The Management of Cerebrovascular Disease

John Marshall

Third edition

THE M[illegible]T OF CEREBROVASCULAR DISEASE

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PREFACE TO THE THIRD EDITION

The decade that has elapsed since the first edition of this book has seen tremendous progress in the diagnosis and management of cerebrovascular disease. Classification has improved and become more meaningful in terms of the pathogenesis of strokes and for their management. The indications for and techniques of angiography have become more clear. Management both short and long-term has improved. These advances have made it necessary to make additions and to re-write extensive sections of the book. In doing so the primary purpose of the book to provide a concise and practical account of how to manage patients with strokes has been kept very much in mind. The additions and revisions have been made without unduly increasing the size of the book in the hope that it will continue to provide practical guidance to all who are concerned in the management of patients with cerebrovascular disease.

I am extremely grateful to Blackwell Scientific Publications and in particular to Mr Per Saugman for undertaking the publication of this third edition.

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PREFACE TO THE FIRST EDITION

The past decade has seen a great upsurge of interest in the problems posed by cerebrovascular disease. Not that cerebrovascular disease is a new phenomenon; patients with strokes have always been a too familiar sight in medical practice. But formerly the diagnosis was unreliable in all but the general statement that the patient had experienced a stroke and therapy was non-existent. The introduction of percutaneous cerebral angiography has changed this and enabled a considerable degree of precision to be achieved as to the site and nature of the vascular lesion. Equally the development of potential methods of treatment, both medical and surgical, has brought to life a hitherto therapeutically sterile field.

The fruits of this development are scattered throughout a voluminous literature and the cerebrovascular bibliography issued by the Joint Council Subcommittee on Cerebrovascular Disease now runs to some 400 pages a year. To keep in touch with the literature is therefore a formidable task even for those who have a special interest in cerebrovascular disease. For the rest, it is impossible. Yet the vast majority of patients with strokes are cared for at home and in general hospitals; hence the need for a book which presents within a reasonable compass the essential principles governing the diagnosis and management of cerebrovascular disease. Undoubtedly there are many advances yet to come, but already there is a sufficient body of sound knowledge to guide the physician in the new approach to the patient with a stroke, and this knowledge is presented here.

One of the problems facing the writer on cerebrovascular disease is to delimit his field. Cerebral aneurysms pose a special problem as there is a tendency to separate them from other cerebrovascular lesions. There are good reasons for this in that they often present in the unruptured state, raising particular questions in differential diagnosis, and at all stages their treatment is primarily surgical. Yet this separation cannot be complete as aneurysms, producing as they do both intracerebral haemorrhage and infarction, often present as strokes. A compromise has been struck here in keeping with the practical aims of the book. The diagnostic aspects of cerebral aneurysms in so far as they may present as a stroke have been dealt with; in addition the criteria for the selection of patients for surgi-

cal treatment and the results are presented. This latter has been included so that the physician who has to decide whether to transfer a seriously ill patient to a neurosurgical centre may have some facts on which to base his decision.

I wish to thank Professor T. Crawford and Dr M. R. Crompton for their collaboration in producing the chapter on 'The pathology of strokes', fully in keeping with the dynamic approach of the book. I also wish to thank the Lysholm Department of Radiology for permission to reproduce a number of radiographs, the Department of Medical Illustration for the reproductions and Mr Wylie McKissock, FRCS, and the Editor of the *Lancet* for permission to reproduce Figure 17. I also wish to thank Dr R. Siekert, Editor of the Proceedings of the Fourth Princeton Conference on Cerebrovascular Disease for providing me with data prior to publication.

I am especially grateful to Dr P. C. Gautier-Smith for reading the entire script and offering much valuable advice and criticism and to my secretaries Miss Beryl Laatz and Miss Maureen Horn for their help. Finally I wish to thank the Nuffield Foundation and the British Heart Foundation who by their generous support of my researches in the field of cerebrovascular disease, provided the opportunity for me to gather the knowledge and experience which are embodied in this book.

