Angiographic and Isotope Pool Circulation Study of the Cerebral Hemispheres After Internal Carotid Artery Occlusion

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The brain, with a pre-existing collateral system, has a unique position in regard to its vascular supply. Willis first recognized the importance of the circle which bears his name in the collateral circulation to the brain. He demonstrated that, in case of obstruction of one of the carotid arteries, the contralateral brain hemisphere could be successfully supplied via the pre-existing communications of the circle of Willis from the contralateral side. However, apart from all important interconnected canal system of the circle of Willis, multiple other anastomotic pathways have been recognized in the recent past. End-to-end anastomoses between the distal branches of the anterior, middle and posterior cerebral arteries have been demonstrated angiographically. Anastomotic channels between the external and internal carotid arteries, namely the angular artery, the superficial temporal artery, the pterygopalatine artery, the inferior orbital artery, the ophthalmic artery, and particularly the mid meningeal and middle cerebral artery are likewise readily demonstrable angiographically. Particularly the direct anastomotic branch between the mid meningeal artery of the external carotid and mid meningeal group of the mid cerebral artery often refills the siphon portion of the internal carotid in cases of complete occlusion of the internal carotid in the neck area. The rete-Mirabile, consisting of small anastomotic branches between the meningeal arteries and the dura likewise serve as a major anastomotic group. These vessels may extend through the bone and anastomose with the arteries of the scalp.

The angiographic examination by arterial injection of radiopaque media gives an adequate anatomic demonstration of the main arteries and collateral systems. However, an accurate determination of cerebral blood flow would be desirable for a better clinico-pathologic correlation of occlusive arterial disease. Measurements of flow rates and pressures following arterial occlusion have been carried out and plastic models allowing detailed measurements at various points have been constructed. The most expeditious estimation of circulation in several organs of the body is derived by monitoring the passage of radio-isotopes in the bloodstream with external counting techniques. From an anatomic point of view, the cerebral hemispheres would appear to be particularly suited for such a study. The topographic separation of the head from the rest of the body allows easy shielding and collimation of the counting apparatus against the blood pool in other areas. The essentially symmetrical hemispheres with normally equal blood supply permit easy comparison and base line. However, it should be noted that, commonly, there is asymmetry in the venous flow with durovenous sinuses draining to one side more than the other. An intravenous injection of radioactive iodinated serum albumin (RISA) with external monitoring and recording has produced consistent and reproducible results. The method is felt to be superior to circulation studies depending upon the radioisotope injection into the carotid artery and recovery of the isotope from the jugular vein; mainly because of the relative ease of intravenous injection as compared to the traumatic multiple arterial and venous punctures necessary with the other technique. Moreover, any change in intracranial contents and irritation of the arterial system may easily result in exaggerated and false values because of resulting spasm of the intracranial arterial system.
TECHNIQUE

Forty to 100 microcuries of radioactive iodinated serum albumin RISA are injected intravenously. The right and left hemispheres are “seen” by a crystal adequately collimated and shielded to allow exposure of the crystal by only the respective hemisphere or part of the respective hemisphere. It is admitted that the contribution to the count rate in anteroposterior projection is greatly influenced by the geometric proximity of the frontal lobe in contrast to the geometrically distant occipital lobe. Moreover, in view of the severe collimation only a portion of the respective frontal lobe and a greater portion of the occipital lobe are “seen” by the crystal. Nonetheless, the accrued error should be the same on the right and left side, assuming that the geometry of source, recipient scintillation crystal and interposed material are maintained. It is conceded that selective thrombosis of the anterior cerebral group or the posterior cerebral group could be reflected by markedly exaggerated values in this data presentation since the geometric factor and inverse square law may considerably influence the count rates under these conditions. The time constant of the rate meter must not exceed one second since the rapidly changing rate of counts has to be recorded accurately to present the data in a proper curve. The impulses received via scintillation crystal are recorded on a count rate meter preferably in a graphic curve demonstration.

The first flat portion of the curve represents the arm-to-brain circulation time. The rapidly ascending part of the curve is initially due to the arterial flow into the hemisphere; the upper one-third of the steeply rising slope is due to a combination of arterial flow, capillary pool, and venous return. The final plateau of the curve is proportional to the isotope volume in the cerebral vascular system after equal distribution throughout the body.

Figure 1: Note the excellent refilling of the siphon segment of the carotid artery via the opthalmic and hugely dilated midmeningeal branches of the external carotid system. (Reproduced from Radiology, 83: 632, 1964).
The slope of the sharply ascending curve is affected by the amount of radio-isotope injected, the rate of blood flow, the sensitivity of the apparatus, and its integration time, and lastly the intactness of the bolus of the isotope. If one excludes the possibility of systemic left-to-right or right-to-left shunts, all these factors will cancel out and only a difference in the rate of blood flow will cause a disparity and difference in the slopes. Thus, it can be safely assumed that a change in the slope reflects the overall arterial flow and the status of the arterial system.

