Studies of the Cerebral Circulation with Labeled
Erythrocytes in Healthy Man

By GUSTAV NYLIN, M.D., F.R.C.P., SVEN HEDLUND, M.D.,
and OLOF REGNSTRÖM, M.D.

In earlier papers, we have studied cerebral blood flow, cerebral blood pool, circulation times, and other parameters of the circulation in a control group and in cases of cerebrovascular diseases. In the last paper, we published mean values for a small control group of 11 patients, most of them epileptics. We obtained high values for both cerebral blood flow and cerebral blood pool in this control group. The percutaneous puncture of the carotid arteries was not performed high enough in the neck to avoid regurgitation of injected labeled erythrocytes into the external carotid artery.

We found it necessary to make the percutaneous punctures of the internal carotid arteries higher in the neck. Our intention was to examine a group of healthy males.

Methods

Twenty-four healthy males, all volunteers, were studied. Their ages varied from 25 to 50 years. They were thoroughly examined before the circulatory studies were undertaken. The examination covered the following items: history, routine examination, ordinary neurological examination, radiological heart volume determination according to an earlier-described method, and electrocardiogram. No abnormality in any respect was found. Some of our studies were incomplete for several reasons: in some cases only the intravenous injection was successful, while in several others it was impossible to puncture the carotids on both sides. The material presented in this paper is a report on 10 healthy males, aged 26 to 46 years (table 1), in whom the examinations were complete in every respect.

The subject had a light breakfast three hours prior to the tests. He was placed in a recumbent position on a table and 2 mg. morphine plus 0.08 mg. scopolamine were slowly injected intravenously.

From the Radiosotope Research Laboratory, South Hospital, Stockholm, Sweden.
Supported by Grant H-3219, National Institutes of Health, U. S. Public Health Service.
Received for publication December 21, 1960.
of the brain were made using two different methods. With the first method, the concentration curves obtained from the samples taken from the two bulbs were used, after labeled blood was injected once into the right and once into the left carotid artery. The theoretical formula used is correct provided the following conditions are fulfilled: (1) the injection is instantaneous; (2) all activity reaches the brain; (3) the blood is well mixed at the points where the samples are drawn and in the draining tubes; and (4) the two bulbs are the only outflows of the brain. Experience shows that conditions (1) and (3) are quite well fulfilled. The other two conditions require a more careful analysis. It should be pointed out that the formula is valid independently of the number of inflows. The equation allows for determination of the flow in each of the bulbs, and if one adds the assumption that there are only two inflows to the brain, one can also compute the flow in each of the carotid arteries. This determination will, however, probably not be as reliable as the determination of the total blood flow through the brain. The mathematical derivation of the equations can be found in an article by B. J. Andersson. The equations are generalizations of a formula given earlier by Hamilton et al. 10

The second method utilized the concentration curves obtained from samples taken from one carotid artery and the two bulbs after an intravenous injection was made. The formula is correct provided all the inflows show the same concentration curve and all the outflows show the same concentration curve. There is no restriction on the number of inflows and outflows. This makes this method very attractive. The measurements must be very precise, since use is made of the difference between the concentration curves from the artery and the bulb, and this difference will be a small quantity. The accuracy of the present measurements seems to be sufficient for this purpose, except in a few cases. When we obtain samples simultaneously from one carotid artery and both bulbs, the method is more accurate. In the practical application of the formula, it has been found possible to make the determination at a number of successive points along the curve, and from these to determine a best mean value. This has increased the accuracy. One disadvantage of this second method, based on concentration curves obtained at the intravenous injection, is that it gives only the ratio of the blood flow and the blood pools of the brain, and not these quantities separately. This ratio is what has been called the turnover, or the inverted value of the mean circulation time, and is not exactly the same as that used by Hamilton. At present, the pool value is computed by combining the formula with the blood flow obtained from the first method. The mathematical formulas will be found in the appendix.

