Stationary Potential of the Brain: Part II. Clinical Studies

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Summary

Stationary potential changes through the scalp and those on the cortex were measured by a high impedance chopper stabilized DC amplifier and calomel half-cell electrodes. For clinical use, a new SP encephalograph was devised. It can detect SP changes at 90 points automatically. SP encephalogram in normal subjects shows a symmetrical voltage distribution over the hemisphere with the highest potential in the vertex (ranging from 10 to 20 mV when the reference electrode was on the nasion). Clinical studies in 345 cases and intraoperative SP measured in 28 cases together with supplemental animal experiments indicated that if the lesion involves the cortex, the SP over the area shows negativity as compared with the normal portion on the order of 5–20 mV, whereas if the lesion is in the subcortex, the cortex over the lesion shows positivity on the order of 5–10 mV. The polarity of SP change is decided by the relationship between the location of the lesion to the cortex. If the lesion is an expanding type such as meningioma, the SP shows “crateriform potential change,” that is, negative in the center of the tumor and positive surrounding it. Slight cortical compression also exhibits slight positivity. Based on the above-mentioned principle of SP change, SP encephalography may be of help in estimating the area, depth, degree and nature of the lesion.

As described in the Part I of our article, the electrical activities of the brain may be classified into three categories: 1) EEG; 2) slowly changing potential (SCP); and 3) stationary potential (SP). The latter two have been usually called DC potentials or steady potentials. Although several researchers have reported DC potential changes in epilepsy in man, namely SCP in our classification,⁴⁾ SP has rarely been studied. Therefore, the significance of this potential in diagnosis of neurological diseases and in understanding the electrical phenomena of the brain has never been pointed out.^{12,16)}

Since 1960, we have measured SP through the scalp or directly from the cerebral cortex in 345 cases of craniotomies. This part of our article deals with the analysis of these SP measurements and their relationship to various brain lesions.

Methods

Measurement of SP requires a special recording system to avoid various nonbiological polarizations. Our system consists of a pair of calomel half-cell electrodes, salt bridges containing saturated KCl-agar, and a high impedance chopper stabilized amplifier (Toa Dempa, AD-3 or PM-19A, with input impedance over 30,000 megohms). Before 1973, a simple method was used. According to the 10–20 electrodes placement system, about 30 points were determined over the scalp. A small amount of bentonite containing saturated KCl solution, 0.1% epinephrine and 4% xylocaine was placed on each of the 30 measuring points and they were covered with small cotton pledgets. A reference electrode was placed on the nasion after the same preparation.

a

b

c

d

Fig. 1 a) Block diagram of the SP encephalograph
 b) External appearance of the SP encephalograph
 c) Derivating equipment of the SP encephalograph
 d) Recording mechanism and the chart for SP encephalograph

An active electrode was put manually on the cotton pledget of each measuring point in turn and the SP value of each point was read from a scale of the high impedance DC amplifier. Details of the technique have been described previously.¹⁴⁾ In 1973, an automatically driven SP-encephalograph was developed (Fig. 1). Since then, this machine has been used for all cases except for patients in an unconscious state.

This equipment automatically records SP changes on the scalp. The SP distribution on the scalp is recorded by 90 units of agar bridges and calomel half-cells, which are led to the automatically changing switches controlled by scanners. The amplified potentials are divided into six grades of potential by a comparator, and displayed as colored dots on a circular chart by a dotting mechanism (Fig. 1d). This equipment can detect each voltage difference of 5 to 10 mV and also has a subtraction system of left to right or right to left. One measurement requires only 3 minutes. The reference point is usually on the vertex.

Results

A. SP encephalograms of various cases

Normal Control: Normal controls (80 cases) showed a symmetrical voltage distribution with the highest potential on the vertex (Fig. 2). When the reference electrode was on the nasion, the highest potentials usually ranged between 10–20 mV. When the voltage pattern deviated from that of the normal control by more than 5 mV, it was considered abnormal.

Intracranial organic lesions: A total of 345 cases with various intracranial organic lesions were studied (Table 1).