**RESULTS**

Fifty-eight patients with known thrombosis of one or both of the internal carotid arteries were subjected to serial carotid arteriograms and serial radio-isotope flow studies. Eighteen of the patients were examined on at least two occasions with an adequate interval between the two examinations to allow formation of collateral supply after the acute arterial thrombosis. These cases classically demonstrated not only a change in the arteriographic pattern with formation of dilated and prominent collateral channels, particularly via the ophthalmic artery, the mid meningeal group, and the pterygopalatine artery with resulting re-opacification of the siphon segment of the affected carotid artery, but showed also a considerable improvement in the isotope pool curve over the affected hemisphere. While the slope would never quite equal the normal side in steepness of ascent, the peak of the arterial and venous maximum isotope pool would equal that of the normal side in several instances. Progressive narrowing of the base of the curve reflects improving and increasing collateral supply, resulting in rapid delivery of the isotope bolus. Delayed descent to the plateau level appears to reflect sluggish venous circulation and prolonged pooling in the capillary bed.

It was of particular interest to note a significant correlation to the clinical picture.

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**Table 1—Correlation of the Arteriographically Demonstrated Lesion to the Isotope Curve Appearance (58 Patients)**

<table>
<thead>
<tr>
<th>Appearance of Radio-Isotope Curve; Peak Height, Width of Base of Curve and Ascent of Slope</th>
<th>Total Number Patients</th>
<th>Lowered Peak</th>
<th>Near Normal Peak</th>
<th>Normal Base</th>
<th>Broad Base</th>
<th>Flat Ascent of the Curve</th>
<th>Normal Ascent of Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Thrombosis</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old Thrombosis</td>
<td>39</td>
<td>2</td>
<td>9</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a. With collateral supply via anterior communicating</td>
<td>11</td>
<td>2</td>
<td>9</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>b. With collateral supply via posterior communicating and vertebral arteries</td>
<td>2</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>c. With collateral supply via the external carotid system</td>
<td>28</td>
<td>9</td>
<td>19</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>d. Collateral supply by recanalization</td>
<td>2</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>e. Combination of a and c</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>f. Combination of c and d</td>
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<td>—</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>Thrombosis of both Carotid Arteries</td>
<td>5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>a. Collateral supply via the vertebral arteries</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>—</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>b. Collateral supply via the external carotid system</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>—</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>c. Collateral supply by recanalization</td>
<td>2</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>d. Combination of a, b and c</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>—</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2—Patients Subjected to Multiple Examinations at About Six Month Intervals*

<table>
<thead>
<tr>
<th>Total Patients in This Group</th>
<th>Appearance of the Radio-Isotope Curve</th>
<th>Steepening of the Ascent of the Count Rate Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase of the Peak</td>
<td>Narrowing of the Base of the Curve</td>
</tr>
<tr>
<td>Acute Thrombosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With increased external collateral supply</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>b. Recanalization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Collateral supply over the circle of Willis</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>d. Combination of a and b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Combination of a and c</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Old Thrombosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. With increase of the external collateral supply</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>b. Recanalization</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>c. Collaterals over the circle of Willis</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>d. Combination of a and b</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>e. Combination of a and c</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>


Figure 2: Note complete obstruction of the internal carotid at the level of the bifurcation and refilling of the siphon segment of the internal carotid predominantly via the markedly dilated ophthalmic artery.
Patients who failed to show any permanent neurologic deficit would usually present an isotope pool curve resembling the normal side in steepness of ascent and width of base, as well as height of the arterial and venous maximum peak. Conversely, subacute thrombosis cases with only poor collateral formation would show an extremely flat ascent of the slope of the isotope pool curve reflecting a delayed and reduced flow of blood to this hemisphere.

The most effective collateral delivery of blood to the affected hemisphere is via the anterior communicator branch and the circle of Willis. The isotope pool curves in these patients showed a fairly steep ascent of the slope, but a somewhat lowered peak. The phenomenon, however, is explained on a technical basis since the crystal is unable to see the entire area supplied by the anterior cerebral group but integrates all of the counts of the occipital region. Hence, the contribution, in spite of the inverse square law, from the anterior cerebral group is less because of the limited amount of area seen by the crystal. Of 11 patients in this group, eight revealed a near normal isotope curve. Apart from a slight delay in the ascent of the curve, there was no substantial difference to the normal side with the exception of a slight decrease in the peak height. In contrast to the patients supplied predominantly via a collateral system, the angle of the ascent slope is not significantly changed in comparison with normal values. However, a narrow base of the curve reflects best the prompt delivery of the isotope in form of a bolus.