Results

Figure 1 shows the four dilution curves from the jugular bulbs after injection of labeled erythrocytes into the right and left carotid arteries, respectively. The abscissa indicates time in seconds after injection; the ordinate indicates the activity of the drawn samples for every second in per mille of total injected activity. In this case, the surface areas of the curves from the ipsilateral bulbs are, on both sides, greater than those from the contralateral bulbs.

The results of the calculations of cerebral blood flow and other parameters are seen in table 2. The dilution curves give information about the speed of circulation in the brain. Recirculation appears about 20 seconds after the carotid injection and the values of activity from the two bulbs coincide strikingly.

Figure 1 demonstrates also the results from the intravenous injection in the same subject. The first dilution curve to the left (black dots) represents the carotid artery and illustrates the inflow concentration of the injected activity into the brain. The two dilution curves from the jugular bulbs (open dots) refer to the outflow concentration of the injected activity from the brain. There are signs of recirculation in both arterial and bulbular dilution curves, at 30 and 40 seconds, respectively. From these curves, both the minute volume of the heart and the mean circulation time in the brain can be calculated; this will be dealt with later in the report. As seen in this figure, the dilution curves from the two bulbs after intravenous injection are symmetrical.

In another subject who received a left carotid injection (fig. 2), the dilution curves from both jugular bulbs are of the same type as in the first-described case, namely, the contralateral bulb drains less activity. On the other hand, in this case no activity at all was obtained from the contralateral bulb when the carotid injection was performed on the right side. The absence of activity occurs rarely. There is, however, recirculation in that bulb.
When all arteries of the brain are injected with labeled erythrocytes, i.e., after an intravenous injection, the curves from the jugular bulbs are strikingly similar, which figure 2 illustrates.

In the subject represented in figure 3, no activity in the contralateral bulb was observed following a right carotid injection. Another observation in the same case is that after intravenous injection there were asymmetrical dilution curves from the two bulbs. This is the only case (out of ten) in which this occurred.

**Drainage of Injected Labeled Cells from the Jugular Bulbs**

It is very rare that the injected erythrocytes drain symmetrically through the two bulbs after an intracarotid injection. In examining more than 100 persons, we have seen it only in very few cases, and in none did we obtain identical curves after both carotid injections. As a general rule, the contralateral bulb drains less activity. This fact can be illustrated by calculating the following surface index for the four dilution curves after the carotid injections. If the surface of the dilution curves in impulses (C), is divided by the total injected activity (a), and this ratio is multiplied by 1,000, we derive the index. The mean values of index for each bulb in 10 normal cases were 1.414 ± 0.136 and 1.796 ± 0.195 after injection into the right and into the left carotid arteries, respectively, in comparison with the contralateral bulbs in which the indices were 0.258 ± 0.087 and 0.909 ± 0.074, respectively. These differences are statistically significant.

If the flow through the right and left jugular bulbs is calculated separately, a difference is obtained. The right bulb seems to drain more of the cerebral blood flow than the left bulb.

The asymmetrical drainage of the labeled cells through the jugular bulbs after intracarotid injections may depend upon the anatomy of the cerebral veins. It is a common experience in the routine performance of cerebral arteriography that the radiopaque medium outlines the arteries only on the side of injection. On the venous side, the large dural sinuses in the midline drain both hemispheres, dividing their contents to the jugular bulbs via the transverse sinuses, where the right bulb, in two-thirds of the cases in anatomical and roentgenological studies, is larger than the left one.11-13 The blood is conveyed, via lateral veins, directly to the same-sided transverse sinus or, via petrosal sinuses, to the jugular bulb.13

In the cases in which no dilution curve was obtained from the contralateral bulb after an intracarotid injection, the transverse sinus...
on the contralateral side was provided with blood only from the same-sided hemisphere by the above-mentioned pathways, and was without connection with the sagittal sinus. This explanation is supported by the anatomical variations of the transverse sinus described by Edwards. 11