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CHAPTER ONE

CEREBRAL BLOOD FLOW

The anatomy of the cerebral blood vessels is too well known to require description here. What is not so well known is the number of collateral channels available to, and the important anomalies which may be present in, the cerebral circulation.

The capacity of cerebral neurons to survive when deprived of their blood supply is very limited. Yet, not every occlusion of a cerebral artery gives rise to symptoms or signs, nor even to asymptomatic pathological changes in the brain. It is, for example, by no means rare to find an occlusion of the internal carotid artery at angiography or autopsy without there being any history of permanent, or even transient, neurological deficit. The reason lies in the collateral circulation which enables blood to reach neurons deprived of their primary supply.

Collateral Circulation

The collateral circulation of the brain has been the subject of many studies, a convenient, well documented, recent reference being the work of Fields, Bruetman and Weibel (1965).

The various parts of the collateral circulation are set out in Table 1. By far the most important of these collateral channels is the circle of Willis. Normally there is no flow of blood round the circle, but if one of its constituent arteries becomes occluded, blood crosses the circle to make good the deficit. This can readily be demonstrated at angiography by the cross compression test (Fig. 1.1) which is a necessary preliminary to assess the efficiency of the circle before ligation of the internal carotid artery.

The efficiency of the circle as a collateral channel may be compromised by congenital anomalies. Alpers, Berry *et al.* (1959) examined 350 brains without gross evidence of disease except for arteriosclerosis.

TABLE I

1.	Circle of Willis	*a.* carotid to carotid
		b. carotid to basilar or vice versa
2.	External to Internal Carotid	
		a. maxillary and ophthalmic
		b. stylomastoid branch of posterior auricular and carotico-tympanic
		c. inferior cavernous sinus branch of carotid siphon and middle meningeal
		d. meningeal branches of external carotid and leptomeningeal branches of internal carotid
3.	External carotid to vertebral—occipital artery to vertebral	
4.	Subclavian and vertebral—deep cervical to vertebral	
5.	Leptomeningeal—anterior—middle—posterior cerebral	

They found that in no less than 48 per cent the circle of Willis did not conform to the normal anatomical configuration. Some of the anomalies consisted of accessory vessels such as three anterior cerebral arteries, or unusual origins of vessels, but others involved the absence or narrowing of vessels; these latter were very likely to reduce the efficiency of the circle as an anastomotic channel. The more important of these anomalies were:

Absence of one posterior communicating artery	2 cases
Absence of the anterior communicating artery with fusion of the anterior cerebral arteries to form one trunk	6 cases
Posterior communicating artery of less than 1 mm diameter	78 cases
Anterior communicating artery less than 1 mm diameter	10 cases
Proximal portion of anterior cerebral artery less than 1 mm diameter	8 cases
Posterior cerebral arising from the internal carotid artery	51 cases

In the event of atherosclerotic narrowing in part of the circle the development of an adequate collateral circulation would be seriously impaired by these anomalies. In many instances multiple anomalies were present; overall, in 27 per cent of the circles one of the component vessels (most frequently the posterior communicating artery) had a diameter of less than 1 mm and in 14 per cent one posterior cerebral artery took its origin from the internal carotid.

Anomalies of this kind are probably responsible for some of the cases in which cerebral infarction follows ligature of the internal carotid artery. When this complication occurs in older patients, it is customary to attribute it to the existence of atherosclerotic changes in their vessels, but sometimes, unfortunately, it occurs in young patients in whom

