SOME ADDITIONAL ELECTROENCEPHALOGRAPHIC
TECHNIQUES FOR THE LOCALIZATION OF
INTRACRANIAL LESIONS

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INTRODUCTION

The importance of electroencephalography as a non-traumatic procedure for the localization of intracranial lesions is becoming increasingly evident. The success of the procedure depends upon the care with which it is applied, upon the variations to which it is subjected for attacking different types of lesions present in different regions, and upon the possibility of building pieces of evidence obtained from recordings into one total pattern of interpretation. Interpretation, though it is an intellectual process which establishes interrelationship between different data, is in the final analysis dependent upon such data. An advance in interpretation would obviously be predicated in part upon the introduction of techniques that would furnish us with new data, and in part upon the availability of correlation of these data on the one hand and the clinical neurological, and neuropathological findings on the other.

Investigators have placed on the skull 16 or 22 leads, and have used different types of monopolar and bipolar recordings for localization purposes. Some have preferred monopolar recordings, whereas others certain types of bipolar recordings which show a reverse phase relationship of slow waves near the lesion areas. Still others use both monopolar and bipolar recordings. It would be difficult to claim absolute success for any one standardized localizing method in all cases as the following variables are likely to show different degrees and types of electroencephalographic changes in the favored and non-favored leads; i.e., size, nature, rate of change, location and milieu of the lesion, and orientation of the lesion to the cortex and to the leads. It is not a question of how many leads are put on the skull that is important, but where they are put on. It is also important how the abnormal electrical activity surrounding the lesion is brought into prominence differentially by a choice of electrode combinations in simultaneous recordings of critical and non-critical areas. Bits of knowledge thus gathered form the basis of the final localizing evaluation. As in the neurological examination the two halves of the body are compared for strength and character of the reflexes, sensation, motor power, etc., so in electroencephalographic localization homologous areas of the two hemispheres, and distant or neighboring areas of the same hemisphere are compared. This comparison involves an
elaborate technique and a prolonged attempt at sorting the essential from the non-essential.

The problem of a close and accurate localization of a lesion electroencephalographically resolves into the following aspects:

1. Elimination of or correction for complicating factors as follows:
   a. Physiological and technical artifacts. (These will not be elaborated here.)
   b. The distance effect. In the comparison of homologous or heterologous areas, the high voltage of slow waves or other waves with long inter-electrode distance should not be considered *per se* to have greater localizing weight than the low voltage of slow waves or other waves with short inter-electrode distance. This is because of the general observation that normally the longer the distance between the electrodes the higher the voltage, and conversely, the shorter the distance the lower the voltage. This principle applies only within certain limits, the reasons being that the four lobes of the brain have somewhat different voltage, and the relationship between voltage and distance is not linear. For example, an increase of 2 cm. beyond an 8 cm. inter-electrode distance would not record as much voltage increase as a similar increase beyond a 3 cm. inter-electrode distance. The distance effect need not always be corrected for, especially when the situation is reversed, the high voltage of slow or other waves with short inter-electrode distance having greater localizing significance than the low voltage of slow or other waves with long inter-electrode distance.
   c. The effect of electrical spread of electroencephalographic signs to homologous areas (particularly in the frontal areas), to contiguous or distant areas that are not the main focus of structural involvement.
   d. High voltage bilateral delta waves or bursts due to “idiopathic” epileptic changes (Fig. 1, strips 4, 5, and 6), prolonged high intracranial pressure, or conditions severely clouding the sensorium.
   e. Generalized slow wave bursts in monopolar or bipolar recordings that are likely to confuse the validity of important differential unilateral bursts of the same or similar types. This is particularly true of deep parasagittal gliomatous neoplasms, vascular lesions, or traumatic lesions having a slight preference for one side.

2. Lateralization.
3. Determination of antero-posterior extension, of medio-lateral extension, of superior-inferior extension, or of parasagittal involvement.
4. Determination of the size and nature of the lesion.

An adequate solution of all these aspects of the localizing problem needs in the first place as many simultaneous comparisons of the involved and the non-involved areas as possible. Even so, one cannot be certain of consistent success or success on all counts. All these aspects cannot be attended to at
the same time; therefore, means for the solution of them, one after the other
or two or more at a time, must be evolved.

