Pulsatile Blood Flow of Gliomas Studied with Implanted Impedance Electrodes*

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Measurement of the regional blood flow through a brain tumor and the brain tissue that surrounds it is a difficult task with conventional methods. Recently, it was found that pulsating cerebral impedance recorded through intracerebral electrodes reflects cerebral circulation. Since April, 1966, we have implanted permanent steel wire electrodes into inoperable gliomas and surrounding tissue in seven patients. Through these electrodes it was possible to follow intracerebral impedance changes daily during the time when the patients were receiving irradiation therapy, usually a 3-month period. In this paper we shall report our recording technique, show some preliminary findings, and discuss them briefly.

Material and Method

Stereotaxic biopsy was carried out on seven patients with inoperable brain tumors. Three of these tumors were classified as astrocytomas, two as multiform glioblastomas, and one as a less well-defined glioma. The biopsy specimen was aspirated through a 2.5-mm-thick cannula introduced stereotaxically. Thereafter an enamel-insulated steel-wire electrode 80 µ thick was introduced through the cannula into the tumor tissue. The bare tip of the electrode was 1 mm long. The cannula was withdrawn. A similar electrode was introduced by free hand into the cortical tissue to a depth of 5 to 10 mm. Both electrodes were attached to the burr hole margin with a silk suture. Their ends emerged through the skin outside the incision wound and were left dangling on the scalp (Fig. 1). Before closure of the wound, the burr hole was covered with gelfoam or tissue cement. Usually no impedance measurements were made until 4 days later when it was assumed that electrode impedance was well stabilized.

Impedance measurements were carried out monopolarly by means of a modified Wheatstone bridge (Impedance Comparator, Type 1605-A, General Radio Company). This bridge gives a direct reading of the impedance difference between the standard and unknown circuit as a percentage of the total impedance magnitude. An oscillator frequency of 10 kc was used. As reference electrode we used two silver plates attached to the scalp. The total surface of these plates was 2500 mm². Since the tip of the intracerebral measuring electrode was only 0.25 mm, it seems justified to assume that impedance measurements refer to the immediate vicinity of the measuring electrode.

The electrodes were left in place for about 3 months during the irradiation. The patients were transported twice a week from the radiological to the neurosurgical department for impedance recordings. The electrodes caused slight crust formation at their points of exit from the skin, but no deeper

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Preliminary Findings

We studied both impedance baseline changes and pulsatile impedance. The baseline impedance of the tumor varied from 1 to 6 kOhms. The impedance was lowest in highly vascularized malignant tumors and highest in fibrillary astrocytomas. Cortical impedance also showed large variations partly dependent on individual and localization factors, but mostly on pressure conditions exerted on the surrounding tissue by the tumor, as will be shown later. On the basis of a single measurement it seems impossible to know whether recordings come from the tumor or from the surrounding tissue. Cysts and abnormally hard tumors may constitute an exception.

The pulsatile impedance, which is caused by the pulsatory blood flow in the vicinity of the electrode tip, was found to give much information on the circulatory conditions in the tumor and the tissue around it. Normally, the intracerebral impedance pulse wave consists of a rapidly falling phase corresponding to the systole, and a rising phase corresponding to diastole. The average time lag between the R-peak of the electrocardiogram and the start of the descending phase is 213 msec. The same time lag is usually found in brain gliomas, while outside the tumor it is greatly increased (Fig. 2). Here, impedance starts rising when it should fall, and the descending phase starts about 200 msec later than in the tumor tissue. This paradoxical impedance pulse wave is a very constant finding in the brain tissue surrounding a tumor. Its cause is presumably an intracranial hypertension. The arterial ventricular cerebrospinal fluid (CSF) pressure wave arrives 70 to 100 msec after the R-peak of the electrocardiogram. If the static intracranial pressure is very high, the CSF pressure wave compresses the capillaries and empties them, as is shown by the rising impedance. The blood flow cannot begin until the pressure wave starts declining, which is about 400 msec after the R-peak. The fact that this paradoxical impedance wave was never seen inside the tumor may be because of the higher mechanical resistance of the tumor vessels. We have not yet measured experimentally what pressure is needed to produce this paradoxically delayed pulsation. The mechanism of retarded flow in the brain under high intracranial pressure may possibly be explained on the basis of our present findings.

Figure 3 shows an example of the mutual

![Figure 2. Left: Consecutive impedance recordings from brain tumor, cerebral cortex, extracranial subcutaneous tissue, and rheoencephalography. Right: Recording in same patient 5 weeks later. Note the paradoxical impedance wave from the cortical tissue.](image-url)
dynamic relationship between the blood flow in the brain tumor and in the surrounding tissue. The baseline impedance of the tumor tissue is fairly constant. Its pulsatory component, on the contrary, starts increasing suddenly, which suggests an increased flow. This is rapidly followed by a very sharp rise in the baseline of the cortical impedance. The pulse amplitude of the rising cortical impedance shows a slight increment. When the impedance pulsation of the tumor tissue starts decreasing, the cortical impedance suddenly falls and its pulse amplitude becomes very small. We witnessed such an event twice. We think that increased flow in the tumor rapidly raises the intracranial pressure; this compresses and empties the capillaries of the surrounding cortex, causing the cortical impedance to rise. This rise may also be caused by an electrolyte shift from the extracellular space. It is conceivable that the incident shown in Fig. 3 has something to do with the plateau pressure waves described by Lundberg. So far we have not carried out simultaneous pressure and impedance recordings on tumor patients.

On the seven patients, we studied the effect of radiotherapy on the tumor impedance and circulation; Fig. 4 illustrates a finding which seems to us typical. In the very beginning of treatment the impedance pulse amplitude increases, possibly due to hyperemia, but during prolonged irradiation the pulse amplitude slowly decreases, indicating impairment of circulation in the tumor. The base line impedance does not show any clear changes during irradiation.

It seems to us that recording of pulsatile impedance from brain tumors and the tissue surrounding them is a valuable method for investigating pathological cerebral circulation. The true nature of pulsatile impedance is still poorly understood, but it is clearly evident that it reflects pulsatile blood flow. One of the basic problems here is how much of the cerebral circulation is pulsatile and how much consists of a steady flow. As yet, we do not know whether the impedance method can be developed into a quantitative method for cerebral blood flow studies, as a qualitative method it gives valuable information on rapid circulatory changes.

Fig. 3. Mutual dynamic relationship between the cortical and the tumor impedance in the same patient. The solid lines indicate baseline impedances. Some examples of the recordings illustrate the simultaneous changes of the pulsatile component of the cortical and the tumor impedance.
Summary

Pulsatile cerebral impedance and blood flow were studied in seven patients with the aid of permanent steel wire electrodes implanted in brain tumors and the tissue surrounding them. The method has been described and some preliminary results presented and discussed.

References