Since the asymmetry of the dilution curves after intracarotid injections was a constant observation in our total material of more than 100 cases, and as the anatomical explanation of this phenomenon does not seem satisfactory in every case, laminar flow in the sagittal sinus is presumed to occur, preventing complete mixing. This opinion is supported by the investigations of Helps and McDonald.14 However, mixing has taken place in the jugular bulbs, as the obtained curves are nicely reproducible, which was stated in an earlier paper.5

After intravenous injection, when all arteries to the brain were provided with labeled erythrocytes, the obtained dilution curves of the two bulbs were, as a rule, identical. As already mentioned, we saw nonsymmetrical curves from two bulbs in only one of these 10 cases. The profile of these curves depends on different factors, for example the length and width of the pathways and their different circulation rates. In clinical cases, as in cerebral atherosclerosis, nonsymmetrical curves are more often found, which will be dealt with in another paper.

**Cerebral Blood Flow (CBF)**

From what has been said previously, it is necessary to inject the labeled cells into both carotid arteries, one after the other, and to sample blood from the two bulbs in order to estimate the cerebral blood flow. Direct puncture of the internal carotid arteries is necessary in order to be able to inject the labeled cells high enough, without regurgitation, into the external carotid artery. If any part of the labeled cells regurgitates into the external carotid, a reduced quantity enters the cerebral arteries, with the result of giving too high values for the cerebral blood flow. In our control material previously published,2 there were a few cases in which we, from simultaneously performed cerebral angiography, knew that the puncture was made in the internal carotid artery and that no important regurgitation had taken place. We noticed that the dilution curves from the jugular bulbs in these cases showed high values for the peak concentration on the ipsilateral side, as a rule more than 1.5 per cent of the injected activity. Moreover, in three cases we had injected the labeled cells also into the common carotid artery on the same side and obtained peak concentration values of the dilution curve, which amounted to less than half the above-mentioned value.

To get a rough idea whether more, or less, activity really reached the brain, we made a
### Table 2
Cerebral Blood Flow (C.B.F.), Pool (C.B.V.), Mean Circulation Time (M.C.T.), and Related Functions in Ten Healthy Males

<table>
<thead>
<tr>
<th>Case number</th>
<th>C.B.F. (a) ml./min.</th>
<th>C.B.F. % of cardiac output</th>
<th>Cardiac output ml./min.</th>
<th>C.B.V. calculated from</th>
<th>C.B.V. in % of total blood volume</th>
<th>Total blood volume ml.</th>
<th>M.C.T.: C.B.V. calculated from</th>
<th>Turnover (T): C.B.V. calculated from intravenous injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>824</td>
<td>10.2</td>
<td>8,100</td>
<td>83</td>
<td>1.6</td>
<td>5.300</td>
<td>6.0</td>
<td>6.0 (10)</td>
</tr>
<tr>
<td>183</td>
<td>1,115</td>
<td>15.1</td>
<td>7,400</td>
<td>135</td>
<td>2.6</td>
<td>5.200</td>
<td>7.3</td>
<td>7.5 (10)</td>
</tr>
<tr>
<td>185</td>
<td>948</td>
<td>12.5</td>
<td>7,600</td>
<td>102</td>
<td>1.8</td>
<td>5.100</td>
<td>6.5</td>
<td>6.9 (10)</td>
</tr>
<tr>
<td>186</td>
<td>691</td>
<td>11.5</td>
<td>6,600</td>
<td>101</td>
<td>2.6</td>
<td>4.600</td>
<td>8.8</td>
<td>8.6 (7.0)</td>
</tr>
<tr>
<td>187</td>
<td>1,067</td>
<td>11.5</td>
<td>9,300</td>
<td>97</td>
<td>1.7</td>
<td>5.800</td>
<td>7.5</td>
<td>7.5 (10)</td>
</tr>
<tr>
<td>188</td>
<td>1,077</td>
<td>11.4</td>
<td>9,400</td>
<td>120</td>
<td>2.8</td>
<td>4.500</td>
<td>6.7</td>
<td>11.0 (10)</td>
</tr>
<tr>
<td>192</td>
<td>791</td>
<td>9.7</td>
<td>8,200</td>
<td>84</td>
<td>1.8</td>
<td>6.100</td>
<td>6.4</td>
<td>8.4 (7.1)</td>
</tr>
<tr>
<td>194</td>
<td>943</td>
<td>15.5</td>
<td>6,100</td>
<td>90</td>
<td>1.3</td>
<td>3.300</td>
<td>7.5</td>
<td>6.7 (9.0)</td>
</tr>
<tr>
<td>196</td>
<td>667</td>
<td>8.8</td>
<td>7,900</td>
<td>85</td>
<td>3.1</td>
<td>2.400</td>
<td>7.7</td>
<td>11.0 (5.4)</td>
</tr>
<tr>
<td>197</td>
<td>671</td>
<td>8.2</td>
<td>8,200</td>
<td>70</td>
<td>2.1</td>
<td>2.400</td>
<td>6.3</td>
<td>11.0 (5.5)</td>
</tr>
</tbody>
</table>

