FURTHER STUDIES ON THE CEREBRAL BLOOD FLOW ESTIMATED WITH THORIUM-B-LABELLED ERYTHROCYTES

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Since our first preliminary report (Nylin and Blömer, 1955) we have continued our studies on the cerebral blood flow with radioactive-labelled erythrocytes. The experimental conditions have been the same as before, with the exception that one of us (H. B.) has used a special technique for blood sampling. Blood is drawn simultaneously from both jugular bulbs. In a rotating disc two rows of test tubes are inserted and the disc placed within an exicator, which is evacuated to a fixed pressure. With this arrangement it is possible to fill two test tubes simultaneously at constant time intervals. A somewhat similar apparatus has been constructed by one of us (G. N.), but as it has not been used in observations described in this report, it will be described and published later.

The same method as in our first report has been applied for labelling the erythrocytes with thorium B as well as for measuring the activity. Mathematical calculations of the cerebral blood flow have been carried out in the same way as in our first report, but some other relationships have also been computed. Thus, the cardiac output from the dilution curves from the jugular bulbs after intravenous injection of thorium-B-labelled erythrocytes has been estimated.

The material is rather heterogeneous. Cases with different clinical diagnoses such as hypertension, cerebral hæmorrhage, and cerebral thrombosis are included as well as normal subjects. It has still not been possible to investigate thoroughly the influence of different clinical conditions on the cerebral blood flow. It is, however, our intention to do this in future studies.

The material has been divided into two groups. In Group I (11 cases) injections of thorium-B-labelled erythrocytes in the internal carotid artery have been performed. Simultaneous sampling of blood from both jugular bulbs has been immediately carried out.

In Group II (18 cases), after injection of labelled erythrocytes in an arm vein, simultaneous sampling has been effected from both jugular bulbs and one brachial artery.

RESULTS

Group. I. Injection of thorium-B-labelled erythrocytes in the internal carotid artery and simultaneous blood sampling from both jugular bulbs.

In 7 cases we succeeded in puncturing the jugular bulb on both sides. Thus two dilution curves were obtained simultaneously. In the remaining four cases only one jugular bulb was punctured. The results are to be found in Table I.

The seven cases with samples drawn simultaneously from both bulbs were 2006, 2007, 2015, 2017, 2029, 2030, and 2031. Only in three of these Cases 2007, 2017, and 2029, did we obtain rather similar results for the cerebral blood flow from the two jugular bulbs. In these cases parallel curves from both jugular bulbs are to be found (Fig. 1 and 2). There is a fairly big difference between the values of the cerebral blood flow calculated from the two dilution curves: in Case

TABLE I
CEREBRAL BLOOD FLOW IN 11 CASES DETERMINED BY INTRA-ARTERIAL INJECTION OF THORIUM-B-LABELLED RED CELLS
INTO ONE CAROTID ARTERY

Case No.	Dilution curve from jugular bulb	Cerebral blood flow (mean value, litres/min.)		Cerebral pool volume (mean value, litres)		Turnover cerebral blood flow cerebral pool volume	Total blood volume (litres)	Cerebral pool volume as percentage total blood volume
2001	R	0.50		0.050		10.0	3.120	1.6
2003	R	1.00		0.100		10.0	3.050	3.3
2006a	L	0.57	0.49	0.065	0.057	8.6	4.010	1.4
2006b	R	0.40		0.048				
2015	R	1.20	0.84	0.075	0.062	13.5	3.980	1.7
	L	0.48		0.048				
2017	R	1.00	0.97	0.065	0.066	14.7	4.550	1.5
	L	0.93		0.066				
2032	R	0.80		0.091		8.8	3.460	2.6
2033	R	0.64		0.046		13.9	2.910	1.6
2007	R	1.07	1.02	0.097	0.094	11.0	3.650	2.6
	L	0.97		0.090				
2029	R	1.36	1.25	0.093	0.085	14.7	4.210	2.0
	L	1.14		0.076				
2030	R	0.78	0.92	0.086	0.100	9.2	2.520	4.0
	L	1.05		0.114				
2031	R	0.59	0.80	0.075	0.095	8.4	3.520	2.7
	L	1.02		0.115				
	General mean	0.84		0.077		11.2	3.544	2.3

