J. Neurol. Neurosurg. Psychiat., 1969, 32, 367-378

Regional blood flow in the normal cerebral hemisphere[1]

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Measurement of the rate of clearance of ^{133}Xenon from the brain after injection of this radioisotope into the internal carotid artery has become an accepted method for estimating cerebral blood flow (Høedt-Rasmussen, 1965, 1967; Ingvar, Cronqvist, Ekberg, Risberg, and Høedt-Rasmussen, 1965). Resolution of the clearance curves into two components, fast and slow, may be carried out (Høedt-Rasmussen, 1965, 1967; Ingvar *et al.*, 1965; Wollman, Alexander, Cohen, Stephen, and Zeiger, 1965; Mallett and Veall, 1965). Many workers feel confident that in normal circumstances, at least, the fast component refers to the clearance of ^{133}Xenon from the grey matter, and the slow component refers to its clearance from the white matter (Kety, 1965). If this hypothesis is correct, it means that from a single clearance curve obtained by a gamma-ray detector monitoring cerebral tissue one may ascertain: (1) the blood flow rate in the grey matter; (2) the blood flow rate in the white matter; (3) the relative weights of the perfused grey and white matter in the field of observation of the detector—for example, the cerebral tissue in a particular field of observation might consist of 56% grey matter and 44% white matter; (4) an average flow rate for the cerebral tissue in the field of observation, knowing the perfusion rates and the relative weights of the two component tissues; this is known as the weighted mean flow rate.

Recently the gradient of the initial slope of the clearance curve when plotted logarithmically has been used as an index of flow (Høedt-Rasmussen, Skinkoj, Paulson, Ewald, Bjerrum, Fahrenkrug, and Lassen, 1967; Paulson, 1968) and its value as a rapid assessment of flow in the resting state, and during short-lived physiological test situations, has been stressed.

In this report the clearance of ^{133}Xenon from the cerebral hemisphere after a single intracarotid injection has been observed by 16 regional detectors monitoring different regions of the hemisphere. The study was designed to investigate the homogeneity of blood flow through different parts of the normal cerebral hemisphere, using the results of two-compartmental analysis carried out on a regional basis. These results have been correlated with the initial slope index values to attempt to analyse more closely what this index actually measures.

The salient finding has been that blood flow is not homogeneous throughout all regions of the normal cerebral hemisphere, but that definite regional differences exist.

MATERIALS AND METHODS

Ten normal cerebral hemispheres have been studied. These were patients in whom carotid arteriography was indicated on clinical grounds because of a suspected cerebral lesion, but in whom there were no abnormal physical signs referable to the hemisphere and in whom the carotid arteriogram subsequently proved to be normal. The nature and significance of the test was fully explained to them. The age and diagnosis of the 10 patients appear on Table I. The blood flow study was performed immediately before the arteriogram. All subjects were lightly premedicated with promethazine hydrochloride 12·5 mg and codeine phosphate 60 mg intramuscularly one hour before the study. All received a local anaesthetic of 2% procaine hydrochloride for the carotid puncture, and all were awake and relaxed during the period of ^{133}Xenon clearance.

The ^{133}Xenon was introduced high in the cervical portion of the internal carotid artery via a thin polyethylene catheter introduced into the common carotid artery in the neck and advanced into the internal carotid artery after visualizing the bifurcation with 2 ml. 60% Urografin. ^{133}Xenon, 5 to 8 mC contained within a volume of 8 ml. sterile normal saline, was injected at a fixed pressure and on the R wave of the electrocardiogram by means of an ECG synchronized mechanical injector (Cordis). After the blood flow study the same volume of dilute contrast medium (20% Hypaque) was injected under exactly the same conditions while two lateral skull radiographs were taken at a one second interval. By this means, confirmation was obtained that no reflux of the

[1]This work has been supported by the National Fund for Research into Crippling Diseases.

TABLE I

DETAILS OF THE 10 SUBJECTS IN THE STUDY

Case No.	Age (yr)	Side of hemisphere	Diagnosis	Arterial pCO_2 (mm Hg)	Mean arterial BP (mm Hg)	Fg mean value for hemisphere (ml./100 g/min)	Fw mean value for hemisphere (ml./100 g/min)	Wg% mean value for hemisphere	$\bar{F}$ mean value for hemisphere (ml./100 g/min)	F(initial) mean value for hemisphere
1	18	R	Epilepsy	44	79	81·9	18·0	56·6	53·8	65·3
2	26	L	Epilepsy	49	89	100·4	19·6	49·0	57·9	81·4
3	38	L	Epilepsy	45	88	110·3	23·2	46·1	62·6	76·8
4	41	L	Ipsilateral 3rd nerve palsy	47	94	73·5	21·7	45·0	44·6	49·8
5	48	R	Ipsilateral orbital pain	40	72	113·0	27·2	43·8	64·4	77·7
6	50	L	Contralateral 2nd nerve glioma	50	85	61·8	20·0	38·7	35·8	40·2
7	54	R	Pituitary tumour	43	96	78·7	19·3	41·7	43·7	54·4
8	55	L	Epilepsy	44	80	73·0	19·8	45·9	44·1	54·7
9	61	R	Pituitary tumour	44	89	76·9	19·0	45·7	45·5	58·0
10	64	R	Ipsilateral optic atrophy	45	115	96·0	28·7	42·4	56·5	61·1
Mean				45	89	86·6	21·7	45·5	50·9	59·9
S.D.						17·1	3·7	4·8	9·3	13·5

^{133}Xenon up the external carotid artery had occurred and the distribution of the ^{133}Xenon within the major vessels of the head was ascertained.

The clearance of ^{133}Xenon from the cerebral hemisphere was monitored for at least 15 minutes by 16 collimated detectors contained in a lead-shielded housing placed next to the lateral aspect of the skull. The collimated detectors were advanced a little way through the housing to be in contact with the scalp. The head and housing were then immobilized in this position, and the position was accurately marked radiographically. During the 15 minutes clearance, a specimen of carotid arterial blood was taken for pCO_2 and Hb estimation by Astrup and spectrometric methods respectively. The mean blood pressure in the internal carotid artery was recorded at three minute intervals by a transducer (Bell and Howell Type 4-327) via the catheter.