Conversely, patients with thrombosis of both carotid arteries and massive collateral supply via the external carotid, the vertebral and posterior communicator arteries showed considerable widening of the base, a less steep ascent, but ultimately a higher

**Figure 3:** Demonstration of excellent cross circulation over the anterior communicator arteries of the circle of Willis with complete filling of the contralateral anterior and midcerebral group.
peak. This again is partially caused by geometric factors determining the data presentation. The area of the posterior cerebral artery is completely seen by the crystal whereas the poorer supplied anterior and midcerebral region is only partially integrated by the crystal. In five patients with thrombosis of both carotid arteries, a dominant supply over collaterals of the external system and the posterior communicator arteries was noted. The considerable broadening of the base of the curve reflects also a sluggish venous and capillary circulation with slow dissipation of the bolus.

Analysis of the isotope curves reveal that the integral area below the curve reflects the total amount of isotope entering the brain blood pool. However, the clinically significant factor is related to the blood flow per unit time. Hence, the adequacy of collateral supply is best assessed by the steepness in the ascent of the slope of the curve and the relative width of the curve rather than overall volume area or peak of the curve.

The most frequently encountered collateral supply way is between the external and internal carotid system. Particularly the ophthalmic, palpebral, and midmeningeal arteries will readily dilate and contribute to collateral supply as demonstrated on serial arteriograms. The pterygopalatine branch can likewise contribute to the collateral blood flow. Of a group of 28 patients, 14 showed a normal base of their radioisotope curve. Eighteen showed near normal ascent of the slope reflecting rapid blood flow via the collateral system. However, in 15 patients, broadening of the base, flatness in the ascent of the isotope curve or both were present. This reflected presence of collateral flow, but definite decrease in flow volume per unit time. It was of interest to note that in many of these patients, the peak of the isotope curve would be near normal. A combination of supply via collateral vessels and via the anterior communicators of the circle of Willis as well as recanalized segment of the thrombosed artery are observed, but did not significantly alter the overall blood flow.

**SUMMARY**

Fifty-eight patients with known occlusive disease of the internal carotid artery were examined by arteriograms and radio-iso

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**Figure 4**: The affected hemisphere shows a 3 second delay in the sharp ascent of the slope. However, the steepness of the angle of the ascent slope reflects excellent collateral circulation via large collateral vessels. The width of the base of the curve is near double that of the normal size. This is probably the most sensitive indicator for assessment of a sluggish capillary and venous circulation and stasis in the brain blood pool.

**Figure 5**: Note the increased width of the base of both the right and left hemispheres. The steepness in ascent is better on the left side reflecting the intactness of the isotope bolus. On the right side, an ascent deflection precedes the left side by almost 2 seconds. This reflects dilatation of the external carotid system often seen in acute cases of carotid artery thrombosis. A relative flatness in the ascent of the slope reflects the relatively poor development of a collateral system.
Isotope flow studies. The arteriograms offered an excellent demonstration of collateral pathways, particularly via the ophthalmic, pterygopalatine and midmeningeal branches of the external system. The patency and presence of anterior or posteriorly communicator arteries are likewise readily assessed by this method. Radio-isotope flow studies were particularly useful for finite assessment of blood flow per unit time to the affected hemisphere. The angle of the ascending slope of the isotope curve, the width of the base, and the angle of the descending slope give a reliable picture of the overall flow rate per unit time to the affected hemisphere. The width of the slope more or less corresponding to the brain pool transit time is the most sensitive indicator. A mean normal brain pool transit time is five to nine seconds. With significant occlusive disease, the transit time may be prolonged 14 to 26 seconds. The angle and steepness of the ascending slope are likewise a sensitive indicator for the intactness of the isotope bolus and rapidity of delivery of blood to the affected area. The overall volume entering the affected hemisphere reflected by the area below the entire curve is the least sensitive and appropriate measurement. The height of the peak of the curve is likewise of secondary clinical significance since sluggishness of the circulation and increased brain pool transit time may actually result in increased height of the peak. An excellent correlation between the clinical picture and the appearance of the isotope curve, as well as the arteriogram was noted in this series. The change in the width of the curve and the width of the base of the curve appeared to bear a most significant correlation to the clinical improvement of the patient and his potential for ultimate recovery.

**Resumen**

Cincuenta y ocho sujetos con oclusion patológica manifesta de la carótida interna fueron estudiados mediante arteriogramas y determinaciones radio-isotopicas del flujo sanguíneo. Los arteriogramas proporcionaron una demostración excelente de la circulación colateral, particularmente via la rama oftalmica, pterygo-palatina y meningea medios del sistema externo. La presencia y permeabilidad de comunicantes anteriores y posteriores son susceptibles también de demostración por este método. Los radioisotopos fueron particularmente útiles para la determinación del flujo sanguíneo por unidad de tiempo en el hemisferio afectado.