2007, 100 c.c., i.e. 10 per cent of the mean, in Case 2017, 70 c.c. or 7 per cent, and in Case 2029, 220 c.c. or 18 per cent of the mean. Rather high values of the cerebral blood flow are obtained, viz. 1020 c.c., 970 c.c., and 1250 c.c. respectively. The blood content of the brain (cerebral pool volume) shows a difference between the calculated values, estimated from two venous curves, in Case 2007 of only 7 c.c., i.e. 7 per cent of the mean, in Case 2017 of only 1 c.c. or 2 per cent, and in Case 2029 of 17 c.c. or 20 per cent. The turnover of blood in the brain (i.e. how many times a minute the cerebral blood is changed) is determined at 11 in Case 2007 and at 14.7 in both Case 2017 and Case 2029.

In the other four, namely, Cases 2006, 2015, 2030, and 2031, there are very great differences between the calculated values of the above-mentioned quantities determined from the two dilution curves of the jugular bulbs. For example, the calculated values for the cerebral blood flow differ by 170 c.c. or 35 per cent in Case 2006, 720 c.c. or 86 per cent in Case 2015, 270 c.c. or 30 per cent in Case 2030, and 430 c.c. or 54 per cent in Case 2031. The dilution curves do not run at all parallel in these cases, as is shown in Fig. 3. The maximum of the dilution curve from the right jugular bulb is reached four seconds earlier than the maximum of the curve from the left one. The differences for the calculated pool volumes of the brain are also very high in these cases.

In the four cases where it was possible to puncture only one bulb, we have calculated the cerebral blood flow from only the one dilution curve (Cases 2001, 2003, 2032, and 2033). The cerebral blood flow varies in these cases between 500 c.c. and 1000 c.c. and the pool between 50 and 100 c.c.

We have calculated the general means of the cerebral blood flow and the other quantities mentioned in 11 cases (Table I) and found that the mean of the cerebral blood flow amounts to 840 c.c. and that of the pool volume to 77 c.c. The cerebral turnover is rather high, namely, 11.2, the total blood volume 3544 c.c. and the cerebral blood flow 2.3 per cent of the blood volume on the average. From the dilution curves the circulation time can be estimated, i.e. the time for appearance of labelled erythrocytes in the jugular vein after injection in the carotid artery. It may be difficult to establish the fastest circulation time. The mean circulation time (the maximum of the dilution curve) is easier to determine. The longest circulation time (i.e. the minimum of the dilution

FIG. 1.—Simultaneous dilution curves from the right and left jugular bulbs after injection of thorium-B-labelled red cells into the left carotid artery.

curve) is rather easy to demonstrate. We have found the following means of the three different expressions for circulation time in the brain: shortest time 5.3 sec., maximum 8.9 sec., and disappearance at 18.0 sec. (heterogeneous material).

Group II. Intravenous injection of thorium-B-labelled erythrocytes and simultaneous blood sampling from brachial artery and jugular bulbs.

In 18 cases injections of the labelled erythrocytes were performed in a brachial vein. In 12 cases the blood sampling was made from one brachial artery and one jugular bulb simultaneously. In six cases blood was sampled from both jugular bulbs. It is not possible to calculate the cerebral blood flow and the cerebral pool volume in this way, but dilution curves from both jugular bulbs may give some information about the blood distribution in the two hemispheres. On the other hand, it is possible by sampling from the brachial artery to calculate the cardiac output. This

FIG. 2.—Simultaneous dilution curves from the right and left jugular bulbs after injection of thorium-B-labelled red cells into the right internal carotid artery. Case 2029, March 25, 1955, Blömer.

