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ULTRASONIC GRAY SCALE DOPPLER IMAGING ANGIOGRAPHY

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Examination of the carotid artery stenosis is very important in the diagnosis of cerebrovascular diseases. New possibilities in the diagnosis of stenotic lesions are provided by ultrasonic Doppler angiography. The aim of this paper is to present a Doppler imaging system developed by the authors for the examination of blood flowing in carotid arteries. The system is based upon a 5 MHz bi-directional *c.w.* Doppler flowmeter with a separate output for anterograde and retrograde flows. A special bank of filters converts signals into various levels of the gray-scale display which correspond to the value of the blood flow velocity. The ultrasonic probe is held by the scanning arm. The position of the probe on the skin of the patient is electronically sensed by the position-sensing circuity which causes the bright spot on the image display to move according to the position of the probe. The Doppler image from the artery is stored in a digital memory system. The clinical results obtained by means of this system showed good agreement with X-ray arteriography for obstructions occluding more than 50 per cent of the arterial diameter.

1. Introduction

The brain stroke is one of the most dangerous diseases which causes a large number of deaths.

The diagnosis of brain diseases which result from ischaemia consists above all in the examination of the carotid artery patency.

X-ray angiography used previously involves the considerable risk of causing complications in patients and is totally excluded in a large number of cases.

New diagnostic possibilities in this field have been provided by ulrasonic Doppler angiography, permitting images of blood flow in vessels to be obtained. In 1972, REID and SPENCER [8] were the first to describe an ultrasonic *c.w.* system for imaging carotid arteries. In view of its similarity to vessel representation in X-ray angiography, this technique was called by its authors Doppler angiography. CURRY and WHITE [2] used colour to code the blood flow velocity, and NOWICKI [7] introduced to this technique a pulse method permitting two-plane imaging of vessels. In Poland the first model of an ultrasonic arterioscope was developed in 1980 [3].

The ultrasonic Doppler method for blood flow imaging maps the blood flow in a vessel, based on the scattering of ultrasonic waves by morphotic elements of blood flowing in the vessel. This permits estimation of the degree of occlusion of vessels from the flow image obtained, localization of stenotic spots and measurement of flow velocity in a given section.

Since 1979, the ultrasonic *c.w.* Doppler method has been used to investigate flows in carotid vessels, at the Institute of Psychoneurology.

The investigations carried out to date on 400 patients, using a UDP ultrasonic flow detector (manufactured by "Techpan") have made possible the study of

1) the usefulness of ultrasonic investigations in the diagnosis of vascular diseases, indicating a high percentage of agreement with the results of clinical studies and X-ray angiography (76 per cent in the material studied); emphasizing the fact that there are possibilities of multiple repetition of the investigation, which permits the evaluation of sclerotic changes [4, 5];

2) the correlation of the results of ultrasonic investigations and X-ray arteriography. Good agreement was found, particularly for occlusion or high vascular stenosis. In the material studied the results agreed in 79 per cent of cases [6]. It was found that it was particularly useful to use the ultrasonic method in the evaluation of the results of operations to improve the patency of extracranial brain-supplying arteries, on the basis of the examination of 25 patients. In those cases the use of X-ray arteriography is absolutely excluded [1].

The present ultrasonic Doppler method gives evidence of reliability, fully justifying the need for the development of this technique, of which the angiosonograph presented here is a consistent example.

2. Instrumentation

Fig. 1 shows a general view of the ultrasonic arterioscope developed by the authors. The system consists of the following units:

1. A mechanical unit, pantograph *1* fixed on a stand which permits the

operation of the device at the bed of the patient in hospital. The pantograph ensures translation of the motion of the probe over the surface of the patients skin at a constant angle of 60° with respect to the skin surface in the motion of a bright spot (cursor) on the display screen.

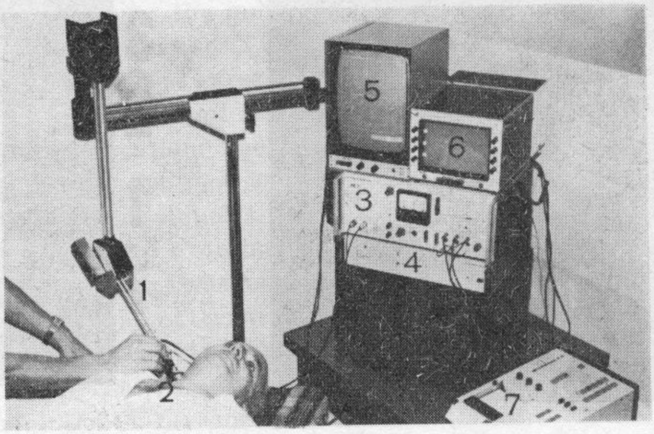

Fig. 1. A general view of the ultrasonic arterioscope: *1* – pantograph, *2* – ultrasonic probe, *3* – two-directional ultrasonic Doppler flowmeter with a system of filters, comparators, coding unit, amplifiers of the coordinate systems of the position of the probe, *4* – image memory system, *5* – TV monitor, *6* – cardiac monitor, *7* – recorder

2. Ultrasonic probe *2* at a frequency of 5 MHz, focusing the ultrasonic beam in the plane of the carotid vessels.

3. Two-directional ultrasonic Doppler flow detector *3*, ensuring the separation of Doppler signals in two channels corresponding to flow velocities in opposite directions. It is possible to register on the external recorder *7* the instantaneous value in the direction + (channel A) or − (channel B) and the resultant flow (channel $A+B$). The Doppler detector is complemented with an imaging signal processing unit. The unit includes filters, comparators and a logical system processing an analog signal of different frequency levels (flow velocities) into a 2-bit binary signal corresponding to a 4-degree grey scale on the display screen.

