A feasibility study of a screening test for abnormalities of carotid blood flow using Technetium-99m

K. E. BRITTON

From the Institute of Nuclear Medicine, Middlesex Hospital Medical School, London

The assessment of cerebral blood flow by means of radioactive isotopes has become routine in some centres. Various techniques are used. Kak and Taylor (1967) have estimated a derivative of the mean transit time of a gamma emitting isotope by means of a scintillation detector set up over the patient's occiput. Other workers have used multiprobe systems of scintillation detectors set up over the cerebral hemispheres or over small regions of the brain and the rates of radioactive xenon clearance in the fields of view of the detectors have been measured (Høedt-Rasmussen, Sveindattir, and Lassen 1966). The xenon may be introduced either by carotid puncture or by the closed inhalation technique of Veall and Mallett (1966). By analogue computation, Veall (1969) has shown that the latter technique gives results as good as those obtained by direct carotid injection of xenon. These studies have advanced the knowledge of the control of cerebral circulation and the effects of various disorders.

It seems to the author, however, that there is a need for a simple index of right and left carotid blood flow that could be obtained, for example, in out-patients with cerebrovascular disease. A screening test for functionally significant abnormalities of the extracranial carotid vessels which might be correctable by surgery would be useful. Patients presenting with hypertension or with transient ischaemic attacks would be selected for arteriography on the basis of such a test. It has been suggested (Edwards, Gordon, and Rob, 1960) that prophylactic cerebrovascular surgery before a stroke occurs offers the best rewards.

Studies have been undertaken using phantoms to determine the feasibility of measuring an index of right and left carotid blood flow. The structure of the orbits is such that one could focus on each carotid vessel at the apex of each orbit if suitably designed collimated scintillation detectors were used. An experiment was undertaken to study whether discrimination is possible between radioactivity in the

two carotid vessels in this region of the skull. A skull was set up with plastic tubes of appropriate size bent into the shapes of the carotid vessels in the carotid syphon and cavernous sinus. Approximately 100 μ Ci of Technetium-99m was introduced into each tube. This is equivalent to the amount likely to be present in each carotid with the first circulation after an intravenous injection of 5 mCi Technetium-99m. The skull was then fixed facing upwards on a couch and scanned by a Mecaserto MO4 scanner with a 3 in. crystal, set up for Technetium-99m, using a 19-hole focusing collimator. Figure 1b shows that adequate separation of the images due to Technetium in the plastic tubes was obtained. Similarly, separation of the images due to Technetium in plastic tubes placed in the position of the vertebral vessels could be obtained by scanning over the occipital region of the skull (Fig. 1a).

From this study it was felt that a pair of suitably designed focusing collimators could be used to separate the arrival times in the two carotids of an injected bolus of Technetium-99m. A pair of 18-hole lead collimators designed by Mr. N. J. G. Brown and built by Mr. F. R. Smith of the Institute of Nuclear Medicine was used. The 18 conical holes each had an external diameter of 3 mm and an internal diameter of 6 mm and were arranged in two circles with radii of 5 mm and 11 mm. The thickness of the collimator was 4.8 cm and the focal length 6 cm, which is the approximate depth of the carotid vessels from the plane of the orbits. The collimators were designed to be inserted in the cylindrical collimators of internal diameter 7 cm used as part of the renography apparatus (Britton and Brown, 1969). The skin crystal distance used was 5 cm. The renography detectors could be set up facing the orbits of the seated patient, each focused on the region of each carotid artery. A third single hole focusing collimator of external diameter 7 mm, internal diameter 13 mm, and thickness 5.2 cm could be inserted into the third renography detector and set up over the

FIG. 1. (a) Skull with plastic tubes: separation of 'vertebral vessels' by scanning. (b) Skull with plastic tubes: separation of 'carotid vessels' by scanning.

region of the origin of the aorta. A skin distance of 6 cm was used for this detector.

In a second experiment a system of plastic tubes was set up to mimic aortic and carotid blood flow. This system was supplied with a constant flow of water from a tank suspended from the ceiling. An injection of radioactive material was made into the upper part of the system. The bolus of activity then passed in the flow of water under the influence of gravity through a wide bore plastic tube filled with plastic chips, to represent mixing in the pulmonary circulation, and thence through a single tube over which was positioned a scintillation detector. The plastic tube system was then made to divide into two and two other detectors were set up over the branches 20 cm below the centre of the field of view of the first detector. The flow rates in each tube were calculated by timed collections of the effluent. I-131 Hippuran was used and the changes of activity with time were recorded on four-track magnetic tape using inputs from the three detectors of the renography apparatus and a time marker. The tape was played back through the apparatus, one track at a time, to a fast pen recorder. The curves obtained were superimposed and Fig. 2b shows typical results when the flows were almost equal. Figures 2a, c, d show the results obtained for different degrees of constriction of one of the tubes. Various parameters can be obtained from these results.

Measurement was made of the time between the peak of the record from the detector placed over the 'aorta', the 'inflow curve' and the peaks of the records from the detectors over the two 'carotids', 'outflow curves' (Table I). This measure of the times between the peak of the inflow and peaks of the

outflow curves is really a measure of mode transit time between the detectors and is inversely proportional to velocity of flow. However, physiologically, it is the volume flow rate, or bulk flow, that matters to the brain (Jennett, 1968). From a consideration of the formulae for estimating velocity

FIG. 2. Radioactivity-time curves obtained from three detectors set up over the plastic tube system representing aortic and carotid flow. Traces on curvilinear paper read from right to left.