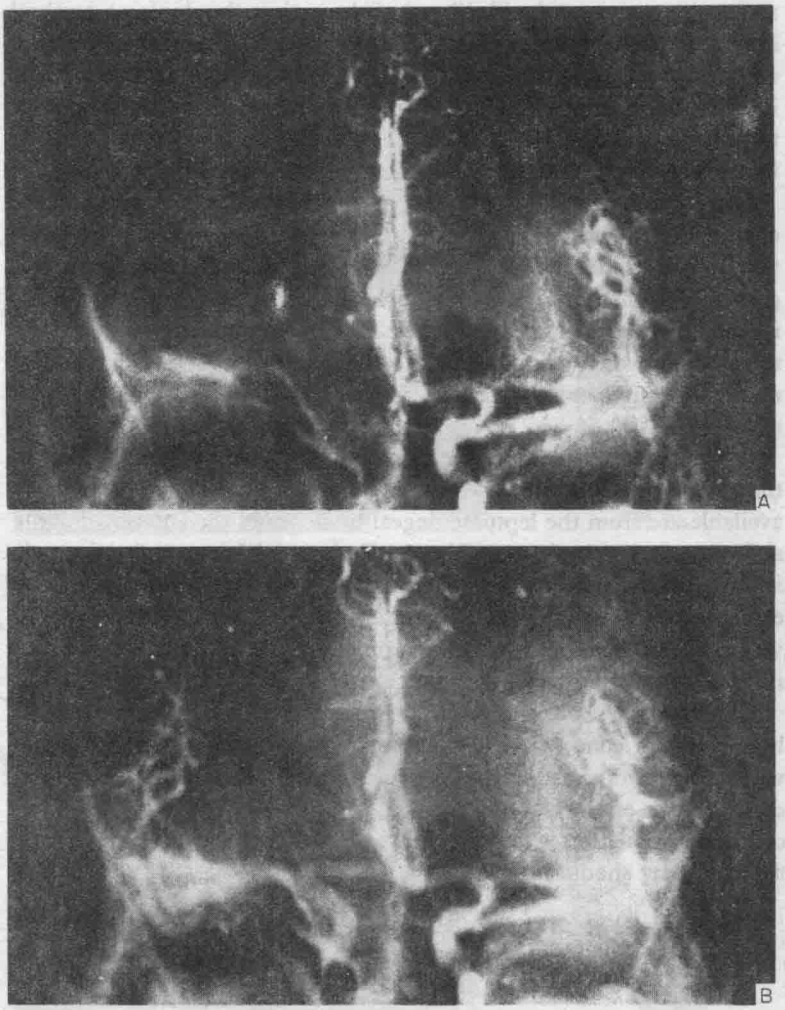


FIG. 1.1. Injection into the left carotid artery without compression of the right carotid (A). Repeat injection into the left carotid artery after the right carotid had been compressed (B). The dye has now filled the right anterior and middle cerebral arteries and the proximal part of the right carotid.

atherosclerotic changes would not be expected. Equally, when occlusion of a major vessel proximal to the circle of Willis is due to atherosclerosis rather than surgery, the likelihood of the patient developing a cerebral infarction must be influenced by the efficiency of the circle of Willis as an anastomosis. It is for this reason that the effects of an occlusion of the internal carotid artery may range from severe infarction of the anterior two-thirds of the ipsilateral hemisphere to nothing at all, the occlusion being found incidentally at a routine autopsy (Fisher, 1951, 1954).

Although the circle of Willis forms the most important anastomotic channel for the cerebral arteries, the other anastomoses have an important role, particularly when the circle is deficient. Indeed the angiographic demonstration of the channels numbered 2a, b and c in Table 1 is evidence that the circle may be deficient, a possibility which must be remembered when planning treatment. Collateral flow via the ophthalmic often supplies the territory of the anterior and middle cerebral artery (Fig. 1.2).

When occlusion involves the origins of the cerebral arteries neither the circle nor the anastomoses 2a, b, c, are of value. The only channels available are from the leptomeningeal branches of the anterior, middle and posterior cerebral artery (Van der Eecken and Adams, 1953) depending on which is occluded and from the meningeal branches of the external carotid artery to the leptomeningeal branches of the cerebral vessels. Retrograde filling of the branches of the occluded vessel from its neighbour can often be demonstrated angiographically (Fig. 1.3).

Our thinking about the cerebral circulation must not be dominated by too rigid a concept of the anatomy of the supplying vessels. Many variations from the orthodox anatomical pattern exist, most being to the disadvantage of the patient. On the other hand, the potential of the collateral circulation is considerable and clearly in the course of treatment nothing should be done which might impede this.