Each detector consisted of a small disc-like thallium-activated NaI crystal, 5 mm in thickness and 11·5 mm in diameter, recessed 6 mm into the front of the cylindrical detector. The centre of one crystal lay 2·5 cm from the centre of any adjacent crystal. Considerable effort was expended to make the detectors as regional as possible—that is, to have the maximum number of counts coming from the region of cerebral tissue in front of any one detector with the minimum number coming from brain tissue lying in front of adjacent detectors. This was achieved by lower-limit discrimination at 77 KeV and collimation with a cylindrical lead collimator (length 40 mm, internal diameter 12 mm, external diameter 22 mm) containing a cruciate baffle running from the front of the crystal to a point halfway along the lead cylinder. The figure of 77 KeV was reached as a result of phantom work, carried out after the method of Clifton and Potchen (1969).

Figure 1 shows the net effect of such discrimination and collimation compared with the counting geometry when the lower limit discriminator was set at 50 keV and the cylindrical collimator was not baffled. The numbers in the figure show the derivation of 100 counts registered by the crystal. (The values were obtained from *in vitro* experimental work in which a small source of ^{133}Xenon was moved in the horizontal plane of the crystal within a dry skull lined with polyethylene and filled with water. The two-dimensional values were then integrated to yield three-dimensional values as in Fig. 1). The region within the inner cylinder represents the brain tissue anatomically in front of only one detector—that is, the region from which the maximum number of counts are required to be derived. After modification of the collimator and discriminator 77% of the counts were derived from this region, representing a considerable improvement on 56% which was the value before modification.

During the clearance of ^{133}Xenon from the cerebral hemisphere, the concentration of ^{133}Xenon within the field of measurement of each detector was registered in terms of count rate in digital form onto a 16 channel one inch magnetic tape recorder (Meditronic). Subsequently the tape could be replayed, two channels at a time through two digital rate meters. This was done in two ways: (1) with a time constant of 0·4 seconds to write out the first one minute of the clearance curve, showing the configuration of this part of the curve, revealing 'arterial' spikes and demonstrating the time taken for the maximum count rate to be achieved. (2) This was carried out with a time constant of 12 seconds to print out the count rate through the whole clearance curve. It was found that shorter time constants did not alter the shape of the clearance curves when plotted logarithmically against time, whereas longer time constants did conceal important details of the early part of the curves.

Analogue write-out of the curves was not employed.

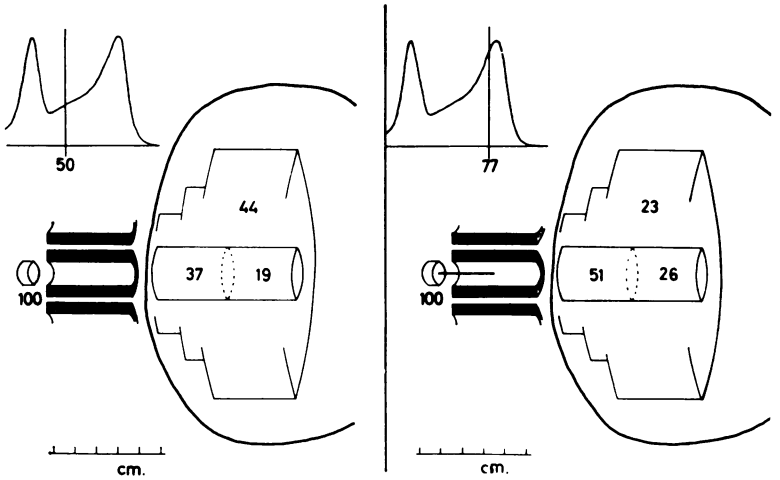

FIG. 1. *Three-dimensional representation of the source of 100 counts registered by a detector (a) on the left, using a simple cylindrical collimator and lower limit discriminator set at 50 KeV; (b) on the right, using the baffled collimator and lower limit discriminator set at 77 KeV.*

After correction for background the clearance curves, as counts per 12 second interval, were plotted logarithmically against time for a minimum of 15 minutes (Fig. 2). Compartmental analysis was performed on these logarithmic plots, and from each clearance curve the following five variables were calculated:

Fg the perfusion rate of the grey matter in ml./100 g/min.

Fw the perfusion rate of the white matter in ml./100 g/min.

Wg the relative weight of the grey matter as a percentage of the total weight of tissue being monitored by the detector.

$\bar{F}$ the weighted mean flow rate in ml./100 g/min: if, for any region of the cerebral hemisphere, the perfusion rates in the grey and white matter are known, and the relative weights of the perfused grey and white matter are also known, an average flow rate for the region can be obtained. This is the weighted mean flow value.

F(initial) the 'initial log slope' flow index estimated from the gradient of the first two minutes of clearance. (Høedt-Rasmussen *et al.*, 1967; Paulson, 1968).

THE MODE OF PRESENTATION OF THE RESULTS In each of the 10 cases, 16 regional values for Fg, Fw, Wg, $\bar{F}$, and F(initial) were obtained. In any one case, for each of the

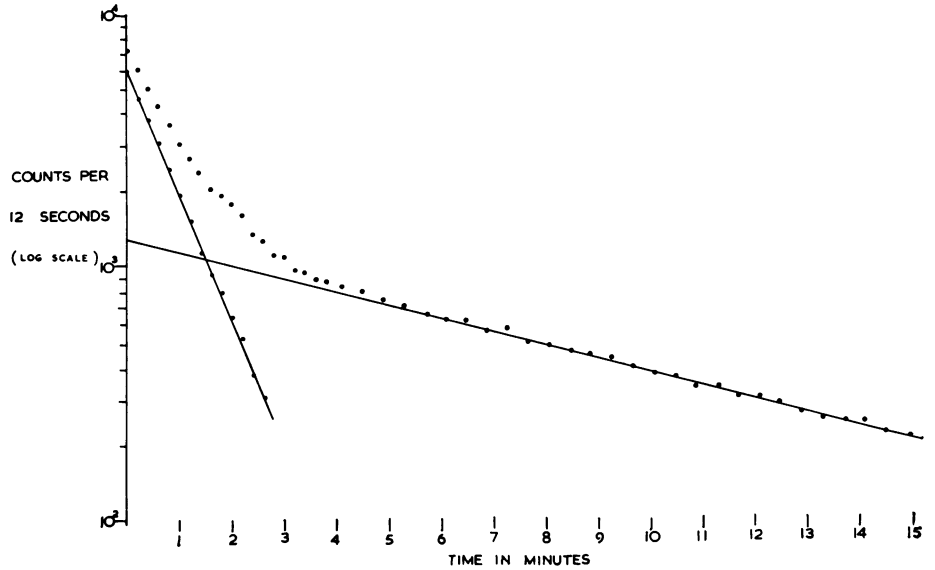

FIG. 2. *A ^{133}Xenon clearance curve, plotted logarithmically against time, represented by the upper series of dots. The clearance of ^{133}Xenon from the white matter is represented by the shallow exponential, and its clearance from the grey matter is represented by the steep exponential.*

five variables, the following procedure was adopted.