1. Brain tumors (119 cases)

a) **Meningiomas (54 cases)** Eighty-nine percent of meningiomas showed potential abnormality which coincided with the location of the tumor; low voltage over the tumor was seen in 15 cases (28%) and high voltage over the tumor in 8 cases (15%). It is interesting to note that about one half of the cases with meningioma (24 cases, 44%) showed a special form of SP distribution which the authors call "crateriform potential change." It consists of negativity in the center (over the tumor) with surrounding pos-

Fig. 2. An SP encephalogram of a normal control, showing symmetrical voltage distribution with the highest potential distribution on the vertex. The reference is on the nasion.

itivity (over the adjacent cortex). The crateriform potential change seemed more or less characteristic of meningiomas or other expanding tumors as seen in Table 1. Figure 3a is a case of right parietal parasagittal meningioma which showed a typical crateriform potential change.

In relation to the incidence of epileptic seizures in meningiomas, 78% of cases showing the crateriform potential change and 60% of cases with simple negativity over the tumor had epileptic attacks, but only 25% of the cases with normal SP pattern had seizures. A steep SP potential gradient caused by the tumor may be irritable to the surrounding cerebral cortex, working in a source-and-sink relationship.¹⁵⁾

b) **Glioma (42 cases)** Ninety-five percent of the cases with gliomas showed SP abnormality corresponding to the location of the tumor; low voltage over the tumor was seen in 50%, whereas high voltage over the tumor was seen in 45%. There was a tendency for the tumors involving the cerebral cortex to develop a negativity, whereas those located in the subcortex to show a positivity over the tumor. A typical SP encephalogram of the latter type is shown in Figure 3b. In gliomas, the authors could not find

Table 1 Cases of SP measurement on scalp

Type of SP change	Nega- tive	Posi- tive	Crateri- form	Irreg- ular	No change	Total
Brain tumor						119
meningioma	15	8	24	1	6	54
glioma	21	19	0	0	2	42
metastatic tumor	2	1	1	4	0	8
pituitary tumor	3	1	0	0	5	9
brain abscess	1	2	2	0	0	5
parasitoma	1	0	0	0	0	1
Intracranial hematoma						48
acute subdural hematoma	4	1	0	0	0	5
acute epidural hematoma	1	6	0	1	1	9
intracerebral hematoma	6	2	0	0	1	9
chronic subdural hematoma	7	17	0	1	0	25
Head injury (without hematoma)						40
contusion (acute stage)	7	0	0	3	1	11
contusion (chronic stage)	6	2	0	0	1	9
depressed fracture	8	10	0	1	1	20
Arteriovenous malformation	11	0	0	0	3	14
Cerebral infarction	8	0	0	0	0	8
Epilepsy						59
non-focal	0	0	0	4	11	15
focal	23	7	0	0	14	44
Brain death						9
Miscellaneous & screening (diagnosis unknown)						48
Total						345 Cases

Fig. 3 SP encephalograms of various intracranial organic lesions

- A case of right parasagittal meningioma, showing typical crateriform potential change. The numbers in the figure are electrode numbers.
- A case of left frontal cystic astrocytoma, showing positivity of 10 mV over the tumor. The stripes correspond with the location of the tumor.
- A case of right chronic subdural hematoma, showing positivity of 15 mV compared with the left side.
- A case of right temporal cerebral contusion, showing negativity of 20 mV. An arrow shows the impacted site.
- A case of cerebral infarction of the left middle cerebral artery, showing negativity compared with the right side.
- A case of epilepsy caused by ectopic gray matter, showing negativity of 5 mV over the focus surrounded by positivity.

the typical pattern of crateriform potential change as seen in meningiomas.

c) Metastatic tumors (8 cases) These tumors sometimes had multiple SP abnormalities, both positivity and negativity over the tumor, resulting in irregular potential patterns of the SP encephalogram.

d) Tumors of the pituitary region (9 cases) These usually had no particular SP abnormality.

e) Brain abscess (5 cases) Usually this group had remarkable potential change. 40% of them showed crateriform potential change.

2. Intracranial hematomas (48 cases)

a) Acute subdural hematoma (5 cases) In the 4 cases that showed negative SP change, severe cortical contusions with hematoma were noted at surgery. One case with positive SP change turned out to be a subacute subdural hygroma with little cerebral damage.

b) Acute epidural hematoma (9 cases) This type of hematoma normally showed a positive potential change as seen in Table 1. These hematoma cases usually had cortical compression without contusions. Once decompression was carried out by operation, potential recovery took place relatively soon.

c) Intracerebral hematoma (8 cases) Intracerebral hematomas due to hypertension or to rupture of venous malformations usually showed a negativity over the lesions.

d) Chronic subdural hematoma (25 cases) Seventy percent of these cases showed a positive SP on the hematoma side (Fig. 3c) and a negative change was seen in 30% of the cases. The polarity of the SP seemed dependent on the volume of the hematoma and the condition of the patient. Large hematomas in serious condition patients had a tendency for the SP to show negativity.