Using a 6-channel Grass electroencephalograph, we have introduced
some special techniques. They can be used with a 3- or 4-channel machine
also, though their scope is in proportion limited. In approximately one-third
of 800 lesion cases including 193 brain tumors, one or more of the following
special techniques have been applied and found to be of particular value. A
statistical study of these cases will be reported later.

**TECHNIQUE**

Before the special localizing techniques are used, the routine electroen-
cephalographic work-up is always done in the following manner (see Fig. 9
for routine lead placements; leads 1 to 8 inclusive and 2 ear ground leads).
Monopolar recording for 5 minutes on 6 channels simultaneously: 1-ground
(parallel ground leads on both ear lobes), 5-g, 2-g, 6-g, 3-g, 7-g; bipolar push-
pull recordings for 2 min. (no ground is used): 1-2, 5-6, 2-3, 6-7, 4-3, 8-7;
bipolar and monopolar recordings for 2 min.: 4-2, 2-6, 6-8, 4-g, 8-g. Then 2-g,
6-g, 3-g, 7-g, 4-2, 8-6 for 2 min. followed by a hyperventilation period for 2
min. (inspiration and expiration 30 to 35 times a min.) and a post-hyper-
ventilation period for the same length of time. If one uses a 3-channel ma-
cine, all types of monopolar and bipolar recordings (antero-posterior bi-
polar, coronal bipolar in the interaural plane) can be used for variable
lengths of time, provided each area figures at least twice in the total number
of recording epochs, so that rare and yet important differential localizing
signs are not missed.

If electroencephalographic lesion signs (high voltage irregular 1 to 3 per
sec. delta waves, sharp waves, etc.) are found in any one of the routine leads,
or if the clinical neurological examination demands a localizing electroen-
cephalographic study even though the routine electroencephalographic ex-
amination does not reveal any lesion signs, additional leads, 12, 16 or more
are put on the skull (Fig. 11). In such a case hyperventilation is omitted or
done at the end of a localizing work-up, provided there is no contra-indica-
tion to hyperventilation. Those homologous leads of the two sides that are most
likely to show greater changes differentially are used for this purpose. A
choice of such leads is therefore possible only after a localizing work-up.
Usually the routine leads give an approximate idea of lateralization, or even
of localization, but that is not often true. In 70 per cent or more of our cases,
4-2, 2-6, 6-8 lead combinations give the first sign of a lesion in the temporal

* A 24-point electrode box has been incorporated in the Grass machine instead of the usual 16-point
box. When more than 24 areas are covered, some unimportant routine leads are used over again and
marked prime, for example, 3', 6', etc., and put into the pin jack holes of the original 2, 6, etc., after
those leads have been taken out of the box. The use of a regular 16-point electrode box can be extended
in this manner, but the procedure is slightly more cumbersome than when a 24-point box is used.

Our system of numbering the leads on the skull is not ideal. Any other system can be used. The odd
numbers for routine and additional leads can be used for the areas of the right hemisphere, the even
numbers for the corresponding areas of the left hemisphere, and either odd or even numbers for the mid-
line leads.
lobe or a neighboring region when no such sign would be picked up in other routine leads. Hence the use of temporal leads routinely is quite essential for preliminary detection, even though there are temporalis muscle artifacts in them. Furthermore, positive localizing or lateralizing findings on a routine lead work-up including the temporal lead recording govern the decision as to which side or areas should be concentrated upon within the economy of available leads.

**Technique 1. The Alternate Unilateral Ground Lead Technique.** Using one ear ground lead at a time, instead of two ear ground leads in parallel exclusively as is usually done, relative to the homologous areas of the two sides of the head (Fig. 9); for instance, lateral posterior temporal, lateral parietal and lower motor regions of both sides are first recorded with both ear ground leads, then with the right ear alone, and finally with the left ear alone. When only the right ear is used for ground, the potentials of these three areas of the left hemisphere are led across the interior of the brain and then through the right ear. On the other hand, when only the left ear is used for ground, the potentials of the corresponding three areas of the right side of the brain are led across the interior of the brain and then through the left ear. In the first instance, the three areas of the right side, and in the second instance the three corresponding areas of the left side are not led across the same portion of the interior of the brain. This provides then a basis for comparison of the homologous areas of the two hemispheres relative to the electrodynamics of the interior of the brain. The same procedure is followed regarding the other localizing leads. (See Fig. 11 for the complete localizing leads.) (See comment.)