Mean: 870 ± 55 11.4 ± 0.8 7,800 ± 360 97 ± 6.0 108 ± 5.2 2.0 ± 0.2 2.2 ± 0.2 5,000 ± 330 71 ± 2.7 6.7 ± 0.3 7.7 ± 0.7 8.3 ± 0.06

### Table 3
Circulation Time in Seconds (Appearance, AP; Peak, P; and Disappearance, D) of the Dilation Curves After Carotid Injections on Both Sides in Ten Healthy Males

<table>
<thead>
<tr>
<th>Case number</th>
<th>Right carotid injection</th>
<th>Left carotid injection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right bulb</td>
<td>Left bulb</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>P</td>
</tr>
<tr>
<td>175</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>183</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>185</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>186</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>187</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>188</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>192</td>
<td>2</td>
<td>5</td>
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<tr>
<td>194</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>196</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>197</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Mean: 3 ± 0.3 6 ± 0.4 14 ± 0.6 4 ± 0.4 7 ± 0.4 13 ± 0.8 4 ± 0.4 7 ± 0.4 14 ± 0.5 3 ± 0.3 6 ± 0.3 15 ± 0.7

0.9 (10) 1.4 (10) 2.3 (10) 1.2 (8) 3.0 (8) 2.4 (8) 1.2 (10) 1.2 (10) 1.5 (10) 6.9 (10) 1.0 (10) 2.3 (10)
correlation between the sum of the two ipsilateral peaks of activity expressed in per cent of injected activity and the calculated CBF. The results from both the earlier studies of control cases, as well as those from the present studies of healthy men, are plotted in figure 4. It can be clearly seen that only four cases of the preceding control material are within the range for the healthy men, both concerning the peak concentration of injected activity and the CBF. In those four cases, radioangiographic control injections proved that no regurgitation into the external carotid artery had taken place. If the peak concentration value is more than 1.5 per cent on each ipsilateral bulb, one can presume that most or all of the activity has reached the brain.

The new normal material presented in this paper from healthy men in whom the puncture of the carotid arteries was performed as high as possible in the neck shows very high peak concentration values, and as a consequence the injections seem to have been performed into the internal carotid arteries. Thus, the calculated CBF is probably correct. However, slight regurgitation to the external artery cannot be excluded in a few cases.

Values for cerebral blood flow are tabulated in table 2 and varied in 10 men from 667 to 1,115 ml./min., with a mean of 879. Expressed in per cent of cardiac output, they varied from 8.2 to 15.5, with a mean of 11.4 per cent. Cardiac output (MV) was calculated on the
Cerebral Blood Volume (CBV)

The pool (CBV), i.e., the blood content of the brain including its larger vessels, varied from 70 to 135 ml. with a mean of 97, calculated from the dilution curves received after the two carotid injections (table 3). When the CBV was calculated with the help of the intravenous injection, it varied from 83 to 140 ml. with a mean of 108, which corresponds rather well with the just-mentioned mean value. The difference between the two values of CBV depends on the difference between the two numerical methods in calculating the mean circulation time (MCT). In table 2, MCT is tabulated, based on the carotid injection and on the intravenous injection. The calculation of CBV in per cent of total blood volume (TBV) shows that the blood content in the brain amounts to roughly 2 per cent of the blood content in the body.