First an outline of the lateral radiograph of the skull showing the precise position of the detectors during the clearance of ^{133}Xenon was drawn. The endocranial margin of the skull was used, the tip of the anterior clinoid process was marked, and the clinoparietal line (Taveras and Wood, 1964) was drawn. This joins the tip of the anterior clinoid process with a point on the skull vault 2 cm above the lambda in the midline. The 16 regional values, in their units of measurement, were added to this diagram (Fig. 3).

From these 16 regional values the mean value for the cerebral hemisphere was calculated. It will be seen from Table I that the mean value for the hemisphere varied considerably in the 10 patients. To make the results of one patient comparable with those of the rest, it was necessary to express the 16 regional values as a percentage of the mean value for the hemisphere (Fig. 3).

The 10 cases were then accumulated onto one diagram by writing all the regional values on one sheet of paper, fixing the positions of the anterior clinoid process and the clino-parietal line (Fig. 4). The inaccuracies due to the 10 heads being slightly different in shape and size were accepted.

The regional values were then grouped into 16 regions over the hemisphere. The mean value and standard deviation for each of the 16 regions was calculated (Fig. 5). Using a pooled standard deviation, derived from the 16 regions, the significance of the difference of the regional values from the mean value of 100 was calculated at two levels of statistical significance (Fig. 6). This was the way in which the regional pattern for each of the five variables was demonstrated in this report.

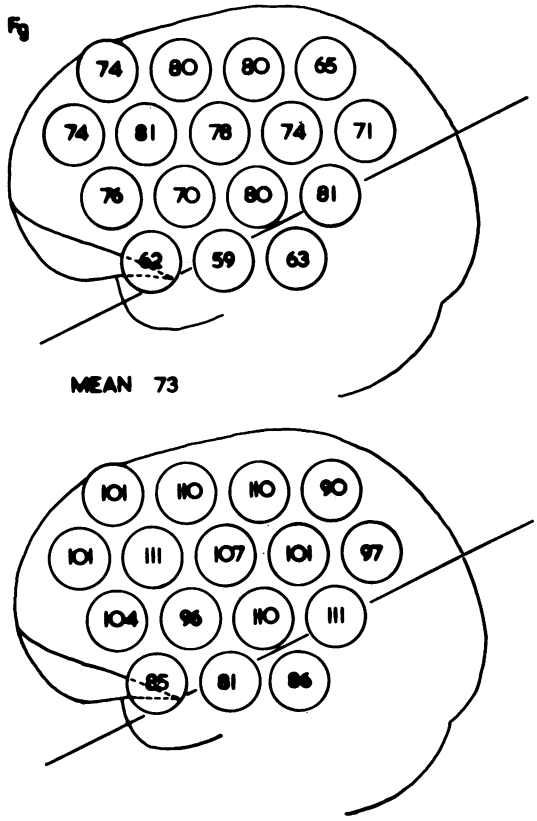

FIG. 3. *Regional values for perfusion of grey matter (expressed as ml./100 g/min) in one cerebral hemisphere are written in the upper part of the figure. The mean value for this hemisphere was 73 ml./100 g/min. In the lower part of the figure the same regional values are re-expressed as percentages of the mean value for the hemisphere.*

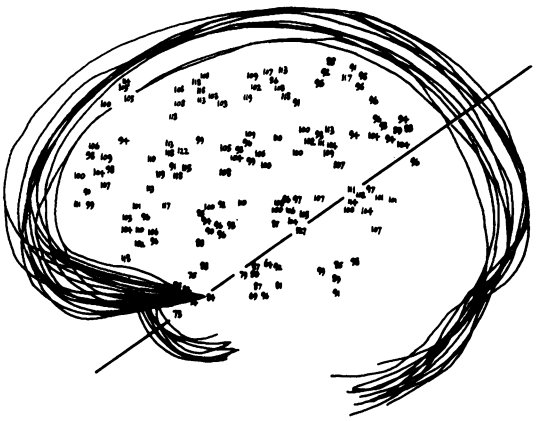

FIG. 4. *The regional values for perfusion of grey matter (expressed as percentages of the mean value for the hemisphere) of all 10 subjects superimposed onto one composite diagram.*

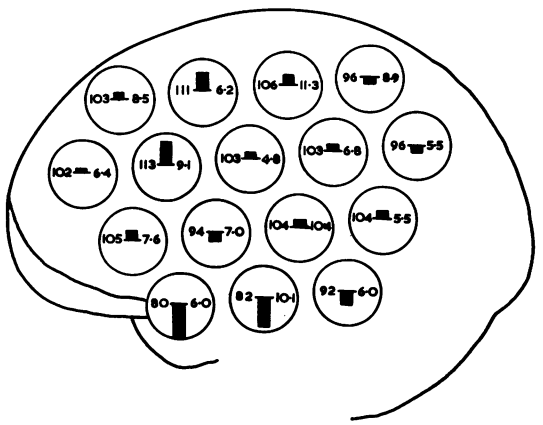

FIG. 5. *Regional values for perfusion of grey matter (derived by grouping of the values in Fig. 5). In each circle the regional value based on the 10 subjects appears on the left, with the SD on that value on the right. The regional values are expressed as percentages of the mean value of the hemisphere.*