This alternate unilateral ground lead technique as applied to the localization of a lesion is assumed to be based upon the physical principle that if a relatively weak alternating potential (of a non-involved region) is routed through or past a very strong alternating potential field (high potential region with reference to a lesion) the former will undergo a change and the magnitude of that change will vary inversely with the distance between the path of the first potential and the field and their relative orientation to each other. Whatever the neurophysiological mechanism of the origin, transmission, or spread of the field, theoretically this principle is true, but practically there are sometimes aberrant unexplained changes or lack of expected changes when one records pathological potentials of the brain. Pending a definite verification of the above-mentioned physical assumption in terms of the known or changing concepts of neurophysiological happenings in the brain, we believe that the use of this technique has abundantly justified itself empirically when corrections are made for the distance effect or other

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* In this study instead of using the term potential difference between an active area and ear ground, terms like leading an active area through the ear ground lead have been used for simplicity.

† By interior of the brain reference is made to all those portions of the brain, both gray and white, either superficial or deep, through which or past which the potentials of an active area are led in straight-line relationship to one of the ear ground leads or the nasal lead.
complicating factors. This technique emphasizes the survey of the third dimension by means of what we may call auro-spherical vectors (see later for explanation).

The practical applications of this technique are:

1. Partial elimination of the troublesome bilateral diffuse delta wave changes (single or serial) that are found in some types of lesion (unilateral temporal lobe lesion, as a glioma, or a glioma in a neighboring region, or abscess) even though they are confined to one hemisphere, when both ear ground leads are used in parallel. This technique is a definite aid in lateralization.

2. Recording of changes surrounding a lesion at a certain depth of the cortex by leading relatively clear areas of one hemisphere through the contralateral ear lead across the interior of the brain or past the involved regions picking up on the way slow wave changes, thus determining the depth of the lesion (Figs. 8, 9, 12, and 13). Parasagittal tumors arising from the falx and extending into the parieto-motor areas have been localized by this technique in combination with the nasal lead-midline parietal lead technique (see below) when other leads have given only equivocal signs.

3. Simultaneous comparison of homologous areas of the two hemispheres posterior to the coronal interaural plane with other homologous areas of the two hemispheres anterior to that plane is easily done, thus determining at a glance the extent of anterior or posterior extension of the lesion.

4. Definite lateralization of a unilateral prefrontal or frontal lesion can be done. We have for some time observed lesions in one anterior frontal region show delta wave changes not only locally but also to a certain extent in the opposite anterior frontal region.1 Yeager16 has also called attention to this fact. For example, in the presence of a right frontal tumor, the left ear ground lead used with the right and the left frontal areas at the same time will eliminate the possibility of a false parasagittal localization by almost suppressing the spread effect of the lesion waves from the right frontal to the left frontal area. In most cases of unilateral prefrontal neoplasm with its medial border closest to the midline this technique is better for lateralization than the usual coronal straight bipolar 3-channel recording of frontal areas (right lateral frontal to right frontal, right frontal to left frontal, left frontal to left lateral frontal, or similar recordings in the premotor coronal plane).

If there is too great an amount of interfering eye muscle potential artifact in the frontal lobe localization, two leads (one on the upper lid and another on the lower lid of one of the eyes) fastened with adhesive tape or collodion can be used in push-pull fashion in one channel to determine whether or not eye potentials synchronize with the so-called slow lesion waves in the frontal areas. If they do, probably there is no localization, but if a frontal area shows delta waves when eyelid leads do not, a localizing sign should be suspected. By holding two balls of cotton over the two eyelids with equal pressure the artifactual eye potential changes can be suppressed, but one cannot always be sure whether or not the pressure is the same on both eyes. If it is not,
artifactual slow waves might appear in one frontal area and not in another
due to unequal movement of the eyes under the cotton balls, thus giving a
spurious localization.