Blood Flow in Single Arteries

The functional aspects of the collateral circulation are well illustrated by observing the effect of occluding a large vessel such as the internal carotid artery in the neck.

When a large artery is occluded, there is an immediate fall in pressure distal to the occlusion (Bakay and Sweet, 1952). In the case of the internal carotid artery this fall extends certainly as far as the fronto-

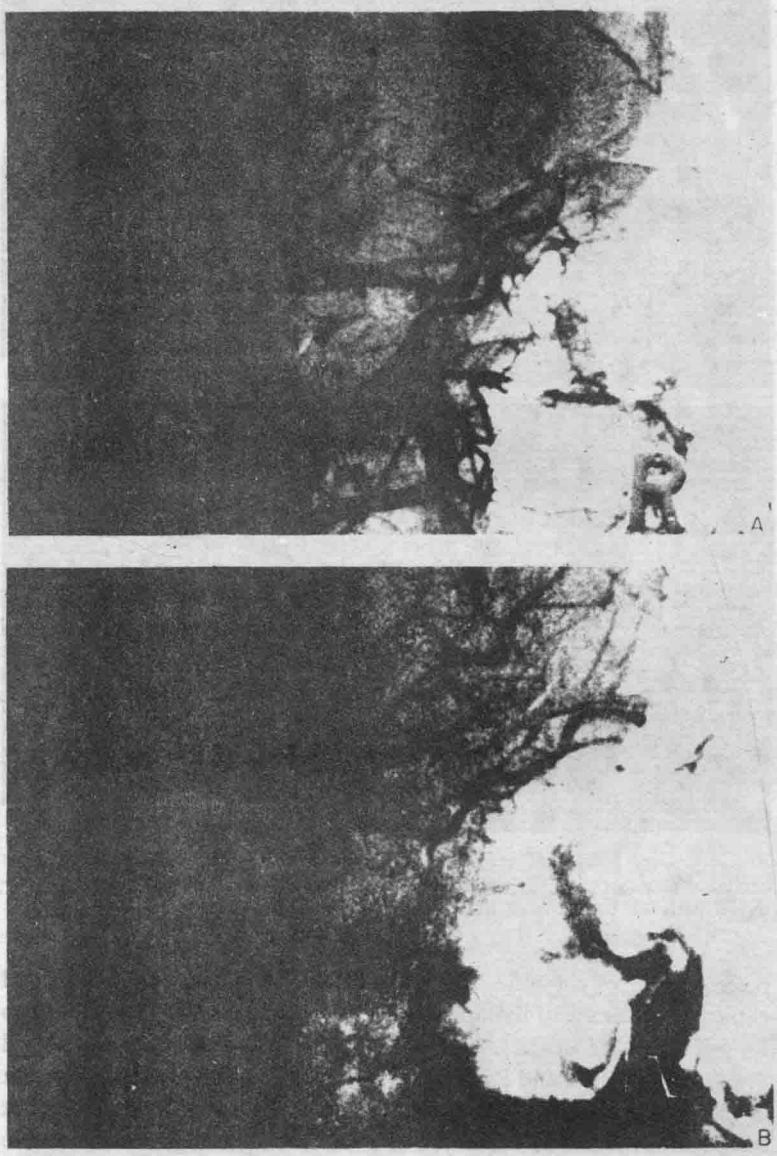


FIG. 1.2. Two phases of a right carotid angiogram in which the internal carotid was occluded in the neck. The terminal part of the internal carotid and its branches are filled via the external maxillary and ophthalmic artery.