may also be approximately calculated from the dilution curve of the jugular bulb. In Table II are collected the results concerning cardiac output, thoracic pool volume, and also the turnover of blood in the thorax, that is, how many times a minute the thoracic pool is changed. If we compare the cardiac output calculated from the dilution curve obtained from the brachial artery with that of the jugular bulb, it is seen that only in one case (2002) was a notably higher minute volume (+2.6 litres) calculated from the dilution curve obtained from the jugular bulb. In all the other cases the minute volume calculated from the dilution curve of the bulb shows, with an extremely small difference, lower values than that obtained from the brachial artery. There is no significance in the mean difference of the values from the 12 cases. On the other hand, if we exclude the higher value received from the jugular bulb in Case 2002, and then calculate the mean difference between the cardiac output calculated from the dilution curve from the brachial artery and that from the

FIG. 3.—Simultaneous dilution curves from right and left jugular bulbs after injection of thorium-B-labelled red cells into the right internal carotid artery.

FIG. 4.—Simultaneous dilution curves from the brachial artery and jugular bulb after intravenous injection of thorium-B-labelled red cells.

TABLE II
CARDIAC OUTPUT CALCULATED FROM SIMULTANEOUS DILUTION CURVES FROM BRACHIAL ARTERY AND JUGULAR BULB

Case No.	Dilution curve from	Cardiac output (l./min.)	Thoracic pool volume (litres)	Turnover cardiac output thoracic pool	Total blood volume (litres)	Thoracic pool as % of total blood	Heart volume	
							litres	l./m. ²
2011	Brachial artery	8.6	1.13	7.6	3.18	35.6		
	R jug. bulb	8.4						
2002	Brachial artery	6.0	1.56	3.9	4.43	35.2		
	R jug. bulb	8.6						
2000	Brachial artery	8.0	1.34	6.0	3.56	37.6		
	R jug. bulb	7.9						
2012	Brachial artery	8.0	1.50	5.3	4.63	32.4	0.91	0.52
	R jug. bulb	7.8						
2013	Brachial artery	5.2	1.08	4.8	4.18	25.8	0.62	0.37
	R jug. bulb	5.1						
2004	Brachial artery	8.4	1.08	7.8	3.83	28.2	0.57	0.34
	R jug. bulb	8.4						
2005a	R and L jug. bulbs	5.2						
2005b	R and L jug. bulbs	5.0			4.77			
2016	R jug. bulb	9.0						
	L jug. bulb	7.8			4.25			
2036	R jug. bulb	3.8			3.88			
2020	Brachial artery	5.9	1.62	3.6	3.94	41.1		
	Jug. bulb	5.3						
2021	Brachial artery	8.2	0.98	8.4	3.56	27.5	0.67	0.38
	Jug. bulb	8.1						
2022	Brachial artery	4.1	0.70	5.9	3.18	22.0	0.70	0.41
	R jug. bulb	3.7						
2008	Brachial artery	9.1	1.08	8.6	3.18	33.4	0.55	0.37
	R jug. bulb	8.9						
	L jug. bulb	8.6						
2026	R and L jug. bulbs	7.5			3.84			
2027	R jug. bulb	5.2			3.72			
	L jug. bulb	5.1						
2034	R jug. bulb	3.4			2.24			
2028	Femoral artery	5.8	1.05	5.5	2.92	36.0		
	R jug. bulb	5.2						
2035	R jug. bulb	10.8			4.74			
	General mean	7.03	1.19	6.1	3.78	32.3	0.67	0.40

Mean values calculated from brachial artery.

jugular bulb, we find the difference to be 236 c.c. As a proportion of the minute volume of the heart this difference amounts to only 3.3 per cent.

The thoracic pool has been determined from the brachial dilution curve of the brachial arterial blood in 11 cases and varies rather inconsiderably among the individual cases. The general mean amounts to 1.19 litre.