As mentioned above, the alternate unilateral ground lead technique is
helpful in temporal lobe localization. For instance, if the left temporal lobe
is markedly involved, then the leads overlying or adjacent to that lobe will
show slow waves (their proportion dependent upon the proximity to the area
of greatest involvement) when led through the right ear alone, whereas the
corresponding areas on the right side led through the same ear will be at that
time entirely or relatively free from such waves. Now if the same left- and
right-sided areas are led through the left ear alone, all of these areas of the
right and the left side will exhibit slow wave changes. The reason is that the
left ear lead then is not an indifferent lead but a “contaminated” active lead
and potentials passing through that lead are affected. This occurs even in the
left hemispheric leads which are at a shorter distance from the left ear than
the right hemispheric leads. Here the short distance does not suppress the
voltage of the slow waves to the degree expected in normal circumstances,
and hence this effect is of localizing value. If the lesion is not exactly in the
left temporal lobe but contiguous to or more or less medial to it, the slow
wave change of the left temporal lobe leads relative to the left ear will be
less than when the left temporal lobe is markedly involved. On the other
hand, the areas of the right temporal lobe being led across the involved
medial border of the left temporal lobe and through the left ear will show
more delta wave changes than the corresponding areas of the left temporal
lobe connected to the ear of the same side. These facts taken together (after
the distance effect is corrected for) establish the extension of a lesion from
the temporal lobe border to the medial regions. Some idea is also obtained
about its depth.

Technique 2. A Nasal Lead is Employed in Push-Pull Fashion in Connection
with Midline Leads or Leads of the Two Hemispheres. The nasal lead is fastened
to a point midway between the bridge and the tip of the nose with two or three
strips of adhesive tape or collodion. This technique is of value for the follow-
ing reasons:

1. Being a point equidistant with relation to homologous areas of the two
hemispheres and being rather distant from any suspected area, it is some-
times of help in the simultaneous comparison of such areas.

2. Deep lesions in the middle or anterior fossa and sometimes in the pos-
terior fossa show differential slow wave changes in the occipital protuber-
ance lead, midline parietal lead, or midline motor lead, or other leads placed
at different heights of the skull on either side when connected with the nasal
lead, though these latter regions themselves are not involved (Fig. 13, strips
1 and 2). The appearance of these changes will depend upon the straight-line
relationship between the hemispheric leads on the one hand and the nasal
lead on the other in reference to the high potential region, and to what extent
this region is in the way of that straight line.
3. When a posterior or anterior part of an affected frontal region is connected with the nasal lead in push-pull fashion through one channel, and simultaneously the same region is connected with one of the ear ground leads through a second channel (technique 1) and with another of the posterior region leads in push-pull on a third channel, it is oftentimes easy to determine by comparison of the amplitude and incidence of slow waves from these simultaneous recordings whether the lesion is more toward the prefrontal than toward the premotor or motor area and whether it leans toward one side or the other (Fig. 11, strips 11 and 12). This is a simultaneous threedimensional survey.

4. A parasagittal lesion in the anterior region or in the interaural plane is localizable by observing the differential changes as between some or all of the midline leads on the one hand and the right and left hemispheric leads on the other recorded simultaneously with relation to the nasal lead. The next point confirms this localization.

5. By connecting either of the two upper middle zygomatic arch leads with the nasal lead (push-pull) on one channel, with the contralateral ear lead (ground) on the second channel, and by using simultaneously on other channels midline leads with the nasal lead or midline leads with one of the ear leads, some idea can be obtained concerning the depth and the lateralization of a lesion, especially of the frontal areas (partially illustrated in Fig. 13). This is another illustration of depth localization by what we may call a system of spherical vectors, not used before to our knowledge for the purpose. By spherical vectors we mean directed lines within a sphere which locate a point or a mass within that sphere with reference to points on the surface of the sphere. The cranial cavity is roughly taken as a sphere though it is not strictly so. The term spherical coordinate can be loosely used in place of the term spherical vector, but the former has an established connotation: spherical coordinates give the position of a point within a sphere in terms of two angles and a distance from the center, which is strictly not the case here.

Parasagittal lesions have always been difficult to localize because: (1) Their electroencephalographic signs are extensively bilateral, thus likely to be confused with indications of a generalized non-focal condition, or (2) Their electroencephalographic signs are inadequate for differential evaluation when they arise from homologous hemispheric leads contiguous to the lesion. To our knowledge, midline leads are not used in conventional localizing procedures. The nasal lead technique used with the midline leads and hemispheric leads (i.e., nasospherical vectors) supplies a real need in parasagittal localization.