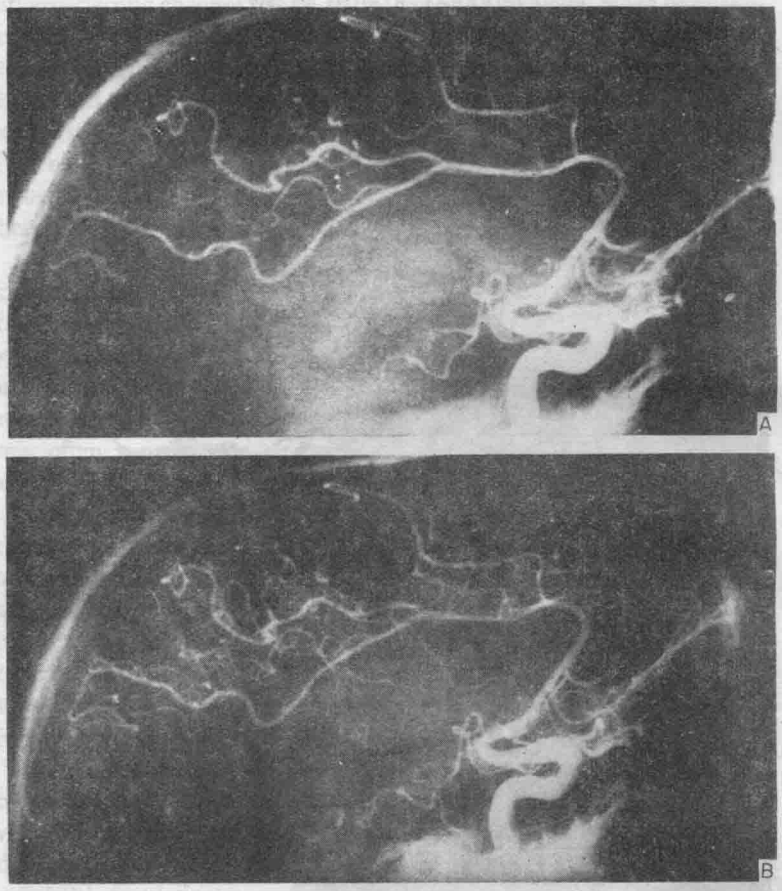
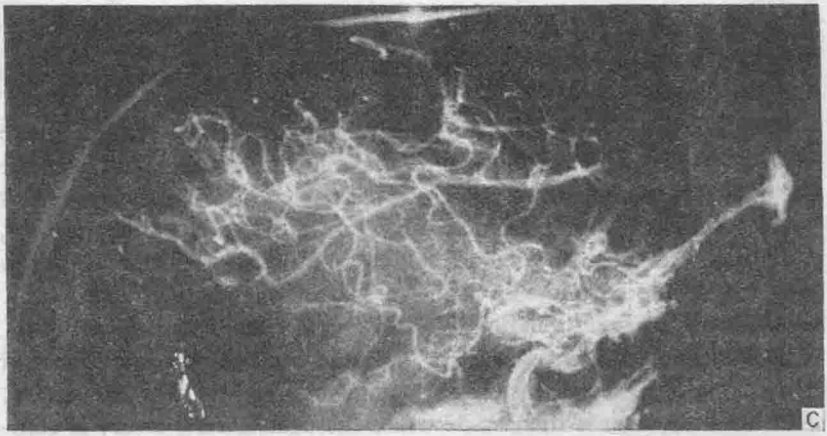


FIG. 1.3. Five phases of a carotid angiogram. The middle cerebral artery is occluded at its origin (A). Its branches progressively fill (B–E) via pial anastomoses with the branches of the anterior, cerebral artery.