TABLE I

MEASURE OF TIME BETWEEN PEAK INFLOW AND OUTFLOW CURVES

		Tube system			Record	
		Volume (ml.)	Time (sec)	Flow (ml./sec)	Transit time (sec)	Slope (cts/sec/ sec)
(a)	L	40	97.5	0.4	4.63	70
	R	360		3.6	1.25	400
(b)	L	128	64	2.0	2.13	190
	R	145		2.3	1.63	260
(c)	L	28	25	1.1	2.63	160
	R	58		2.3	1.38	340
(d)	L	98	63	1.6	1.5	270
	R	190		3.0	0.88	280

of flow in tubes and bulk flow in tubes, it is likely that the mode transit time would be inversely proportional to the square root of the bulk flow—indeed, a plot of mode transit time versus reciprocal of square root of bulk flow appears linear (Fig. 3).

FIG. 3. Plot of transit time versus reciprocal of square root of volume flow.

The correlation coefficient of 0.967 is highly significant ($P < 0.01$). Thus, although a simple measure of transit time between the peak of the inflow and peaks of the outflow curves may not be a good direct index of differences in bulk flow in the carotids, its relationship with the reciprocal of the square root of the bulk flow may be useful.

Various estimates of the shapes of the curves obtained may be obtained. The initial slope of the curve recorded over the carotid depends on, among other factors, the deformation in shape of the front edge of the injected bolus of activity. The shape of the later part of the curve is likely to depend as much on the distribution of isotope through the brain as on carotid blood flow. The correlation between the measured rate of rise of the initial slope of radioactivity recorded over each 'carotid' and the volume flow rate in each tube is shown in Fig. 4, values

FIG. 4. Plot of the rates of rise of the initial slopes of the outflow curves from the two 'carotids' versus the volume flow rates.

in Table I. The correlation coefficient is 0.89 and is highly significant ($P < 0.01$).

An estimate of the shape of the input function to the carotids is provided by the detector over the 'aorta'. Therefore, an alternative approach would be to compute the spectrum of transit times between the detectors by consideration of a measure of the deconvolution of the inflow curve required, to superimpose it on each outflow curve, as has been suggested for computer assisted blood background subtraction renography (Brown and Britton, 1969). The measure of the spectrum of transit times between aorta and each carotid might allow an index of 'turbulence' of the flow to be determined. This theoretical approach has not yet been attempted.

Other parameters measured were the area under each curve, the time between the start of the initial slope and the peak of each outflow curve, the time between the start of the initial slope of the inflow curve and the start of the initial slopes of the outflow curves, and ratios of the heights of the curves. None of these measurements correlated with the measured volume flow rates as well as did the measurement of the rate of rise of the initial slope of each outflow curve.

Records were obtained from patients seated with the detectors positioned over each orbit and over the root of the aorta as outlined above. Three to 5 mCi of Technetium-99m was injected into an antecubital vein of each patient studied just before the performance of brain scans requested on clinical

FIG. 5. Record obtained using a collimated scintillation detector over a patient's orbit during an injection of 5 mCi of Technetium-99m. The record, on curvilinear paper, reads from bottom to top.

grounds. A typical record is shown in Figure 5. It can be seen that the initial slope of the curve recorded over the orbit can be easily measured. The appearance time in the field of view of each detector can also be measured but the time to peak is more difficult to assess. Similar results may be obtainable from detectors with collimators focused on the vertebral vessels as they run medially behind the lateral masses after curling out of the transverse processes of the atlas, before entering the foramen

magnum. These preliminary studies indicate that it is feasible to make these measurements on patients undergoing brain scans so that the value of these indices of carotid and vertebral blood flow can be assessed. When a suitable fast three-pen chart recorder is available a clinical trial will be undertaken.

SUMMARY

In a branching plastic tube system representing aorta and carotid or vertebral vessels, different volume flow rates were produced by partial constriction of one tube. Using radioactive tracers differences in velocity flow have been related to differences in volume flow in the system. Immediately after an intravenous injection of Technetium-99m, given in order to perform brain scanning, using scintillation detectors positioned over each orbit and the anterior chest, it appears feasible to screen for functionally significant stenoses of carotid vessels in man.

I would like to thank Mr. N. J. G. Brown and Mr. A. E. Todd-Pokropek for their help in making the recordings, Mr. F. R. Smith for building the lead collimators, and Dr. M. Kremer and Dr. E. S. Williams for encouraging this study.

REFERENCES

- Britton, K. E., and Brown, N. J. G. (1969). The use of the radioactive renogram in the reticulos. *Brit. J. Radiol.*, 42, 34-43.
- Brown, N. J. G., and Britton, K. E. (1969). The renogram and its quantitation. *Brit. J. Urol.* (in press).
- Edwards, C. H., Gordon, N. S., and Rob, C. (1960). The surgical treatment of internal carotid artery occlusion. *Quart. J. Med.*, 29, 67-84.
- Hædø-Rasmussen, K., Sveinsdottir, E., and Lassen, N. A. (1966). Regional cerebral blood flow in man determined by intra-arterial injection of radioactive inert gas. *Circulat. Res.*, 18, 237-247.
- Jennett, W. B. (1968). Experimental studies on the cerebral circulation: clinical aspects. *Proc. roy. Soc. Med.*, 61, 606-610.
- Kak, V. K., and Taylor, A. R. (1967). Cerebral blood-flow in subarachnoid haemorrhage. *Lancet*, 1, 875-877.
- Veall, N. (1969). Symposium on cerebral blood flow. British Institute of Radiology. (To be published.)
- , and Mallet, B. L. (1966). Regional cerebral blood flow determination by ^{133}Xe inhalation and external recording: the effect of arterial recirculation. *Clin. Sci.*, 30, 353-369.