3. Head injuries (40 cases)

a) Cerebral contusions (20 cases) Almost all cases in the acute stage of cerebral contusion showed negative potential changes. Figure 3d shows a typical SP encephalogram of such a case. In cases of cerebral contusion in the chronic stage (later than one month), the SP

again showed negativity with several exceptions.

b) Depressed skull fractures (20 cases) Among 20 cases of depressed fracture, 10 cases showed positive and 8 cases negative SP changes. At surgery, a tendency for the negativity to be related to cortical damage was found again.

4. Vascular lesions (22 cases)

a) Arteriovenous malformations (14 cases) Eleven cases (79%) of these 14 cases showed a negative potential change. The nidus which was smaller than walnut size developed no potential abnormality.

b) Cerebral infarction (8 cases) All such cases showed a negative SP change corresponding to the lesion (Fig. 3e).

5. Epilepsy (59 cases)

Cases of cryptofocal or non-focal epilepsy usually showed a normal SP distribution, whereas cases of focal epilepsy often exhibited abnormal SP changes. About one half of the latter showed negative SP over foci. An example of such a case is illustrated in Figure 3f.

6. Brain death (9 cases)

Sixteen measurements were performed on 9 cases. Complete brain death showed no SP potential gradient relative to the nasion.

B. Measurement of cortical Sp

The cortical SP distribution was measured in 28 cases at neurosurgical operations (Table 2). The cortical SP changes almost coincided with SP encephalogram on the scalp. SP changes on the scalp seem to reflect the cortical SP potential change. Figure 4a shows the cortical SP change of a case of convexity meningioma. The SP over the tumor was about 6 mV more negative than the surrounding cortex. In this case, a reference electrode was placed on the neighboring bone. Figure 4b shows the SP distribution of a case of subcortical glioma. The SP over the tumor was about 6 mV more positive than the surrounding cortex. The epileptic foci usually exhibited negativity. Spiking was usually recorded from the border of the most negative portion. Figure 4c shows the SP distribution of a case of ectopic gray matter as a cause of uncontrollable epi-

Table 2 Cases of SP measurement of cortex

Type of SP change	Negative	Positive	Irregular	No change	Total
Brain tumor					
meningioma	7	1	0	0	8
glioma	3	1	0	1	5
other tumors	1	3	0	0	4
Intracerebral hematoma	1	0	1	0	2
Epilepsy	4	0	0	2	6
Depressed fracture	2	1	0	0	3
Total					28 Cases

lepsy. The case exhibited an area of steep negativity of 4 mV, under which ectopic gray matter was discovered. After excision of the lesion the epileptic seizures became controllable.

C Experimental study

Nineteen cats (2–3 kg) were anesthetized with 25 mg/kg pentobarbital, immobilized with galamine, and artificially ventilated. The measurement of SP was performed with calomel half-cells and salt bridges, and a high impedance chopper stabilized DC amplifier (Toa/Dempa AD-3). Experimental models of intracranial lesions were made by the following three methods: 1) cortical compression was produced by ballooning, or infusion of autogenous blood into the epidural space. The infused volume was about 2 ml; 2) cortical lesion was produced by electrocoagulation, by cortical excision or by

cerebral contusion. The lesion sizes were 5 mm in diameter; and 3) subcortical lesion was made by electrocoagulation through an inserted needle 0.5 mm in diameter or intracerebral injection of 1 ml of autogenous blood. In the former method, the lesion was about 5 mm in diameter.

The results of experimental studies: In the experimental cortical compression, after having temporarily deflected to the negative side, the SP soon changed to the positive side on the order of 5 mV and the positivity continued for more than one hour (Fig. 5a). Cortical lesions always showed negativity on the order of 5–20 mV and continued for several hours without any exception (Fig. 5b). The subcortical lesion exhibited positive SP change on the order of 5–10 mV (Fig. 5c).

Fig. 4 Intracranial recording of SP. The reference electrode was placed on marginal skull.

- A case of meningioma, showing negativity of 8 mV compared with surrounding cortex.
- A case of subcortical malignant glioma, showing positivity of 6 mV over the tumor.
- A case of focal epilepsy, showing negativity of 4 mV in the focus.

Fig. 5 SP changes on experimental cerebral lesions.