It should be emphasized that with the use of nasal and upper zygomatic arch leads eye potentials and twitching of the nose are often sources of very troublesome artifacts. Slow wave phase reversals between two zygomatic leads used monopolarly are often seen as such artifacts. In such cases these leads should never be depended upon. At least one frontal lead and an uninvolved distant hemispheric lead should always be kept in connection with
the nasal lead for a control observation of eye potential artifacts and correction for the distance effect.

**Technique 3. Common Bipolar Lead Technique.** This involves the use of a middle parietal lead or a vertex lead, provided it does not overlie an involved area, in push-pull fashion in connection with homologous areas of two sides posterior and anterior to the coronal interaural plane or near it. The vertex lead can be used in connection with different leads on the same side (in such a case correction for distance effect or areal peculiarities must be made). The vertex lead would then be a center, and other connecting leads would act as radiating lines, though all of them would not have the same distance. This technique is a modification of the technique used by Case and Bucy and Glaser and Sjaardema. The vertex-posterior temporal, vertex-lateral parietal, and vertex-lower motor regions of both sides can be recorded simultaneously on 6 channels. Then vertex-anterior temporal, vertex-premotor, vertex-zygoma of both sides is utilized. Next vertex with some of the posterior areas and vertex with some of the anterior areas can be recorded simultaneously.

This technique is of value when employed alone or simultaneously with other techniques for two reasons:

1. Since the vertex lead is equidistant in reference to the homologous leads of the two hemispheres, it is not necessary to correct for the distance effect upon such leads as in alternate unilateral ground lead technique.

2. Keeping the vertex lead common or constant, one can assess simultaneously the decreasing or increasing amplitude or incidence of slow waves anteriorly vs. posteriorly, or laterally vs. medially. Concerning very deep midline lesions (callosal or sub-callosal), the value of this technique is at times small unless it is used as an accessory to the alternate ground lead or nasal lead techniques, since such lesions show either bilateral changes or very minimal non-differentiating changes in the skull leads. However, the vertex lead technique has been found to be useful in localizing left parieto-occipital gliomas extending to the depth of the corpus callosum by the observation of local unilateral delta waves superimposed upon bilateral changes associated with callosal involvement.

The advantage of this common vertex bipolar technique over coronal right to left straight bipolar recording (one dimension) or antero-posterior straight bipolar recording (second dimension) in the conventional 16-electrode diagram of the skull is that the former has the capacity of comparing the leads in two dimensions simultaneously, rather than one dimension at a time as in the conventional procedure, even though two interhemispheric diagonal recordings are used in the latter. This does not mean that one-dimensional bipolar recording (antero-posterior, then coronal latero-medial) serially is at times not indicated or not useful.

We realize that the two-dimensional survey can locate a mass or lesion present in the third dimension, but because of the very nature of the technique the third dimension cannot be adequately explored by it. However, when the two-dimensional survey is reinforced simultaneously by the survey
of the third dimension as exemplified in the alternate unilateral ground technique and the nasal lead technique, the procedure is of greater help in localization. The third dimension is surveyed, as mentioned before, by spherical vectors, with two fixed points—one or the other ear lead and the nasal lead (disregarding the direction of the potentials in reference to the vector "arrows"). The spherical vectors are directed lines (1) between one or the other ear lead and the hemispheric leads or midline leads, and (2) between the nasal lead and the hemispheric leads or midline leads. These two types of vectors can intersect or nearly intersect. The useful localizing vectors are those which by intersecting with each other or by remaining free lines show the most delta wave changes revealing the depth and the spread of the lesion.

