Chapter 10

Cerebral Blood Flow and Metabolism

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The brain relies on adequate delivery of O₂ and glucose to maintain oxidative glycolysis and so provide energy [36]. With a reduction in O₂ delivery, compensatory mechanisms maintain the physiological milieu. When these mechanisms are exhausted the brain is vulnerable to further insult. Enhancement of these compensatory mechanisms where possible could be a further aim of intensive therapy. This requires measurement of cerebral blood flow (CBF) but the spatial and temporal resolution of available techniques is insufficient to allow routine clinical measurement of CBF [30] and cerebral metabolic activity. When such measurements do become available it may be possible to recognize pathophysiological processes, instigate appropriate treatment, and predict prognosis.

To date, the most important clinical indicator of gross brain dysfunction in the patient on an intensive care unit has been the level of consciousness. However, when unconsciousness supervenes as a result of either sedation or as a result of the disease process itself, the components of a coma scale cannot be elicited.

Physiological monitoring of brain function in the unconscious state is still in its infancy. No one technique is perfect and all have drawbacks, commonly in terms of spatial or temporal resolution. The specificity and sensitivity of a particular measurement is highly relevant to any management decision. It may not be adequate to draw conclusions from only one value in an unstable situation where continuous data are far more useful. The values obtained may be definitely abnormal, or this may only come to light with the use of provocative tests. It is perhaps a reflection on both the limitations of measurement techniques and the complexity of the disease processes that measurement of CBF has not yet made a significant impact in routine monitoring. Nevertheless, since the 1940s much important information has been gathered of direct relevance to the clinician.

Cerebral Blood Flow

History of Measurement

Burrows demonstrated that the amount of blood in the brain can vary and that this may be responsible for clinical signs [10]. Some 40 years later Roy and Sherrington measured changes in the vertical diameter of the brain in an open cranium [89]. Kety and Schmidt measured CBF quantitatively by application of the Fick principle [45]. According to this principle CBF can be calculated as:

\[
\text{CBF} = k \frac{A}{A - V}
\]

where \( k \) = blood-brain coefficient of a tracer
\( A \) = arterial concentration of the tracer
\( V \) = concentration of the tracer in the jugular venous bulb

It is assumed that the cerebral venous concentration of a diffusible tracer is equivalent to that in brain tissue. To satisfy this condition the highly diffusible gas nitrous oxide was used as the tracer. Cannulation of an artery and the jugular venous bulb was necessary to withdraw samples. This method was superseded by the use of \(^{133}\text{Xe}\) as a tracer [41].
Present Methods of Measurement

A variety of techniques are used and can be broadly divided into those that provide hemisphere or localized regional CBF (rCBF) by a two-dimensional method and those that provide the greater spatial resolution of a tomographic method.

$^{133}$Xe Clearance

$^{133}$Xe is a soluble inert gas which rapidly diffuses from blood to brain. Gamma-rays emitted through the skull are sensed by collimated detectors and the rate of clearance of the isotope is analysed to give a measure of CBF. This method provides two-dimensional data and is currently the most relevant to intensive care patients. A suitable portable machine has been developed (Novocerebrograph, Novo Instruments, Denmark) (Fig. 10.1). Ventilated patients with intra-arterial, multiple intravenous infusions and unstable physiology do not therefore have to be transferred to a CBF laboratory.

An adult dose of 10–20 mCi $^{133}$Xe is injected intravenously or 30–40 mCi are inhaled. This gives uptake doses of 10–15 mCi in adults, most of which has been exhaled into a radioactive gas trapper by the end of a 10-min period. Background activity levels are calculated, together with the activity of the end-expired air. These measurements are necessary to correct for recirculating xenon and the effect this has in reducing the observed clearance rate.

The two detectors used to measure hemispheral CBF are usually placed over the somatosensory cortex immediately adjacent to the scalp. In this position they will chiefly measure flow in the middle cerebral artery territory but there is a relative insensitivity to blood flow in deeper cerebral regions. If a restless or agitated patient moves the detectors after the injection of the isotope, the clearance curve is rendered useless. A study typically takes 15 min and if during this time there are rapid changes in CBF an averaged result is obtained. However, an index of CBF has been developed which requires only 2 min of data collection to measure the initial slope of xenon clearance [80].

Ambient conditions must be standardized. If the patient is conscious, a quiet, tranquil environment is required. CBF may also be affected by motivation [88]. Arterial blood gases should be known, especially the CO$_2$ tension; the systemic blood pressure should also be measured. The blood–brain coefficient of $^{133}$Xe changes with haematocrit and body temperature – these must be measured and any necessary correction applied [11]. More than two detectors can be used but “cross-talk” may then become a problem [5].

There are theoretical problems associated with the use of xenon clearance to measure CBF. The most important is that of “look-through” and it is an obvious limitation of any two-dimensional method [65]. If flow in a given volume of tissue is zero, then no $^{133}$Xe will enter that tissue – no clearance curve will be obtained and the total count measured by the detectors will be reduced. If CBF varies widely throughout the hemisphere and especially if there are low flows, the $^{133}$Xe clearance method will give an erroneous result. There is a further problem in that xenon will diffuse from an area of low to an area of high perfusion. A uniform partial pressure of xenon will not be achieved and again the clearance curve will not accurately reflect CBF.

Fig. 10.1. A portable machine to measure CBF: the Novocerebrograph.