Turnover (T), an expression of how many times the CBV was exchanged per minute, is tabulated in the last columns of table 2. The mean value amounted to 8, with a range of 5 to 11.

Velocity of Circulation in the Brain

The dilution curves from the bulbs, obtained after carotid injections gave information about circulation time in the brain. In table 3 are tabulated appearance time (AP), peak concentration time (P), and disappearance time (D) for ipsi- and contralateral dilution curves after injection into right and left carotid arteries respectively. It was easy to fix the peak concentration time and rather easy to fix the appearance time—the most rapid passage of any labeled cells. The disappearance time, i.e., when the downslope of the dilution curve reached a constant level, was more difficult to determine. The different parameters of the circulation time did not vary a great deal among the 10 normal subjects. The means of AP were three seconds for the ipsilateral jugular dilution curves, irrespective of whether the injection was made in the right or left carotid artery. The same result was obtained for the peak concentration time with a mean of six seconds. The mean value for disappearance time of the ipsilateral curves was one second longer when the left carotid artery had been injected. From the two contralateral bulbs similar values were obtained for the mentioned parameters, but the AP and the P were both one second, as an average, longer than the corresponding values from the ipsilateral bulbs. Similar observations were described in an earlier publication. The uniformity of the circulation times among the 10 normal subjects is schematically seen in figure 5, where only one case strikingly differs in showing a rather long circulation time. We have no explanation either technical or clinical for this exception.

Discussion

In the control group of subjects reported in an earlier paper,5 regurgitation of the in-
jected labeled blood appeared in the external carotid artery in most of the cases. In the present studies we tried to puncture the internal carotid arteries percutaneously, and from the values of the peak concentration, we concluded that in most cases no labeled cells entered the external carotid artery. It may be added that the earlier control group consisted mainly of epileptics, while the present group was comprised of normal healthy males. We found that the mean value for CBF in normal males was 879 ml./min.

The indicator-injection method with Evans blue has been applied by Gibbs, Maxwell, and Gibbs, who exposed the carotid and jugular vessels on one side and estimated the cerebral blood flow from only one jugular dilution curve. In seven cases they obtained an average value of 617 ml./min. This method, however, is based on the assumption that an indicator injected into one internal carotid artery is mixed with the total cerebral circulation by the time it arrives in one internal jugular vein. This presumption was shown to be incorrect, a fact that was stated by Shenkin, Harmel, and Kety. They tried to compensate for the unequal distribution by sampling from the two jugular bulbs and pooling the obtained concentration values. They used Evans blue as indicator and injected an exposed carotid artery on only one side. The average for such determinations in five patients was calculated to be 986 ml./min.

As is stated in our mathematical analysis of the problem and demonstrated in our observations on the asymmetrical drainage of the blood through the jugular bulbs, it is necessary to inject the indicator into both internal carotid arteries and sample simultaneously from both jugular bulbs to get a true value of the cerebral blood flow. One exception should be mentioned, i.e., in cases in which the dilution curves from the two jugular bulbs after one carotid injection are identical, the calculation can be performed only from this data on the basis of the Stewart-Hamilton formula. In fact, this phenomenon has been observed only in a few cases in over a hundred examined.

As was stated earlier, the accuracy of the values for the cerebral blood flow depends upon the extent of the presumption that the internal jugular veins drain all the cerebral blood and that no contamination from extracerebral sources is present.