Triangulation, which in ordinary recordings is a variant of the two-dimensional survey, is of definite value in localization, but when there are wide-spread bilateral slow wave changes in the skull leads, long-distance triangulation is often useless or at least inferior to other methods. This is also true of short-distance triangulation. However, when the slow waves are scattered over one hemisphere or a large part of it as with infiltrating gliomas, a short-distance triangulation has its value. In such cases triangulation between three leads approximately 5 cm. apart in the posterior region, then another similar triangulation in the parieto-motor-temporal region and another one in the anterior region would probably bring out the 180 degree reversal of phase of delta waves of highest voltage or sharp waves in the neighborhood of the most involved area. In comparing these three sets of triangulation or any closely compact sets of triangulation for phase reversal of delta waves, two facts need be remembered: first, the sides of the triangle or triangles that are compared should be approximately equal in length especially when comparing delta waves; secondly, a genuine phase reversal should not be confused with an instrumental phase reversal. Sometimes two leads in the lesion area may show genuine phase reversal when compared with two leads in an area at its proximate border (Fig. 11, strips 11 and 12). Also occasionally the normal temporal lobe may show some delta or sharp waves genuinely reversed in phase compared to similar waves coming from the involved temporal lobe.

At times triangulation has a negative value. If, for instance, a short-distance triangulation (5 cm.) between the right premotor area, the left premotor area, and the midline frontal area, shows some minor low voltage slow waves, but no clear phase reversals as between any two of the three leads, it is likely that the lesion is not immediately subjacent to these leads. When this sort of triangulation is simultaneously used in combination with the recording from an upper zygomatic arch lead led through the contralateral ear ground across the brain, the presence of a deep lesion in the frontal region may be revealed, if there is one present. Pituitary adenomas are difficult to localize even with the use of this technique. Rare or occasional changes in some cases of pituitary tumor, however, betray their presence when this technique is applied (see Fig. 8).
In summary, the order of localizing work-up is as follows:
1. Routine work-up.
2. Use of technique 3 (common bipolar vertex lead recording in connection with all the localizing and some routine leads).
3. Use of antero-posterior bipolar recordings of homologous localizing leads of both sides.
4. Use of technique 1 (alternate unilateral ground lead recordings in connection with localizing leads).
5. Use of technique 2 (nasal lead push-pull recording in connection with the midline leads, occipital protuberance lead and other hemispheric leads according to estimated need).
6. Combined use of these techniques in different lead combinations as necessary to bring out differential changes in critical areas as compared to non-critical areas. A combination of simultaneous two- and three-dimensional survey is emphasized here.

RESULTS
The following neoplasms have been selected from a large series to illustrate the use of the above-mentioned techniques.

Case 1. L. W. was a 32-year-old white male admitted to the University Hospital on Aug. 6, 1942, with the story of bilateral anosmia of 3 years' duration, amnesic spells, and generalized grand mal convulsions at infrequent intervals for the past 2 years. During the 6 months pre-

![EEG recordings](attachment:image.png)

Fig. 1. Case 1. The 3 upper EEG strips were taken simultaneously as were the lower 3 strips.

vious to admission, he had experienced increasing nervous irritability and failing memory. Examination revealed bilateral choked disk, bilateral anosmia, and a questionably slight increase in the response of the deep tendon reflexes on the left.

Electroencephalographic analysis was interpreted as showing a right-sided frontal lesion (Figs. 1 and 2).

A ventriculogram and an arteriogram showed questionable right frontal localization. At
operation a large, predominantly right-sided olfactory groove meningioma was removed (Figs. 3 and 4).

**Fig. 2.** Case 1. A few seconds after the last 3 strips of Fig. 1. The first 3 strips (straight coronal bipolar recording of conventional type across entire prefrontal regions) show high voltage slow waves appearing irregularly superimposed with many muscle artifacts.

**Fig. 3.** Case 1. Ventriculogram showing suspicious blunting of tips of frontal horns (brow-up projection). Gas in suprachiasmatic region suggestively outlines posterior extension of mass in anterior fossa. The hyperostosis frontalis had no relation to the neoplasm. Not definite.
Explanation of Fig. 1

In this case routine leads were placed on the skull in addition to one lateral prefrontal on each side of the head. Our special localizing techniques were not used in this case. Note occasional 3 per sec. lesion waves in the right lateral frontal and right frontal areas but not in the left frontal area (monopolar recording with parallel ground ear lead). It was suddenly noticed (strips 4, 5, and 6) that from the right and the left side of the frontal areas slow waves were developing. At that time straight bipolar recording was done as between right mid-temporal to right lateral frontal, right lateral frontal to right frontal, and right frontal to right motor. These waves came with increasing amplitude and slow wave lengths for about a minute during which time the patient was lying quietly on the stretcher.