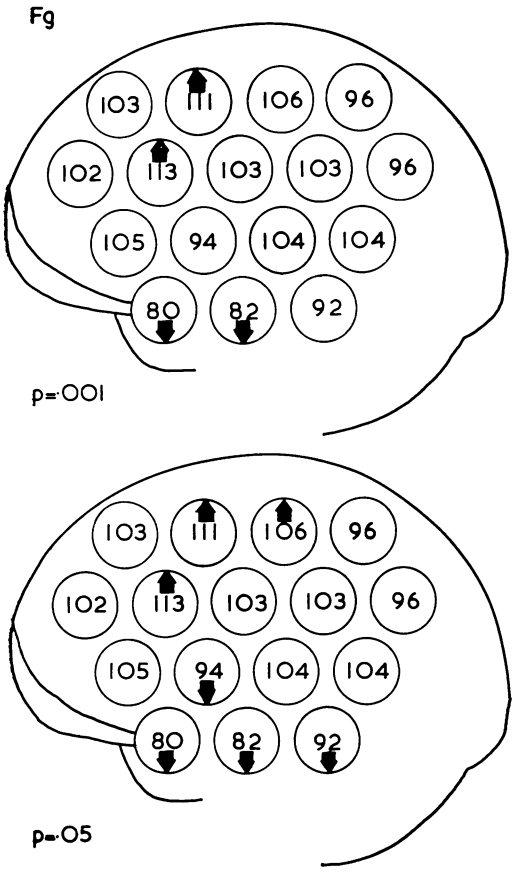

FIG. 6. *The same regional values for perfusion of grey matter as in Figure 5. Here the regions which are significantly different from the mean value for the hemisphere at the 0·001 level are indicated in the upper part of the figure, and at the 0·05 level in the lower part of the figure.*

RESULTS

Table I shows the mean hemisphere values for the five variables which were measured, Fg, Fw, Wg, $\bar{F}$, F(initial), together with the age, diagnosis, mean blood pressure, and arterial pCO_2 levels at the time of the blood flow study in the 10 subjects.

Figures 6 to 10 show the mode of distribution of the five variables throughout the hemisphere, the values being expressed as percentages of the mean for the hemisphere.

PERFUSION OF THE GREY MATTER The mean values for the hemisphere showed considerable variation among the 10 cases, who were studied under the same conditions with similar $ApCO_2$ and mean blood pressure levels (Table I). This variation could not be correlated with age or any other clinical feature of the subjects. Figure 6 shows that the grey matter in the temporal region was less well perfused with blood than the rest of the hemisphere, and an area in the precentral region was more highly perfused than the rest of the hemisphere.

PERFUSION OF THE WHITE MATTER Considerable variation was found among the mean values for the hemisphere in the 10 subjects. Fg and Fw appeared to vary independently in the 10 subjects (Table I). Figure 7 shows that the white matter in the region of the internal capsule was more highly perfused than the rest of the white matter in the hemisphere. Low values for white matter perfusion were found in the frontal region.

THE DISTRIBUTION OF GREY MATTER WITHIN THE HEMISPHERE Table I shows the value of 45·5% for

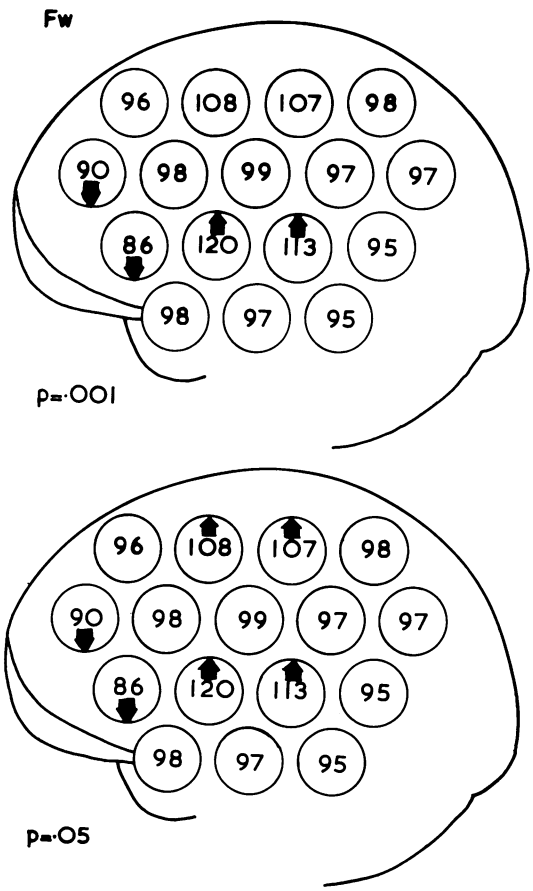

FIG. 7. *Regional values for perfusion of white matter based on the 10 subjects (see legend of Fig. 6).*

the mean value of the percentage weight of grey matter in the hemisphere in the 10 subjects. From this Table it is apparent that there was less variation about this mean value than there was in the case of the mean values for the perfusion of the grey and white matter. No correlation of the observed variation in the amount of grey matter with age or clinical features of the subjects was found.

There was a very definite regional pattern for the distribution of grey matter throughout the cerebral hemisphere as shown in Figure 8. High values corresponding to 55 to 60% grey matter were found over the insular region extending forwards and downwards to the anterior tip of the temporal lobe. Very low values corresponding to 30 to 37% grey matter were found in the regions of the corpus callosum and corona radiata. Over the convexity of the hemisphere, measured tangentially by the detectors used in this study, intermediate values corresponding to 50% grey matter were found.

The five left hemispheres and the five right hemispheres were separately grouped and compared. Though there was more grey matter in the mid-temporal region on the left, more grey matter in the parietal region on the right, and very close agreement between the two sides in all other regions, none of these changes was big enough to assume statistical significance.

