Assessment of Cerebral Circulation (Cortical Blood Flow) with an Infrared Microscope

BY ROBERT E. ANDERSON, ARTHUR G. WALTZ, M.D., TAKENORI YAMAGUCHI, M.D., AND ROBERT D. OSTROM

Abstract:
An infrared microscope was used for the remote detection of the surface temperature of the cerebral cortex of experimental cats. With this instrument a qualitative assessment of the circulation of the cerebral cortex can be made without interference with the integrity of the brain or vascular tissues or the reactivity of blood vessels. Although the instrument is sensitive enough to detect minor changes of cortical blood flow, its use appears limited to the detection of rapid or transient changes of cerebral circulation and is not suitable for long-term measurements of surface temperature of the brain.

ADDITIONAL KEY WORDS
- brain temperature
- cerebral cortex
- surface temperature
- cerebrovascular disorders
- infrared measurement

The detection of rapid or transient changes in the circulation of blood in brain regions is important for an adequate study of the responses of the cerebral circulation to changes of perfusion pressure, local or systemic CO₂ tension, or other variables. Ideally, methods for investigating the cerebral circulation should provide a quantitative measure of cerebral or cortical blood flow. Unfortunately, quantification of rapid changes of regional cortical blood flow does not seem possible since reliable methods for measurement of blood flow in tissue require measurements of the changes of concentration of diffusible indicators during a steady state of at least several minutes.

If the blood of an animal is warmer than the exposed brain, simple measurement of the surface temperature of the cortex in a region remote from visible blood vessels will provide an assessment of regional tissue circulation. A change of surface temperature will reflect a change of blood flow, blood volume, or blood temperature. However, such measurement will reflect a change of blood volume only transiently since a changed amount of blood near the surface of the brain quickly reaches temperature equilibrium. A transient change of blood volume must be related to a change of blood flow; therefore, a change of local surface temperature of the brain will reflect a change of regional blood flow if compensation is made for changes of blood temperature.

The temperature of an object can be measured from a distance by detection of the wavelength of electromagnetic radiation in the infrared range emitted by the object. At the temperatures encountered in the brains of experimental animals, the wavelength of emitted infrared radiation varies from approximately 9.3 to 9.4 μ. Using a commercially available infrared detection device, we have been able to measure and continuously record the temperature of a small region of cerebral cortex and thus assess the cortical circulation in a number of experimental situations.

From the Mayo Clinic and Mayo Foundation: Sections of Neurology and Cerebrovascular Clinical Research Center, Rochester, Minnesota.

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INFRARED MICROSCOPY AND CEREBRAL CIRCULATION

FIGURE 1
Response of temperature of cerebral cortex, measured by infrared microscope, to reduction of $P_aCO_2$ (reflected by end-tidal $CO_2$ concentration) and resultant reduction of cortical blood flow. $CO_2$ in air inspired by animal decreased from approximately 4% to 0 at arrow. BP = mean systemic arterial blood pressure, measured from aorta. BLOOD TEMP = temperature of blood in aorta. $CO_2$ = end-tidal $CO_2$ concentration. Full-scale deflection of brain temperature is 1 C.

FIGURE 2
Response of temperature of cerebral cortex, measured by infrared microscope, to changes of arterial blood pressure produced by infusion of phenylephrine. Failure of brain temperature to increase immediately as BP increased may have resulted from decrease of blood temperature and cardiac arrhythmia produced at first by rapid infusion of cold solution of phenylephrine in saline. Note brain temperature paralleling BP in midportion of recording. Note also return of brain temperature toward baseline level despite continued elevation of BP, indicating (delayed) autoregulation. Full-scale temperature deflection is 1 C.
Methods
A study of the usefulness of an infrared microscope for the detection of transient or rapid changes of the cerebral circulation was made in four cats. The animals were anesthetized with pentobarbital injected intrapleurally and placed in a head holder. The surface of the cerebral cortex was exposed by craniectomy and removal of the dura, and the brain was protected with a thin film of Saran, which is transparent to radiation of wavelengths of 9.3 to 9.4 μ. A tracheostomy was performed. A catheter was placed in the aorta through a femoral artery for the measurement of mean systemic blood pressure with a strain gauge and for the withdrawal of blood samples for the determination of arterial P_{O_2}, P_{CO_2}, and pH. Temperature of blood in the aorta was measured by a thermistor passed through the other femoral artery. The femoral vein was catheterized for the intravenous injection of drugs and for supplemental anesthesia. End-tidal CO\textsubscript{2} concentration of the expired air was monitored with an infrared CO\textsubscript{2} analyzer, and sampling was from a catheter placed in the tracheostomy.

The surface temperature of the brain was measured with an infrared microscope. An objective lens of 1× was used with the sensor, allowing the lens to be placed 9 inches from the brain, to give a field of view 1 mm in diameter.

For the experiments the instrument was focused on regions of the cortex that appeared avascular, remote from large and medium-sized arterioles and venules. The output from the sensor was modified by a 15,000-microfarad capacitance to provide a time constant of 7½ seconds for recording on a polygraph.

Results
With a time constant of 7½ seconds, the recording of cortical temperature was relatively stable and unaffected by minor or transient changes of ambient temperature, such as those produced by the operation of focusing lamps and flash lamps for photography. Changes of cortical circulation (cortical blood flow) were detected in response to changes of systemic blood pressure, arterial CO\textsubscript{2} tension, and death of the animal (figs. 1, 2, and 3). At the level of sensitivity needed to detect these rapid or transient changes of cerebral circulation, instability, drift, changes of ambient temperature, and changes of blood temperature required repeated balancing of the temperature recording to prevent it from going off the scale of the polygraph.

Discussion
Thermistors and thermocouples have been used for measurement of cortical temperature, but because of the sensitivity required, these sensors are greatly affected by changes of ambient temperature.\textsuperscript{1} Even turning on a light or walking near the animal can often produce a change in the temperature being recorded. Systems of paired thermistors or thermocouples, with one of the pair heated\textsuperscript{2} or cooled externally,\textsuperscript{3} use heat as a diffusible indicator. Paired sensors are less sensitive than simple thermistors or thermocouples to changes of ambient temperature or temperature of the blood, but difficulties of calibration and instability still are considerable. All these devices must touch the brain, a potential disadvantage, since even light pressure on the brain can interfere with local circulation, particularly if the brain is pulsating. In addition, heated or cooled thermal sensors may interfere with local circulation because of effects of the temperature differential on vascular reactivity.


\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Response of temperature of cerebral cortex, measured by infrared microscope, to death of animal caused by injection of KCl. Note rapidity of cooling of brain after cessation of cardiac activity. Full-scale temperature deflection is 1 C.}
\end{figure}
The infrared microscope used for the present study does not touch the brain, and no energy is transmitted to or removed from the cortex; therefore, the instrument itself cannot produce changes in the circulation, the reactivity of the blood vessels, or the integrity of the tissues. The instrument is sensitive enough to detect minor changes in the cerebral circulation resulting from changes of systemic blood pressure or arterial $P_{CO_2}$. Compensation for changes of blood temperature must be made, as with all thermal sensors. Although instability is no greater than that of other thermal sensors$^{1,8}$ and the effects of changes of ambient temperature are minimal, instability is such that the instrument probably is not suitable for long-term investigations of the cerebral circulation. However, it appears to be useful and valuable for the study of rapid or transient changes of cortical blood flow.

References

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