polar branch of the anterior cerebral artery. It can be demonstrated clinically by means of the ophthalmodynamometer, there being a sharp drop in pressure in the eye-ball on the affected side (Liversedge and Smith, 1961; Lowe and Stephens, 1961). At the same time there is a rise in blood pressure proximal to the occlusion (Stern, 1962). This is not confined to the affected artery, but is part of a general rise of pressure in the arterial system. In the case of the carotid artery this rise must be accompanied by a fall in cerebrovascular resistance, for the blood flow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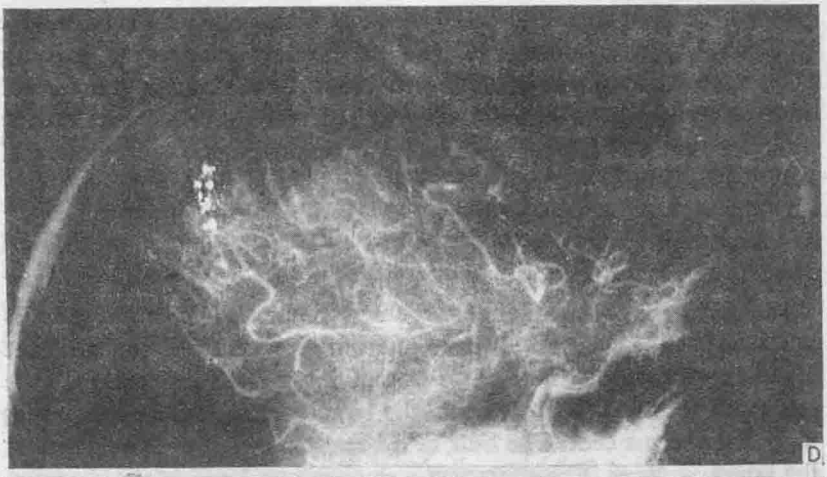
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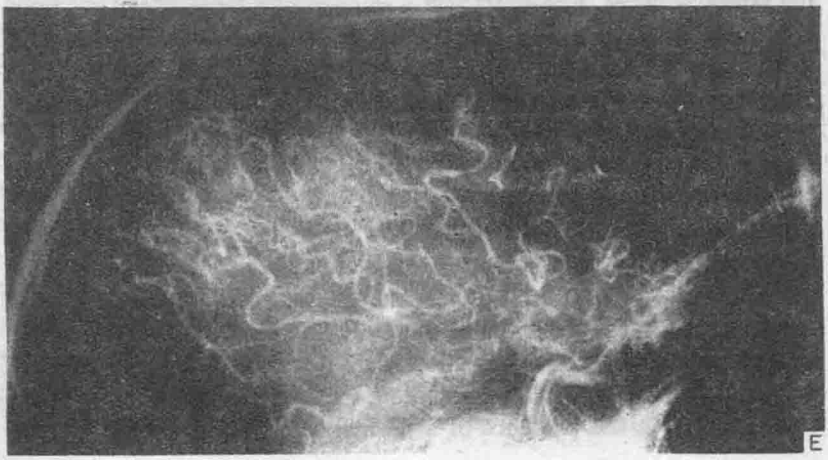
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through the contralateral carotid is greatly increased (Hardesty, Robert, Toole and Royster, 1961).

The significance of these changes is clearly apparent. Normally, there is no flow of blood through the circle of Willis from the territory of one major vessel to another; a point of pressure equilibrium is reached at some point along the anastomotic channel (Shenkin, Harmel and Kety, 1948). If, however, the pressure falls in one of the constituent arteries and rises in another, flow through the anastomotic channel must occur. This fact is utilized in angiography to obtain cross-compression films. The carotid artery on one side is injected with radio-opaque dye and films taken which usually show only the branches of the injected carotid. A second injection is then made while the contralateral artery is compressed. The pressure differential thus created usually results in the dye passing over to the opposite side via the anterior communicating artery (Fig. 1.1). The finding of increased blood flow through the carotid artery after a spontaneous occlusion of the vessel on the opposite side indicates that a similar shift of blood is occurring across the circle of Willis to supply the territory of the occluded artery.

STENOSIS OF A SINGLE ARTERY

The evidence as to what happens following stenosis of a single artery is much less satisfactory. It is apparent from direct measurements of the blood-pressure in the circle of Willis that only a small proportion of the resistance to blood flow occurs in the large arteries, amounting to not more than 10 per cent. The bulk of the resistance to flow is met with at the arteriolar level. The effect that a stenosis of a large artery has upon blood flow depends not only on the degree of the stenosis but also upon its shape, length and the shape of the arterial segments before and after the stenosis. In addition the development of a collateral circulation which shunts blood around the stenosis influences the peripheral blood flow. Despite the number and complexity of the factors involved it has been possible to show that a stenosis must be of severe degree before it has any effect upon blood flow. Brice, Dowsett and Lowe (1964) created a short artificial constriction of the carotid artery in man whilst measuring the distal blood flow with an electromagnetic flowmeter. They found that irrespective of its initial size the lumen had to be reduced to 2 to 4 sq mm before blood flow was affected. When in addition the effect of collateral circulation is taken into account it seems unlikely that stenosis of one artery in the presence of a normal lumen in the other arteries