REGIONAL WEIGHTED MEAN FLOW VALUES The overall mean value for the weighted mean flow in the 10 hemispheres of this study was 50·9 ± 9·3 ml/100 g/min. (Table I). This compound expression of regional flow, depending on the values for Fg, Fw, and Wg in the region, shows a regional pattern (Fig. 9) based upon the distribution of Fg, Fw and

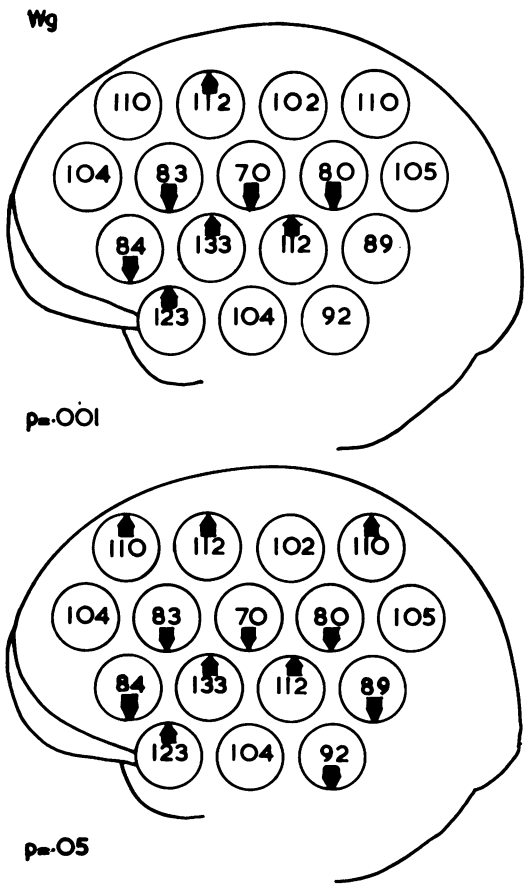

FIG. 8. *Regional values for the relative weight of grey matter based on the 10 subjects (see legend of Fig. 6).*

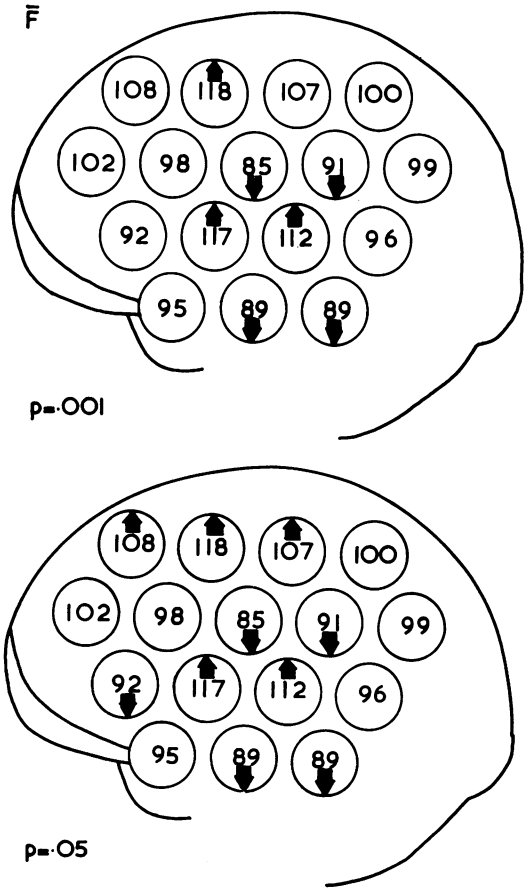

FIG. 9. *Regional values for weighted mean flow based on the 10 subjects (see legend of Fig. 6).*

Wg throughout the hemisphere. High values were found in the insular region and, to a lesser extent, over the convexity in the precentral regions. Low values were obtained in the temporal regions, especially posteriorly, and in the regions of the corona radiata in the parietal regions.

THE 'INITIAL LOG SLOPE' FLOW INDEX The overall mean value of 59·9 (Table I) is numerically nearer the $\bar{F}$ value than the Fg value. The variation around the overall mean of F(initial) is slightly greater than that around either the $\bar{F}$ or Fg mean values.

The regional pattern of F(initial) is shown in Figure 10. This pattern was found to resemble most the regional pattern of $\bar{F}$, rather than those of Fg, Fw, or Wg.

The F(initial) regional values have been correlated with the regional values of Fg, $\bar{F}$, and Wg by drawing regression lines. There was virtually no correlation between F(initial) and Wg and only a poor correlation between F(initial) and Fg. There was however a very strong correlation between F(initial) and $\bar{F}$ as shown in Fig. 11, which contains all the individual regional values from the 10 subjects plotted in their original units of measurement. It can be seen that the initial slope flow index gives a progressive over-estimation of $\bar{F}$ at higher flow levels. Within these limits, however, a F(initial) value can be related to a $\bar{F}$ value.

REPRODUCIBILITY OF THE METHOD If one variable—for example, Fg—appears high in one region of the hemisphere when measured on one occasion but appears low when measured on a second occasion, two explanations are possible. The more likely is that the method of measurement is inaccurate and does not yield the same result on two occasions in the presence of identical conditions. The second explanation is that there is little or no measurement error but that there are regional changes in the variable itself from time to time. These two explanations could not be separated in the present study, but the magnitude of the two possibilities combined together could be estimated and was called *measurement error* in this report.

In five of the 10 subjects, a second separate study of blood flow was performed 30 minutes after the

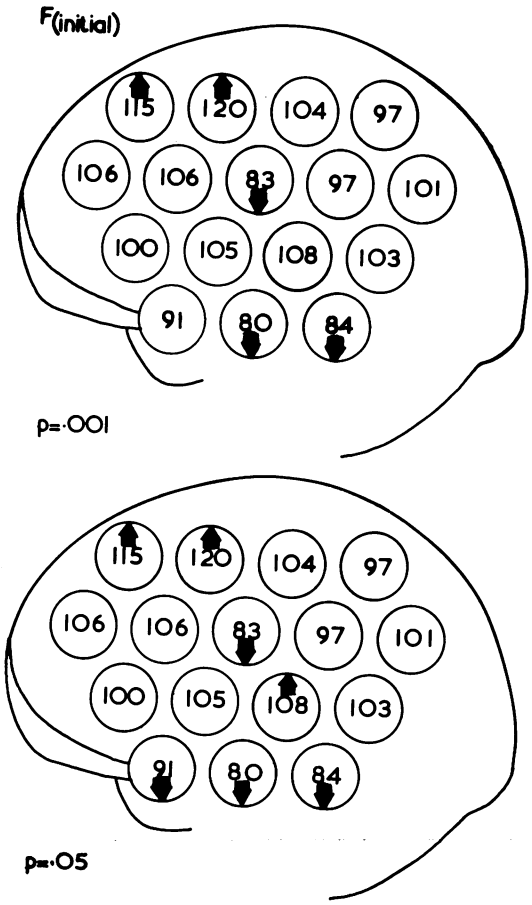

FIG. 10. *Regional values for the initial log slope flow index based on the 10 subjects (see legend for Fig. 6).*

