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Balloon Catheter as a Model of Cerebral Emboli in Humans

GY. GÁCS, M.D., F. T. MÉREI, M.D. AND M. BODOSI, M.D.

SUMMARY A striking similarity has been found between the distribution of occlusions in various cerebral arteries and the statistical regularity of the pathways of balloon catheters drifting freely in the blood stream. Based on the assumption that the course of a balloon is determined by the same hydrodynamic laws as that of an embolus of similar size, it is concluded that the majority of occlusions of the cerebral arteries are of embolic origin. Emboli, then, might also be an explanation for most of the TIAs.

Stroke Vol 13, No 1, 1982

KNOWLEDGE of the pathogenesis of occlusions of the intracranial arteries would be important to therapy. Despite several studies of this problem it cannot be decided whether a particular occlusion has its origin in a local thrombus or in an embolus. Recently the theory of the embolic origin of intracranial vascular occlusions has been favored. However, primary evidence for it is still lacking.

There are considerable, regular differences in the incidence of occlusions among the individual intracranial arteries. These differences are regarded by several workers as a proof of local thromboses because emboli might be expected to have an irregular distribution. Others consider possible a certain regularity in the distribution of occlusions even in the case of emboli, because of the laminar blood flow in the cerebral arteries. Our balloon catheterizations seem to be suitable for checking the probable course of emboli in the main human intracranial arteries.

Materials and Methods

A total of 960 angiographies performed in patients having had ischemic events in the carotid territory were analyzed in order to determine the frequency of occlusions of intracranial arteries. One hundred and forty-two of the 960 patients had TIA, while the others had strokes of varying severity. In 221 of the 960 angiograms we found intracranial...

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Supported by the Scientific Research Council, Ministry of Health, Hungary (3-21-0301-04-0/M)
occlusions. The indication for angiography was TIA in 49 patients and stroke in 172.

The balloon catheterization was performed as described in detail previously by Gács. The most important features of this technique are as follows: A thin soft polyethylene catheter (0.45 mm in outside diameter) having a latex balloon (0.6-0.8 mm in outside diameter) with a calibrated leak in its tip is introduced into the carotid artery. The length of the balloon is between 4-5 mm. The slightly inflated balloon (0.05-0.2 ml in volume) is carried along by the blood flow, pulling the catheter after it. When the catheter is allowed to move freely, the balloon can be regarded as an embolus of the same size. Consequently, its most preferred pathway if there is any, will presumably be similar to that of an embolus.

The spontaneous pathway of the balloon was followed in 42 cases. The site where the "balloon embolus" stopped was checked by injecting a radio-opaque dye through the calibrated leak in the balloon: superselective angiography (fig. 1).

All 42 patients who were selected for balloon catheterization had cerebrovascular disease and subsequently underwent an EC/IC bypass operation. During the operation fluorescein angiography was used to localize the ischemic area and to study the

<table>
<thead>
<tr>
<th>Site of occlusion</th>
<th>Number of patients</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior cerebral artery</td>
<td>15</td>
<td>6.8</td>
</tr>
<tr>
<td>Middle cerebral artery</td>
<td>206</td>
<td>93.2</td>
</tr>
<tr>
<td>Main trunk</td>
<td>64</td>
<td>29.0</td>
</tr>
<tr>
<td>Main branches just</td>
<td></td>
<td></td>
</tr>
<tr>
<td>beyond trifurcation</td>
<td>38</td>
<td>17.2</td>
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<tr>
<td>Orbitofrontal artery</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Operculofrontal artery</td>
<td>10</td>
<td>4.5</td>
</tr>
<tr>
<td>Rolandic artery</td>
<td>13</td>
<td>6.0</td>
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<tr>
<td>Parietal arteries</td>
<td>29</td>
<td>13.1</td>
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<tr>
<td>Angular artery</td>
<td>39</td>
<td>17.6</td>
</tr>
<tr>
<td>Temporal arteries</td>
<td>11</td>
<td>5.0</td>
</tr>
<tr>
<td>Total</td>
<td>221</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 1. Superselective angiogram of a trapped balloon embolus. The radio-opaque dye was injected through a calibrated leak in the balloon. The balloon is situated in a branch of the anterior cerebral artery (a and b), and in branches of the middle cerebral artery (c and d).
blood flow from the direction of the intact to the ischemic hemisphere via the anterior communicating artery. To achieve this the balloon catheter was introduced into the internal carotid artery opposite to the stenotic or occluded side. No angiographically visible alteration of these vessels was found.

Drifting of the balloon with the blood flow is influenced only by the degree of its inflation and not by the curves in the vessels or the catheter, presuming that it can freely be carried along by the balloon. The latter was carefully observed on the X-ray image intensifier in all patients. Thus the results discussed in the present paper should be regarded as byproducts of these procedures.