4. Image memory unit *4*, permitting the storing of arteriograms and their display on the screen. The capacity of the memory is 32k bits ($128 \times 128 \times 2$). The system generates a signal which ensures the achievement on the screen of a two-part image field, with a possibility of an independent recording and storing of the image in both. It also generates a grey-scale band and a flickering bright spot that shows the position of the probe.

5. Black and white or colour TV monitor *5*.

This system can be connected to TIH (Time Interval Histograph) analyser which permits histograms to be shown on the monitor screen.

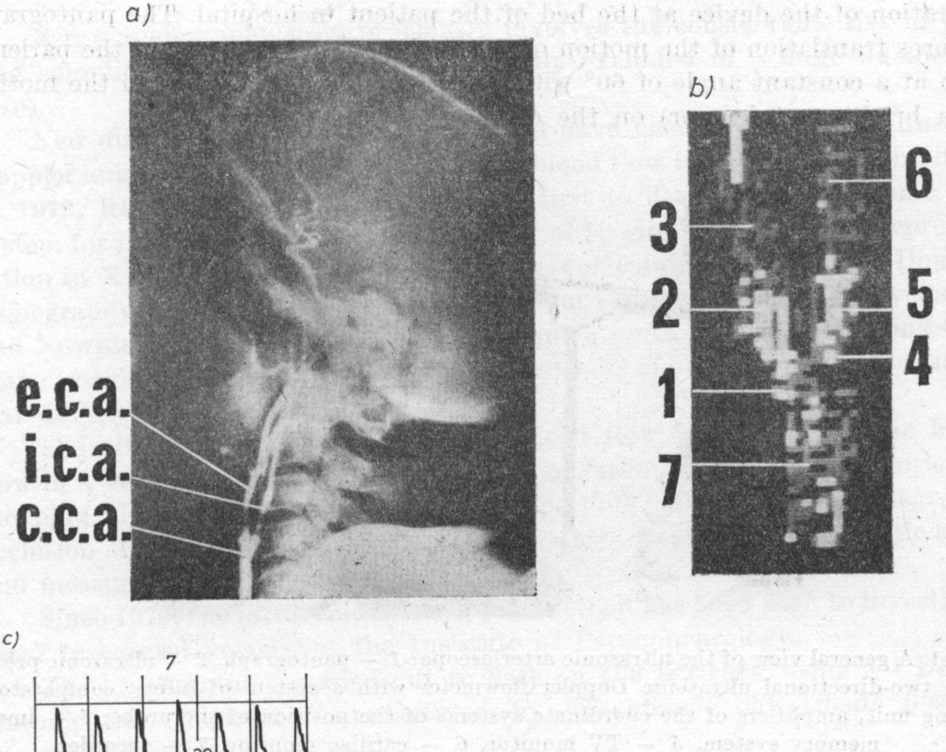

Fig. 2. X-ray (*a*) and ultrasonic (*b*) arteriogram of the carotid arteries and recordings of blood flow velocities in the area of the bifurcation (*c*). *1* – in the external carotid artery, before the stenosis, *2* – in the external carotid artery, in the stenosis, *3* – in the external carotid artery, after the stenosis, *4* – in the internal carotid artery, before the stenosis, *5* – in the internal carotid artery, in the stenosis, *6* – in the internal carotid artery, after the stenosis, *7* – in the common carotid artery. *c.c. a* – common carotid artery, *e.c.a* – external carotid artery, *i.c.a* – internal carotid artery

3. Clinical experimental investigations

The present ultrasonic angiosonograph was used in clinical investigations aimed at the evaluation of the carotid artery patency. A group of 11 patients were examined. The results of ultrasonic investigations were compared with the results obtained using the method of X-ray angiography. As an example, Fig. 2 shows an ultrasonic and X-ray arteriogram of a patient with a stenosis of the external and internal carotid arteries just after the bifurcation. It also shows recordings in a system of zero-crossings of blood flow velocities recorded in the area of the bifurcation. The recordings show a distinct increase in blood flow velocity in the stenotic spot compared with the blood flow velocities measured before and after the stenosis.

In the patient group examined using X-ray angiography the stenosis of the common carotid arteries was found in one case, of the internal carotid arteries in eight cases and of the external carotid arteries in two cases. The degree of all the stenosis cases exceeded 50 per cent. Moreover, in four patients complete occlusion of the internal (three cases) and external (one case) carotid arteries was found using the X-ray method.

The results of the investigations by ultrasonic Doppler angiography were in agreement with those of X-ray examinations in all the cases under study.

4. Conclusions

Preliminary clinical investigations have confirmed the usefulness of ultra sonic angiography in the evaluation of the patency of carotid arteries. The device developed by the authors ensures the possibility of mapping blood flows in blood vessels. The grey scale used by the authors permits the distinguishing of stenotic sections of the vessel through which blood is flowing at increased velocity bright and very bright fields on the monitor screen and the localization of occluded spots in the vessel, which is signalled by the absence of flow (dark field = background on the monitor screen).

Investigations performed on 11 patients have shown agreement between the results obtained by the ultrasonic method and those of the X-ray method in the localization of stenotic spots and occlusion in the carotid arteries.

Further investigations will attempt to determine to what extent the method of ultrasonic angiography permits the degree of the stenosis of a blood vessel to be found.

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