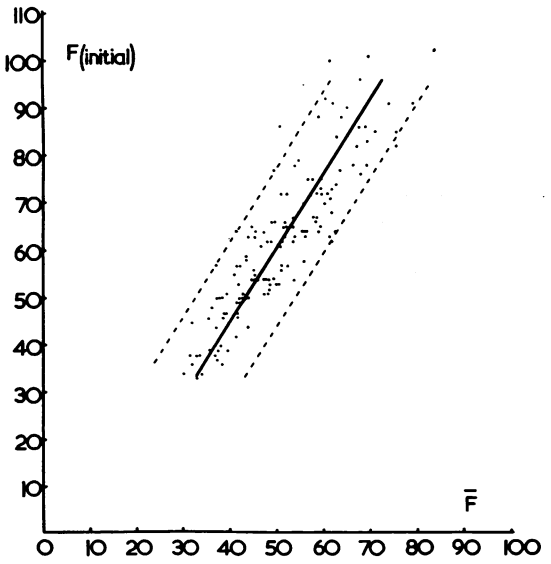

FIG. 11. *The correlation of the initial log slope flow index with the weighted mean flow value ($r = 0{\cdot}876$, $n = 140$). Both are expressed in their units of measurement in this figure. From the regression line, $\bar{F} = 12{\cdot}1 + (0{\cdot}627 \times F(initial)) \pm 5{\cdot}3$.*

first, by which time there was no ^{133}Xenon remaining in the hemisphere from the first injection. The results for any one patient were prepared exactly as described. Each regional value, expressed as a percentage of the mean for the hemisphere, was established for the first and second studies respectively (Table II). The difference between the two values was calculated. The standard deviation of the difference between the 16 regional values on the two occasions of measurement was estimated and called 'SD(diff.)'. 'SDdiff.' is an estimate of the SD due to measurement error based upon two observations, and has to be divided by $\sqrt{2}$ to yield the value of the SD due to measurement error.

TABLE II

THE RESULTS OF TWO SEPARATE ESTIMATIONS OF PERFUSION OF GREY MATTER IN 16 REGIONS OF ONE CEREBRAL HEMISPHERE

Detector	*Fg expressed as percentage of mean*		*Difference between A and B*
	Study 1 A	*Study 2 B*	
1	112	102	+ 10
2	115	118	− 3
3	85	95	− 10
4	100	96	+ 4
5	102	97	+ 5
6	112	109	+ 3
7	104	113	− 9
8	107	113	− 6
9	89	94	− 5
10	125	122	+ 3
11	106	96	+ 10
12	92	92	0
13	95	97	− 2
14	72	64	+ 8
15	88	86	+ 2
16	96	109	− 13
Mean	100	100	0
SD			6·8 = SD (diff)

$$\text{SD due to measurement error} = \frac{\text{SD(diff.)}}{\sqrt{2}} = 4{\cdot}8$$

Table III shows the SD due to measurement error for each of the variables Fg, Fw, Wg, $\bar{F}$, and F(initial) in each of the five subjects. It also demonstrates the overall SD due to measurement error for each variable based upon the 5 × 16 separate values. From these figures it can be said that Fg, expressed as a percentage of the mean for the hemisphere, can be calculated with a standard deviation of 5·3%, and similarly the limits of accuracy of measurement for the other variables is known.

TABLE III

ESTIMATION OF MEASUREMENT ERROR

Case no.	*SD due to measurement error*				
	Fg	*Fw*	*Wg*	$\bar{F}$	*F initial*
1	4·4	5·5	4·8	5·3	3·8
3	4·8	4·4	2·8	4·3	6·2
6	6·2	3·9	4·8	3·6	5·4
7	5·7	5·6	4·5	5·3	8·0
8	5·1	6·0	5·0	4·2	4·6
All five together	5·3	5·1	4·4	4·6	5·8

The mean results for the hemisphere, and the conditions of arterial pCO_2 and blood pressure, for the two occasions of measurement are shown in Table IV. It will be noted that there was a tendency for all the flow values, and the estimated weight of perfused grey matter, to be lower on the second study than the first. This occurred although the second arterial pCO_2 level tended to be higher than the first.

Experimental work performed to confirm the pattern of distribution of the grey matter in the hemisphere derived from ^{133}Xenon clearance A normal brain was removed at necropsy and fixed in such a way as to minimize any anatomical distortion. After fixation, the left hemisphere was removed, laid upon its medial aspect, and sliced in the coronal and horizontal planes to reduce the hemisphere to a number of rectangular blocks. The amount of grey and white matter in each block was estimated by careful dissection and weighing. The weight of grey matter was then expressed as a percentage of the total weight of each block (Fig. 12). The total weight of grey matter expressed as a percentage of the total weight of the hemisphere was 57% grey matter.

The 38 regional values were then expressed as a

TABLE IV

DETAILED RESULTS IN THE FIVE SUBJECTS STUDIED TWICE

Case no.	*Arterial pCO_2 (mm Hg)*		*Mean arterial BP (mm Hg)*		*Fg mean value for hemisphere (ml./100 g/min)*		*Fw mean value for hemisphere (ml./100 g/min)*		*Wg% mean value for hemisphere*		*$\bar{F}$ mean value for hemisphere (ml./100 g/min)*		*F(initial) mean value for hemisphere*	
	1	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
1	42	44	74	79	88·9	81·9	19·3	18·0	58·3	56·6	59·4	53·8	73·2	65·3
3	44	45	86	88	113·2	110·3	24·1	23·2	51·0	46·1	68·8	62·6	82·9	76·8
6	44	50	82	85	67·4	61·6	21·0	19·9	41·4	38·1	39·7	35·4	43·9	40·2
7	40	43	97	96	78·3	78·7	19·9	19·3	42·8	41·7	44·4	43·7	53·0	54·4
8	42	44	84	80	82·4	73·0	20·8	19·8	49·5	45·9	51·0	44·1	64·6	54·7