Shenkin et al. demonstrated that only 2.7 per cent of the blood in the internal jugular veins was of extracerebral origin. We have confirmed this in our own investigations. Anatomically, it is likely that only a small part of the cerebral blood will pass by other ways than via the internal jugular veins.

Kety and Schmidt, Scheinberg and Stead, Bernsmieer and Siemons, and Lassen, with their inert gas diffusion methods, have obtained mean values of about 50 to 65 ml./100 Gm. of brain. With the assumption of a brain weight of 1,400 Gm., the cerebral blood flow can be calculated to be 700 to 900 ml./min. It is known, however, that the brain weight varies. Our method has the advantage of determining the cerebral blood flow in absolute values in the single case.

In this present group, the cerebral blood flow was calculated, on the average, as 11.4 per cent of the simultaneously estimated cardiac output. No correlation was observed between the cardiac output and the cerebral blood flow. The blood pool (CBV) of the brain
was determined by two methods for calculation of the mean circulation time. Roughly, both methods gave the same value of the CBV, about 100 ml., i.e., about 2 per cent of the total blood volume of the body. Although it was possible to estimate the cerebral blood flow and pool in absolute values, it seems to us that the determination of the velocity of the blood flow through the brain is of more diagnostic importance.

If we compare our results for these 10 thoroughly investigated healthy males with the results in our control group in an earlier investigation, we find that all present parameters show one second longer circulation time. This difference can partly be explained by the more basal relaxed conditions in the present investigation. Another explanation may probably be that in the control group 4 ml. of blood was injected more forcefully than in the present group of healthy men, in whom only 1.5 ml. was injected.

It should be pointed out that the values of the mean circulation time as a rule agreed very well, either calculated from the jugular dilution curves after carotid injections or computed from the curves after intravenous injection, as previously described. This supports our opinion that intra-arterial injections of small quantities of blood will not appreciably influence the mean circulation time.

It was shown in our earlier publication that in patients with cerebral atherosclerosis the circulation times were prolonged when compared with the control group. Further, it should be added that in the presented normal subjects the dilution curves, after intracarotid injections, are of similar shape as in the above-mentioned control group. In patients, alterations of the shape of these curves were observed, which gives valuable information from a diagnostic point of view.

The velocity of the blood flow through the brain has also been determined by cerebral angiography. The basis of these estimations varies among authors as to the choice of starting and end points for measuring the circulation time. This causes difficulties in comparing the results. A review of the angiographic investigations will be found in a monograph by Tönis and Schiefer. In our earlier publication, we found our method to be more sensitive than the angiography in estimating the circulation time.

By using the isotope technique for external recording of the impulses by scintillation counters, attempts have been made to obtain information about the circulation in the brain. We have tried a similar method for recording the impulses bloodlessly over the bulbs in order to get the circulation time in the brain. For exact information, however, the method described in this publication has proved to be superior.

**Summary**

A thorough investigation of 10 healthy males, 26 to 46 years old, has been performed. One and a half ml. of their own erythrocytes, labeled with $^{32}$P, was injected intravenously and dilution curves obtained simultaneously from one carotid artery and the two jugular bulbs. Thereafter, the same amount of labeled blood was injected into both carotid arteries, following one another, and dilution curves from the two jugular bulbs were simultaneously obtained. A total of seven dilution curves was collected in each case. The percutaneous punctures of the carotids were high enough in the neck so that it is highly probable that the injections were made into the internal carotid arteries. Calculations of the cerebral blood flow and the cerebral blood volume in absolute values were performed. The mean value of the cerebral blood flow amounted to 876 ml./min., i.e., 11.4 per cent of the cardiac output. The pool of the brain was calculated to about 100 ml. When a carotid artery was injected, the appearance and peak concentration times estimated from the dilution curves obtained from the ipsilateral bulbs were the same whether the injection was performed in the right or left side. The corresponding times for the dilution curves obtained from the contralateral bulb agreed, whichever the side on which the injection was performed. They were, however, one second longer than the ipsilateral ones. The
determination of circulation time is of diagnostic value, according to an earlier publication. A simplified bloodless method has also been tried.