Results

The distribution of the 221 occlusions among the intracranial arteries is shown in table 1. A 1/14 ratio was found between the occlusions of the anterior and the middle cerebral arteries. The most frequently affected cortical branches are the angular and the parietal branches of the middle cerebral artery.

The distribution of the “balloon emboli” in the intracranial arteries is shown in table 2. The balloons drifting freely in the blood flow “chose” the middle cerebral artery in 39 out of the 42 cases, but got trapped in the anterior cerebral artery in only 3 of them. Thus, the ratio between “balloon-embolism” of the anterior and that of the middle cerebral arteries was also 1/14. The more distal landing points of the balloons in the middle cerebral artery were in its main trunk (8), the suprasylvian trunk (30), and the temporal arteries (1).

Discussion

We have long known that occlusions of the small intracranial arteries play a much more important role in the genesis of cerebral infarction than previously presumed. Angiograms made shortly after the onset

<table>
<thead>
<tr>
<th>Localization of the “balloon-embolus”</th>
<th>Number of cases</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior cerebral artery</td>
<td>3</td>
<td>7.1</td>
</tr>
<tr>
<td>Middle cerebral artery</td>
<td>39</td>
<td>92.9</td>
</tr>
<tr>
<td>Main trunk</td>
<td>8</td>
<td>19.0</td>
</tr>
<tr>
<td>Main branches just beyond trifurcation</td>
<td>11</td>
<td>26.2</td>
</tr>
<tr>
<td>Orbitofrontal artery</td>
<td>-</td>
<td></td>
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<tr>
<td>Operculofrontal artery</td>
<td>2</td>
<td>4.8</td>
</tr>
<tr>
<td>Rolandoic artery</td>
<td>3</td>
<td>7.1</td>
</tr>
<tr>
<td>Parietal arteries</td>
<td>5</td>
<td>11.9</td>
</tr>
<tr>
<td>Angular artery</td>
<td>9</td>
<td>21.4</td>
</tr>
<tr>
<td>Posterior temporal artery</td>
<td>1</td>
<td>2.4</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 2. Schematic presentation of the distribution of the spontaneous occlusions and the “balloon emboli.” Lower numbers: percentage distribution of the spontaneous occlusions; upper numbers: percentage of the balloon-emboli. The small differences in distribution between the sites of lodgement of the balloon and those of the emboli can be explained by the fact that while the size of the balloon was rather constant, those of the emboli were not. Major emboli were lodged in the main trunk, whereas smaller bits reached more distal branches of the middle cerebral artery. OBFA = orbitofrontal artery; OPFA = operculofrontal artery; CSA = central sulcus artery; PAA = parietal arteries; ANGA = angular artery; TAA = temporal arteries.
of the symptoms revealed cortical branch occlusions also in a considerable number of TIA patients.14

Pathological and angiographical studies seldom permit definite distinction between thrombi and emboli. Old, organized emboli and thrombi are indistinguishable under the microscope, and the angiographic appearance of occlusions seldom offers data for a decision. The frequency of embolism used to be underestimated, although Chiari11 drew attention to the importance of mural internal carotid thrombosis in cerebral embolism as early as 1905. After Fisher,12 Gunning,13 et al., it was McBrien et al.14 and others who stressed the view that primary thrombotic occlusion of the intracranial arteries represents a rarity.15, 16 At the same time other workers17 found a much greater frequency for local thrombi than for emboli.

The question of relative frequency could be studied by comparing the incidence of spontaneous intracranial vascular occlusions with that of “balloon occlusions” of the same arteries. Our findings (table 2) indicate that there is a predictable regularity in the distribution of the paths taken by the balloon, probably owing to the laminar nature of blood flow. Consequently, other particles, i.e. emboli of the same size, will drift into the various cerebral arteries with the same predictability. There is a similarity between the incidence of spontaneous vascular occlusions and that of balloon emboli (fig. 2). Bearing these observations in mind, one may conclude that the majority of intracranial vascular occlusions are of embolic origin.2

Our experience with balloon catheters offers a good explanation both for the relatively low rate of anterior cerebral artery occlusions and for the differences in the incidence of cortical branch occlusions of the middle cerebral artery. Furthermore, the laminar flow of emboli explains the puzzling uniformity of consecutive ischemic events.8 Finally, while some workers regard the rarity of transient symptoms of the anterior cerebral and temporal regions (e.g., jargon aphasia) as a strong argument against embolism,9 this fact appears to have its explanation in the relative “safety” of these regions from the balloons and emboli.

Although the primary goal of our investigations was to draw a comparison between balloon emboli and angiographically proved occlusions of embolic origin, some conclusions can be drawn from them which suggest transient ischemic attacks might be regarded as of embolic origin.

References


Balloon catheter as a model of cerebral emboli in humans.
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doi: 10.1161/01.STR.13.1.39

*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

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