produces a significant change in cerebral blood flow. This indicates that the often made suggestion that disobliteration of one internal carotid artery when the other vessels are healthy helps a patient by improving cerebral blood flow is without scientific foundation. This does not mean that the operation is without value. It may well benefit the patient by removing a site at which emboli may be formed to be later dislodged and carried peripherally to occlude smaller vessels. This example indicates how, in the present state of knowledge about cerebrovascular disease, every suggestion requires careful scrutiny; hypotheses which superficially appear plausible are often seen on deeper reflection to have little prospect of being true.

Cerebral Blood Flow

It is common in clinical circles to talk of variations in blood pressure and to relate them to the development of neurological symptoms and signs in patients with cerebrovascular disease. This is a natural tendency as it is the blood pressure which the clinician commonly measures in his patient. But it must be remembered that it is cerebral blood flow, not blood pressure, that is the ultimate factor determining the availability of oxygen to the brain; blood pressure, though important, is but one of the factors concerned in cerebral blood flow.

THE PRESSURE HEAD

The cerebral blood flow, which is usually expressed in ml of blood per 100 g brain per minute, is the resultant of two forces, the pressure available to drive the blood through the vessels and the resistance that it meets. The available pressure, or pressure head, is the difference between the pressure on the arterial side and that on the venous side; it is the fall in pressure across the capillary bed which provides the pressure head to move the blood. A variety of factors is concerned in maintaining the arterial pressure, the level of which is constantly fluctuating throughout the cardiac cycle between the diastolic and systolic extremes. For this reason in experimental work, the arterial pressure is usually expressed as an approximation called the mean arterial pressure; this is the diastolic pressure plus one half the pulse pressure. The mean arterial pressure is affected more by a rise in diastolic pressure than by a rise in systolic. This is important clinically for the loss of elasticity of the large

vessels in atherosclerosis often produces considerable rise in systolic blood-pressure without much increase in the diastolic pressure. The mean arterial pressure in such patients is not greatly increased. On the other hand, in arteriolosclerosis there is considerable rise in the diastolic pressure as well as the systolic, hence the mean arterial pressure is very high.

The pressure on the venous side of the cerebral circulation must also be taken into account. This is raised, along with the venous pressure in other systems, in the presence of obstruction to the pulmonary circulation and in right heart failure. Also because the cerebral veins and venous sinuses have thin walls, a rise in intracranial pressure as may occur in the presence of a space-occupying lesion is readily transmitted to the venous pressure. This rise of pressure on the venous side lowers the pressure head and the resultant fall in cerebral blood flow may well be an important factor in producing the impairment of cerebral function which may be encountered in these circumstances. Clearly there is a complexity of factors affecting the pressure head.

THE CEREBROVASCULAR RESISTANCE

The cerebrovascular resistance, which is usually expressed in mm Hg, is also compounded of several factors. These are:

1. the functional tone of the vessels;
2. the structure of the walls of the blood-vessels;
3. the pressure on the vessels from without, i.e. the intracranial pressure;
4. the viscosity of the blood passing through the vessels.

The relationship between pressure and resistance is expressed by the formula

$$\text{Cerebral blood flow} = \frac{\text{Blood pressure}}{\text{Cerebrovascular resistance}}$$

MEASUREMENT OF CEREBRAL BLOOD FLOW

Cerebral blood flow (CBF) in man has been measured by a variety of means which have been reviewed by Marshall (1964a). Most of our early knowledge of the physiology of the cerebral circulation was obtained by the nitrous oxide method introduced by Kety and Schmidt (1945). The