotid artery stenosis is based on a measurement of the smallest diameter of the stenosis compared to that of the normal vessel distal to the stenosis or distal to a poststenotic dilatation. Arbitrarily, a stenosis reducing the diameter of the artery more than 50% has been classified as "severe," and one reducing it less than 50% as "slight." In severe atherosclerosis, there will be angiographically visible atherosclerotic changes in most parts of the vessel without obvious narrowing of the lumen, whereas in slight atherosclerosis the changes will only be localized or scattered. "Kinking" means an almost 90° angulation of the vessel in the neck without obvious organic stenosing lesions at the place of angulation.

Results and Discussion

The angiographic findings are compared to ultrasonic findings in Table 1. Since only four cases of "kinking" were examined, these constitute no basis for an evaluation of this condition and are only included for the sake of completeness. A clearer impression of the number of false positives and false negatives is given in Table 2. Table 3 summarizes the ultrasonic estimation of pulsations in cases of arteriosclerosis.

In 42 cases of angiographic occlusion or severe stenosis only two were estimated ultrasonically as having normal pulsations, giving a false negative rate of almost 5%. One had a stenosis with a 70% reduction in the diameter of the vessel, which is on the borderline of what has experimentally been demonstrated to be necessary to cause a decrease in blood flow and pressure distal to a stenosis. Furthermore, the patient was hypertensive, a condition which from experience is known to increase ultrasonic pulsations. The other patient had a total occlusion...
Ultrasonic evaluation of carotid artery

TABLE 2
Echographic findings compared to angiographic findings in 142 internal carotid arteries

<table>
<thead>
<tr>
<th>Echographic Pulsations</th>
<th>Angiographic Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occlusion and Severe Stenosis</td>
</tr>
<tr>
<td>none</td>
<td>11</td>
</tr>
<tr>
<td>moderately or severely reduced</td>
<td>21</td>
</tr>
<tr>
<td>slightly reduced</td>
<td>8</td>
</tr>
<tr>
<td>normal</td>
<td>2</td>
</tr>
</tbody>
</table>

and there seems to be no reasonable explanation for this failure.

In 13 patients with occlusion, there were varying degrees of echographically reduced pulsations. The explanation for this may be that with a small change in the direction of the transducer in search for pulsating echoes, the ultrasonic beam hits smaller arteries in the same region with a collateral blood flow from the contralateral hemisphere. Such an explanation would be in concordance with the findings in the extremities, where the pulsating echo movements in an artery with a collateral blood flow cannot be distinguished from those obtained from a stenosed main artery.

In three cases of severe stenosis no pulse synchronous echo movements were seen on the oscilloscope screen, most probably because of too weak pulsations in the artery distal to the stenosis.

Among 100 patients with normal angiograms or slight (presumably hemodynamically insignificant) stenoses, 29 were estimated ultrasonically to have reduced pulsations. Out of these, 17 had a slight stenosis; however, a localized stenosis may be the only visible sign of a more widespread but still undetectable atherosclerotic change in the wall of the artery that causes arterial rigidity and thereby decreases pulsations. In support of this assumption, it can be seen from Table 3 that most cases of angiographically demonstrable atherosclerosis cause decreased pulsations, although this is not mandatory. Of the 12 patients with reduced echographic pulsations but normal internal carotid angiograms, six had angiographic signs of atherosclerosis elsewhere. Three had only a peripheral carotid angiogram, which does not exclude stenosing lesions proximal to the point of contrast injection. This leaves 3 patients with no explanation for the difference between the angiographic and echographic findings. Although the value of this method in selecting supposedly hemodynamically significant stenoses for operation is reduced by the large number of false positives, most of these cases had some sort of vascular disease.

It is not possible to do angiography on all patients in whom a carotid artery stenosis cannot be ruled out clinically. Thus, there is a need for diagnostic methods that can select patients for angiography, and ultrasonic study of the internal carotid artery seems to be one such method. It is easy and quick to perform, without any risk or inconvenience to the patient, and is a bedside method that can be carried out on almost any patient.

Conclusions and Summary

The visual impression of movements of the ultrasonic echoes from the pulsating internal carotid artery has been used as an indicator of the condition of this artery in 325 patients; 123 of these patients had angiograms for comparison. The method demonstrated pathological pulse conditions in 40 of 42 patients with occlusive or severe stenoses of the common or internal carotid arteries. Of 100 patients with normal angiograms or nonsignificant stenoses, 29 had echographically reduced pulsations. If the method were
used for the selection of patients for angiography, 5% with operable lesions would be missed while 30% with nonoperable conditions would be referred to angiography. When combined with other methods of investigation (ophthalmodynamometry, oculosphygmyography, thermography, etc.), these percentages can be lowered. The ultrasonic examination of pulse conditions should only be part of the diagnostic study in cases suspected of carotid artery disease, but as such it has been found to be valuable.

References

Received for publication March 13, 1970.
Address reprint requests to: J. Kvist Kristensen, M.D., Department of Surgery H, Gentofte Hospital, 2900 Hellerup, Copenhagen, Denmark.