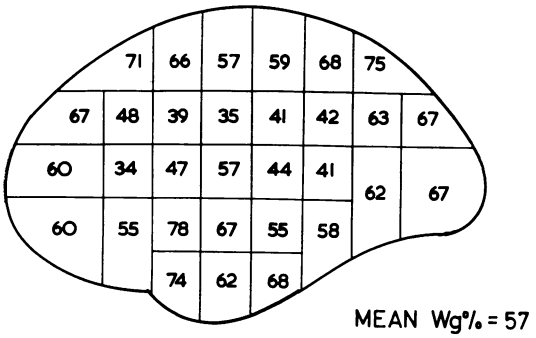

FIG. 12. *The relative weight of grey matter in different regions of one normal post-mortem cerebral hemisphere. The weight of grey matter is expressed as a percentage of the total weight of brain in each region.*

percentage of the mean for the hemisphere (57%), and in this way figures were obtained which were directly comparable with the accumulated normal Wg pattern derived from the clearance of ^{133}Xenon (Fig. 13). The correlation both in terms of pattern and actual numerical values was good.

DISCUSSION

When the clearance of ^{133}Xenon is recorded from the cerebral hemisphere, the clearance from two tissues, grey and white matter, is really being recorded simultaneously. These tissues differ widely in their perfusion rates, and also differ widely in their relative amounts in different parts of the hemisphere. The clearance curves can be resolved into the two components which represent grey and white matter respectively. It is therefore possible to identify the rates of perfusion of the grey and white matter, and the relative amounts of these two tissues, on a regional basis throughout the normal hemisphere.

PERFUSION OF THE GREY MATTER The variability in the mean values (Table I) in the 10 normal hemispheres is interesting, if blood flow is intimately dependent on metabolic demands. There were no obvious clinical differences between patients with grey matter perfusion rates of over 100 ml./100 g/min and those with rates of 60 to 70 ml./100 g/min. A wide range of values for the perfusion of grey matter exists in normal people.

Regional differences in grey matter perfusion throughout the normal cerebral hemisphere have not been previously documented, except by Ingvar *et al.* (1965) who showed significantly lower cortical flow in the 'temporal' region using their four detector unit. They thought this regional difference might be due to isotope recirculation, but this seems to be most

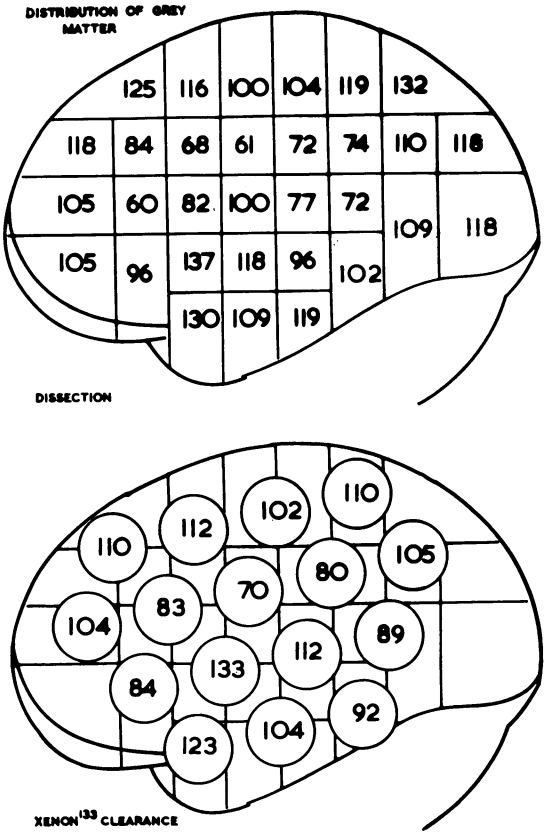

FIG. 13. *Regional values for the relative weight of grey matter, expressed as percentages of the mean value for the hemisphere. In the upper part of the figure the values are obtained from one normal post-mortem cerebral hemisphere, in the lower part from the ^{133}Xenon clearance curves in the 10 subjects of this study.*

unlikely for three reasons. First, we have found recirculation to be higher in the frontal region than in the temporal region. Secondly, the perfusion of grey matter is estimated from the first three to four minutes of clearance in most cases, and the count rate over the head due to recirculating isotope does not become maximal until two and a half to three minutes after the onset of clearance. Thirdly, the count rate due to recirculation is not large enough to have any significant effect on the slope of the clearance of ^{133}Xenon from the grey matter.

Thus it appears that the high values for cortical flow in the precentral region and the low values in the temporal region are genuine.

The low values in the temporal region are not due to the basal ganglia, as the basal ganglia lie on the horizontal level of the insula, higher than the

detectors covering the temporal lobe. The low values are thought to represent low perfusion of the cortex of the temporal lobe itself.

The reasons underlying the high precentral and low temporal values of cortical flow are obscure.

PERFUSION OF THE WHITE MATTER The high values for perfusion of the white matter in the region of the internal capsule can be correlated well with the morphological studies on the human cerebral arterial vasculature made by Ross Russell (1963). Using a microradiographic technique for the examination of small cerebral arteries, he demonstrated the abundance of small perforating arterial vessels, between 100 to 400 μ in diameter, entering the globus pallidus and putamen and traversing the internal capsule to reach the caudate nucleus and thalamus. Ross Russell observed that these vessels had fewer branches in the internal capsule than in the grey matter of the basal ganglia. There is, however, no doubt that the white matter of the internal capsule has more vessels of this size running through it than white matter anywhere else in the hemisphere. Whether this is associated with a higher capillary density in the white matter of the internal capsule than the white matter elsewhere in the hemisphere was not part of Ross Russell's study. Klosovskii (1963), on the basis of extensive capillary staining studies of human and animal cerebral hemispheres, found that the arterial branches supplying the basal ganglia form networks with each other and with the vessels of the adjacent white matter. The capillary networks of the basal ganglia and adjacent white matter are thus closely interconnected, so much so that arterial branches may seem to spread beyond the limits of the basal ganglia and to anastomose in their vicinity with vascular branches in the white matter.

A definite statement that the capillary density of the white matter of the internal capsule is greater than that of the rest of the white matter in the hemisphere, cannot be found in the literature. Nevertheless an anatomical correlation with the high perfusion of the internal capsule is thought to be present in (1) the abundance of small arteries running through it and (2) the close interconnection of the capillary networks of the internal capsule and the basal ganglia.