El promedio normal del tiempo de transito es de cinco a nueve segundos. En las alteraciones patológicas oclusivas de importancia este tiempo puede aumentar hasta de 14 a 26 segundos. El angulo y el gradiente de la rama ascendente de la curva es también un indicador sensible de la integridad del bolo isotopico y de la rapidez del aporte sanguíneo a la porción afectada. El área bajo la curva, como expresión del volumen total de sangre que entra en el hemisferio afectado, es el índice menos apropiado y exacto en este tipo de investigación. La altura de la curva es así mismo de importancia clínica secundaria. En nuestra serie observamos una correlación excelente entre el cuadro clínico, la curva isotopica y el arteriograma. Los cambios en la latitud de la curva y en la base de la curva presentan una correlación muy significativa con la mejoría clínica y las posibilidades de recuperación definitiva.

**Resumen**

Cinquante huit malades ayant une maladie occlusive connue de l'artère carotide interne, ont été examinés par des études artériographiques et de circulation de radio-isotopes. Des artériographies ont donné une excellente preuve des voies collatérales, en particulier à travers les branches ophtalmiques, pterygo-palatines et méningées moyennes du système externe. La perméabilité et la présence de communicantes antérieures ou postérieures sont facilement démontrées par cette méthode. Les études de circulation de radio-isotopes ont été particulièrement utiles pour la détermination définie du flot sanguin par unité de temps à l'hémisphère intéressé. L'angle de la pente ascendante de la courbe d'isotopes, la largeur de la base, et l'angle de la courbe descendante, donnent une image fidèle du flot sanguin total par unité de temps à l'hémisphère considéré. La largeur de la pente correspondant plus ou moins au temps de traversée de la réserve cérébrale est l'indicateur le plus sensible. Un temps moyen normal de traversée cérébrale varie de 5 à 9 secondes. Avec une maladie occlusive
significant, le temps de traversée peut être prolongé de 14 à 26 secondes. L’angle et la rapidité d’ascension de la courbe est de même un indicateur sensible pour l’intégrité du bol isotope, et pour la rapidité d’apport du sang à la région considérée. Le volume total pénétrant dans l’hémisphère considéré, traduit par la surface se trouvant sur la courbe entière, est la mesure la moins sensible et appropriée. La hauteur du pic de la courbe, a de même une signification clinique secondaire, étant donné que le ralentissement de la circulation et l’augmentation du temps de traversée de la réserve cérébrale peuvent entraîner une augmentation de la hauteur du pic. Une excellente corrélation entre le tableau clinique et l’apparition de la courbe d’isotope aussi bien que l’artériographie a été notée dans cette série. Les changements dans la largeur de la courbe et la largeur de la base de la courbe semblent présenter une corrélation significative avec l’amélioration clinique du malade et sa possibilité de guérison ultérieure.

ZUSAMMENFASSUNG


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EXTERNAL DETECTION OF AN INTRAVENOUSLY INJECTED RADIO-ISOTOPE


OLDENDORF, W. H., CRANDALL, P. M., NOR


TAVERAS, J. M., MOUNT, L. A. AND FRIEDEN


For reprints, please write: Dr. Lang, Methodist Hospital, Indianapolis.

PROGNOSIS OF COAL-MINERS WITH LUNG CANCER

A retrospective survey was conducted on 746 hospital patients from South Wales, of whom 172 had been miners and 518 non-miners. During the first five years of followup, there was no appreciable difference in survival rates between the two occupational groups, whether they were treated surgically or otherwise, and the rate of surgical resection was similar in each group. However, an analysis of the miners' experience in relation to the presence and extent of coincidental pneumoconiosis showed a consistent association, survival increasing with a rise in the radiographic category of simple pneumoconiosis. The highest two-year survival rates in the series were in the small proportion of miners with categories 2 and 3 pneumoconiosis. This association would be expected if the spread of lung cancer in miners' lungs was impeded by coal-dust.


EXTERNAL RESPIRATORY FUNCTION IN MYOCARDIAL INFARCTION

External respiration in 30 patients 30 to 60 days after acute myocardial infarction, and in 20 patients at periods ranging from six to 12 months was investigated. In patients at different periods after myocardial infarction, functional disturbances of the external respiration were manifested by an increased minute ventilation, decreased vital capacity, reduced maximum breathing capacity, reserve air and coefficient of oxygen consumption, decreased oxygen absorption per minute. In 90 per cent of patients examined 30 to 60 days after acute myocardial infarction, the author noted respiratory insufficiency. Investigations performed 6 to 12 months later disclosed respiratory insufficiency in 80 per cent of cases. The author attributes functional disturbances of the external respiration to latent right ventricular insufficiency.