The turnover of the thoracic pool is calculated at 6.1 per minute. The thoracic pool as a percentage of the total blood volume is determined at 32 per cent. Not all cases have had their heart volume examined, but in the six cases where this has been done the heart volume had normal values. Fig. 4, 5, and 6 show how similar the dilution curves from the brachial artery and those of the jugular bulb prove to be. Fig. 6 shows simultaneous dilution curves obtained from the brachial artery and both jugular bulbs. It is striking in this case that the two dilution curves from the veins run parallel and give the same values of the cardiac output and that about the same value is calculated from the dilution curve from the brachial artery. As in our first publication, however, we have found that the dilution curves from the two jugular bulbs differ in some cases; one example is given in Fig. 7. It is probable that this fact explains the rather great difference between the cardiac output calculated from these two curves. The time difference for the maximum

FIG. 5.—Simultaneous dilution curves from the brachial artery and jugular bulb after intravenous injection of thorium-B-labelled red cells.

FIG. 6.—Simultaneous dilution curves from the brachial artery and both jugular bulbs after intravenous injection of thorium-B-labelled red cells.

FIG. 7.—Simultaneous dilution curves from both jugular bulbs after intravenous injection of thorium-B-labelled red cells.

of the two dilution curves amounts to no less than 6 sec. If we compare the mean of 840 c.c. of the cerebral blood flow in Table I with the mean of 7030 c.c. of the cardiac output in Table II, we find that the cerebral blood flow is 12 per cent. of the cardiac output.

DISCUSSION OF THE RESULTS

The question arises whether the dilution curve from the jugular bulbs really represents, at least in normal conditions, a mixing curve of all the blood in the brain independently of whether the injection of the blood has been done through one or both carotids or through the vertebral arteries. The arterial anastomoses in the brain and especially the big venous sinuses probably support the assumption that the blood received from the jugular bulb is mixed with all the blood in the brain, at least in normal conditions. One would expect to receive parallel dilution curves from the two veins. Our determinations on the cerebral pool seem to show that the brain contains astonishingly small quantities of blood—about 80 c.c. or only 2 per cent of the total blood volume. The remarkable fact in our results is that the cardiac output, whether calculated from the dilution curves from the brachial artery or from the jugular bulbs, has the same value. This would probably not happen if there was not complete mixing with a rather small quantity of blood in the brain. As has been mentioned before, our material does not consist of uniform normal cases, and pathological cases are included in it. It is our intention to get a larger group which could be divided into normal and pathological cases. Therefore this paper also must be regarded as a preliminary report. As a probable example of unequal distribution of blood in the brain we have Case 2016 (Fig. 7), where the two simultaneous dilution curves do not run parallel and have strikingly different values for the cardiac output. Why this is so we cannot yet tell. Probably the same happens in Case 2015 (Fig. 3). Mostly we have obtained parallel dilution curves from both jugular bulbs whether, as in Cases 2007 and 2029, after intracarotid injection or as in Cases 2008 (Fig. 6), 2027, and 2026 after intravenous injection. These results also speak in favour of the assumption that there has been complete mixing of the blood in the brain. Our studies, even though only preliminary, have, we feel, made a contribution to our knowledge concerning the mixing and distribution of blood in the brain that may be of practical importance in clinical conditions.

If we are right in assuming that complete mixing between the injected substance and all the blood in the brain occurs, the calculation of the cerebral blood flow is probably correct and the value of 840 c.c. for the mean cerebral blood flow would be reasonable and constitute 12 per cent of the cardiac output—a quantity more acceptable than the 20 per cent that has previously been assumed.

SUMMARY AND CONCLUSIONS

With increasing experience of our method we have continued our study of the cerebral blood flow by means of thorium-B-labelled erythrocytes.

If parallel curves from both jugular bulbs are obtained it is probable that complete mixing has taken place with all the blood in the brain. Differences between them may be of clinical importance.

The values of the cerebral blood flow are absolute values and not relative ones as are those obtained by the nitrous oxide gas method.

The cerebral blood flow has been determined, the mean value being 0.84 litre or about 12 per cent of the cardiac output.

The cerebral pool volume (the content of blood in the brain) is found to be 77 c.c., only 2 per cent of the total blood volume, a figure that has not hitherto been determined.

The turnover of blood in the brain is 11.2 per minute or twice that in the thorax, which has a value of 6.1.

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