- a) Cortical compression by ballooning, showing positive SP change.
- b) Cortical lesion produced by electrocoagulation, showing sustained negative SP change.
- c) Subcortical lesion produced by subcortical injection of autogenous blood, showing sustained positive SP change after initial temporary negative change.

Discussion

DC potential of the brain was discovered by Richard Caton in 1875.²⁾ He noted that by sensory stimulation a shift of major potential occurred on the cerebral cortex of the rabbit. This potential may have been equivalent to the SCP in our classification of electrical phenomena of the brain. For a long time since then this kind of brain potential rarely interested researchers, until Goldring et al.⁴⁾ recorded a negative shift accompanying epileptic seizures in man. There have been very few articles in the literature about the measurement of DC potentials in man, particularly about the SP, except for a series of publications from our department.^{3,8~11, 13~15)}

The results of these clinical and experimental studies on the SP in normal and various pathological conditions suggest that there are certain principles governing the change of SP. Lesions involving the cerebral cortex cause more negative SP levels in the area (on the order of 5 to 20 mV) than that in the surrounding normal cortex.

Lesions involving only the subcortical white matter, produce a slightly positive (5 to 10 mV) SP level over the lesion. Slight compression on the cortex also results in a slight positive displacement of the SP level over the lesion.

For an understanding of the mechanisms of these SP change principles under various conditions, the origin of the SP has to be clarified. In fact the origin of the SP is in dispute, but the authors have already presented a working hypothesis elsewhere.^{14,15)} To summarize, the authors consider that the SP level of the cerebral cortex reflects the ionic distribution on the neuronal surfaces under the electrode, which constitutes the resting membrane potential. Theoretically glial cells and neurons with short axons can be regarded as closed dipole layers, in a volume conductor, therefore, their potentials are usually measured as zero. Neurons with myelinated long axons can be regarded as open dipole layers and the potential of the cell surface toward the electrode is not completely cancelled by the potential of the opposite inner surface. Therefore, positive SP is demonstrated in the normal cerebral cortex.

If there is a cortical lesion, neurons and glial cells are damaged, resulting in negative injury potentials of this area as compared with the surrounding normal cortex (Fig. 6a). The negativity of a large cerebral lesion may be explained as a result of deficiency of normal positive SP (Fig. 6b). Keating and Kempinsky⁶⁾ demonstrated that acute, circumscribed injury of the brain resulted in injury potentials which formed an electrical field extending well beyond the spatial boundaries of the injury. They made lesion by ablation of the brain or occlusion of the middle cerebral artery. Kempinsky⁷⁾ demonstrated that the resting pia-ventricular steady potential in the cat was ordinarily surface positive, ranging from less than one to as much as 7 mV, and occlusion of the middle cerebral artery was usually followed by a prominent sustained surface negative steady potential shift in the cortex supplied by this vessel. The surface negative potential shift produced by such vascular occlusion attained an amplitude of 5–11 mV negative. He concluded that the steady potential shift following vascular occlusion is a basic property of focal injury of the mammalian brain. He deduced that the origin of steady potential gradients resulting from focal cerebral

Fig. 6 The hypothetical explanation of the SP change in various cerebral lesions.

injury is explainable in terms of the algebraically summated effects of injury of individual anatomical units. Anthony et al.¹⁾ demonstrated that three kinds of SP changes could occur following middle cerebral artery occlusion in dogs: a rapidly developing negative SP shift, a slowly developing negative SP shift, or a period of SP instability. Appearance of SP change during temporary occlusion was usually associated with development of sustained neurological deficits. Heilbrum and Goldring⁵⁾ studied the SP change when the left middle cerebral artery was permanently occluded in 30 dogs under anesthesia. All dogs showing a rapid or slow SP shift developed neurological deficits. Animals without neurological impairment following occlusion were found only among those that had shown no SP change or only baseline instability. These experimental results support the authors' clinical and experimental studies.

If there is a space occupying lesion such as meningioma, normal positive SP potential is

absent; consequently the area over the tumor shows negative SP change (Fig. 6c). Surrounding the tumor, the neurons are densely located because of pressure, therefore the potential around the tumor shows positive SP potential change. Thus the "crateriform potential change" is produced (Fig. 6d). If the lesion is located in the subcortex, the number of open dipoles increases, therefore the SP measured from the cortical side shows a positive SP change (Fig. 6e).

Based on the above-mentioned principle of SP change, one may be able to estimate the area, depth, degree and nature of lesions by means of SP encephalography, probably more accurately than by means of EEG.

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