Acknowledgment

We wish to express our thanks to the Chief of the Geriatric Clinic, South Hospital, Associate Professor I. G. Porjé, who has facilitated our investigations.

Appendix

\[ \text{Qi} = \frac{I_1}{C_{22}} - \frac{I_2}{C_{21}} \]

\[ q_1 = \frac{I_1}{C_{11}} \cdot \frac{C_{22} - C_{12} \cdot C_{21}}{C_{11}} \]

\[ q_2 = \frac{I_2}{C_{11}} \cdot \frac{C_{22} - C_{12}}{C_{21}} \]

\( q_1 \)—denotes the outflow through the right jugular bulb in ml/min.

\( q_2 \) —denotes the outflow through the left jugular bulb in ml/min.

\( I_1 \) —the total amount of injected activity in the right carotid artery in impulses/min.

\( I_2 \) —the total amount of injected activity in the left carotid artery in impulses/min.

\( C_{11} \) —the activity of the surface of the dilution curve when the slope is logarithmically extrapolated to zero from the right jugular bulb injecting the right carotid artery, in impulses/ml.

\( C_{21} \) —the activity of the surface of the dilution curve when the slope is logarithmically extrapolated to zero from the right jugular bulb injecting the left carotid artery, in impulses/ml.

\( C_{12} \) —the activity of the surface of the dilution curve when the slope is logarithmically extrapolated to zero from the left jugular bulb injecting the right carotid artery, in impulses/ml.

\( C_{22} \) —the activity of the surface of the dilution curve when the slope is logarithmically extrapolated to zero from the left jugular bulb injecting the left carotid artery, in impulses/ml.

Total cerebral blood flow = \( q_1 + q_2 \)

The pool of the brain = \( q_1 \cdot T_1 + q_2 \cdot T_2 \)

where

\[ q_1 = \frac{q \cdot \phi_{22} - q_2 \cdot \phi_{12} \cdot \phi_{21}}{\phi_{11} \cdot \phi_{22} - \phi_{12} \cdot \phi_{21}} \]

\[ q_2 = \frac{q_2 \cdot \phi_{11} - q_1 \cdot \phi_{12} \cdot \phi_{21}}{\phi_{11} \cdot \phi_{22} - \phi_{12} \cdot \phi_{21}} \]

\( T_1 = \phi_{11} \cdot T_{11} + \phi_{21} \cdot T_{21} \)

\( T_2 = \phi_{12} \cdot T_{12} + \phi_{22} \cdot T_{22} \)

\( T_{11} \) —center of gravity (centroid) of the dilution curve for right jugular bulb injecting right carotid artery.

\( T_{21} \) —center of gravity (centroid) of the dilution curve for left jugular bulb injecting right carotid artery.

\( T_{12} \) —center of gravity (centroid) of the dilution curve for right jugular bulb injecting left carotid artery.

\( T_{22} \) —center of gravity (centroid) of the dilution curve for left jugular bulb injecting left carotid artery.

\[ \phi_{11} = \frac{C_{21}}{I_1} \cdot q_1; \phi_{21} = \frac{C_{21}}{I_2} \cdot q_1; \phi_{12} = \frac{C_{21}}{I_2} \cdot q_2 \]

\[ \phi_{22} = \frac{C_{22}}{I_2} \cdot q_2 \]

The index \( \frac{V}{q} = \frac{C_\infty - C_0}{C_0} \), where \( V \) is the relation between the pool of the brain (V) and the flow (q). The latter one is derived from the first part of our calculation. \( (C_\infty) \) is the surface of the arterial dilution curve, and \( (C_0) \) is the surface of the dilution curve from the bulb, both simultaneously received after intravenous injection. \( (C_0) \) is the activity when equilibrium has been obtained after the injection.

References


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Circ Res. 1961;9:664-674
doi: 10.1161/01.RES.9.3.664

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7330. Online ISSN: 1524-4571

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