Low values for white matter perfusion were found in the frontal regions. These low values are most probably artefactual due to the slow clearance of ^{133}Xenon from the poorly perfused extracerebral structures supplied by the supraorbital, supratrochlear, and meningeal branches of the ophthalmic artery. This artefact is unavoidable, since the ^{133}Xenon is injected into the internal carotid artery proximal to the origin of the ophthalmic artery.

REGIONAL DISTRIBUTION OF GREY MATTER The overall mean value for the relative weight of grey matter in the 10 hemispheres of this study was 45·5%. This is very similar to the values appearing in other series in which a value for the percentage weight of grey matter is derived by compartmental analysis of ^{133}Xenon clearance curves recorded by laterally situated detectors (Ingvar *et al.*, 1965; Høedt-Rasmussen, 1967; Munck, Bärenholdt, and Busch, 1968). By post-mortem dissection the relative weight of the grey matter in one normal hemisphere was found to be 57%, and this value is similar to the results of other workers using *in vitro* methods (described by Høedt-Rasmussen, 1967). In general the ^{133}Xenon method gives lower values for hemisphere grey matter than *in vitro* methods. The most likely explanation for this lies in the facts that the medial aspect of the hemisphere is virtually all grey matter, and ^{133}Xenon emits a low energy gamma ray of 81 KeV with low tissue penetration. Being furthest away from laterally situated detectors during ^{133}Xenon clearance studies, the medial grey matter contributes relatively less than its anatomical weight.

The degree of correlation between the distribution of grey matter throughout the hemisphere estimated by dissection and by ^{133}Xenon clearance was high. This was construed as good evidence that what has been called grey matter estimated from the fast component of the clearance curves does actually represent grey matter.

The marked regional pattern for the distribution of the grey matter in the hemisphere is not surprising. Figure 14 is a tracing of a coronal section of the brain (taken from the atlas of Dalmas and Pertuiset, 1959) also showing four detector fields. When highly regionalized detectors are being used, one would anticipate high values for Wg to be recorded from detector 3, low values from detector 2, and intermediate values from detectors 1 and 4. In the 10 normal cases, the mean value for Wg in the insular region was almost twice the mean value in the adjacent region overlying the corona radiata and corpus callosum.

REGIONAL WEIGHTED MEAN FLOW VALUES In any region of the hemisphere the weighted mean flow in the region being monitored by a detector depends upon the magnitude of Fg, Fw, and Wg in that region. Mean flow may be low because of low perfusion of the grey matter, or because of a reduced amount of perfused grey matter, or, to some extent, because of low perfusion of the white matter. ($\bar{F}$ is numerically more dependent on grey matter than white matter perfusion because the former is very much larger. If Fg is halved,—for example, 80 becomes 40—it has a much greater effect on $\bar{F}$ than if Fw is halved—for

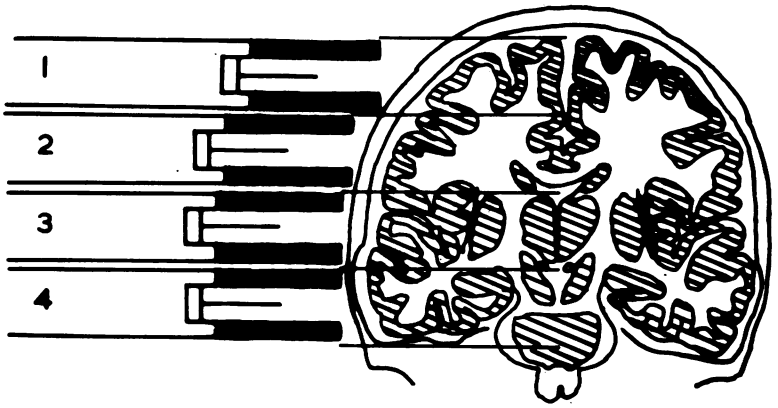

FIG. 14. *A coronal section of brain (taken from the atlas of Dalmas and Pertuiset, 1959) also showing four detector fields.*

example, 20 becomes 10). If one only has a mean flow value, or an index of mean flow such as F(initial), and one obtains an abnormal value, one does not know whether this is due to an abnormality in the perfusion of the grey matter, or an abnormality in the amount of grey matter perfused, or even due to an abnormality of white matter perfusion.

As cerebral blood flow detectors become more regional, the lack of homogeneity of perfusion and distribution of the grey and white matter is revealed. Mean flow values and indices become progressively less informative. It becomes necessary to identify the two individual components separately, so that the maximum amount of information from the clearance curves is obtained, and an accurate estimate of perfusion of the cerebral tissue in that region is given.

SUMMARY

1. Cerebral blood flow has been estimated in 16 regions of 10 normal cerebral hemispheres using the intracarotid ^{133}Xenon injection method. The detectors were situated on the lateral aspect of the skull. The clearance curves were resolved by compartmental analysis to give regional values for perfusion of grey matter (Fg), perfusion of white matter (Fw), the relative weight of grey matter in the region (Wg), and the weighted mean flow value for the region ($\bar{F}$).

2. The perfusion of grey matter was low in the temporal region and high in the precentral region.

3. The white matter of the internal capsule was more highly perfused than the white matter elsewhere in the hemisphere.

4. The regional distribution of the grey matter was well shown by this method, with high values in the insular region, low values over the corona radiata and corpus callosum, and intermediate values over the convexity of the hemisphere.

5. Using regional detectors which show the lack of homogeneity of Fg, Fw, and Wg throughout the normal hemisphere, $\bar{F}$ values were found to be less informative, and more difficult to interpret, because a low $\bar{F}$ value in any region may be due to either low Fg, low Fw, or low Wg.

6. The 'initial log slope' flow index was found to correlate best with the $\bar{F}$ values, rather than with Fg, Fw, or Wg values.

The authors would like to acknowledge the help of Professor P. Armitage of the Department of Medical Statistics and Epidemiology at the London School of Hygiene and Tropical Medicine, also the University College Hospital Medical Physics Department (in particular Mr. D. J. Wills and Mr. K. Cassells) for their help in modification of the equipment, and Mrs. J. B. Wilkinson and Miss S. M. Bell for their technical assistance.

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