Explanation of Fig. 2

At this time the patient had a psychomotor seizure. He attempted to sit up on the stretcher, looked confused, and said, “Why am I here? Give me a cigarette.” He was reassured and coaxed to lie down upon the stretcher. He did not remember this episode and answered on questioning that he felt all right. He was allowed to smoke. The lower 3 strips of this figure were taken on the same leads 16 min. following the upper 3 strips. The patient had been talking normally immediately before the lower strips were taken. Note the high voltage delta waves from the right lateral frontal and right frontal reversing their phases at the right frontal lead. No such waves are found in the left frontal lead. On the basis of sporadic delta waves before the spell and the remarkable continuous change lateralized some time after the
spell, it was concluded that there was a lesion in the right frontal region. At this time no special techniques as set forth in this paper were used. The antero-posterior extension and the depth of the lesion could not be determined in consequence.

Case 2. M. W. was a 43-year-old white female admitted to the University Hospital on May 29, 1943. She had experienced severe daily headaches for 5 months previous to admission. Examination disclosed early choked disk O.U. with a questionable right homonymous field defect. There was some minimal increase in the deep tendon reflex activity on the right side. There was a positive extensor plantar response on the right.

Routine skull x-rays were normal.
Electroencephalographic analysis disclosed a left occipital localization (Fig. 5).
Ventriculography and arteriography were not satisfactory for definite localizing purposes (Fig. 6).
At operation a left occipital pole endothelial sarcoma was removed.

![Fig. 5. EEG in Case 2. Bipolar recording. Leads and calibration are as indicated.](image)

**Explanation of Fig. 5**

The electroencephalogram shows the presence of 1.5 to 2 per sec. delta waves in reverse phase in the left occipital area (first 2 strips) but not in the same area on the right side (the last 2 strips). Only routine leads were placed on the patient in addition to 2 posterior leads in the lateral parietal area, one on each side. At that time no special techniques were used for localization. No idea was obtained concerning the depth of the lesion or its exact location.

Case 3. S. S. was a 49-year-old white male admitted to the University Hospital on June 11, 1946, with a history of failing vision O.S. of 5 years duration which had progressed to total blindness O.S. at the time of admission. During the year previous to admission he had begun to experience diminution in visual acuity O.D. On admission visual acuity O.D. was 6/30 and there was a temporal hemianopic defect O.D. He had experienced severe frontal headaches for several months 4 years previous to admission, but had had no headache for the 3-year period preceding admission. Three months before admission he had developed typical diabetes insipidus. Fasting blood sugar determinations were normal.

X-rays of the skull showed extensive intrasellar erosion (Fig. 7).
Electroencephalographic analysis of rare changes disclosed deep frontal localization with equal preference for both lobes (Fig. 8).

At operation a chromophobe adenoma of the pituitary gland was found invading the frontal lobes.
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Fig. 6. Case 2. Ventriculogram of poor diagnostic value due to inadequate amount of gas filling the system. Vestibule of left ventricle is displaced anteriorly.

Fig. 7. Routine roentgenogram of skull in Case 3 showing total intrasellar type of erosive destruction produced by large chromophobe adenoma of pituitary which had burst through diaphragma sellae and infiltrated surrounding regions.
Fig. 8. Case 3. EEG on right, and diagrams on left. Stippled area indicates the lesion.

Explanation of Fig. 8

The 6 upper strips were taken simultaneously as were the lower 6 strips. Nasal lead, 6', is put within parenthesis in the lesion diagram because it is anterior to the coronal section through the premotor area. There are some spiky waves, some irregularity of the amplitude modulation, scattered slow waves and low voltage fast activity in the total period of recording; otherwise the pattern is not too abnormal. Note that when the midline premotor area, 2', is led in push-pull fashion through the nasal lead, 6', it shows (3rd strip) slightly more undulations and slow wave changes than when the same area is led through the right ear alone simultaneously (6th strip). Area 12, when led through the nasal lead alone, 6', (9th strip) or through the right ear alone (12th strip) shows a sudden high voltage slow wave burst. Areas 13 and 14 when led through the nasal lead, 6', show only minimal slow wave change (strips 7 and 8) synchronous with but of much lesser voltage than area 12-right ear or area 12-nasal (strips 9 and 12). However, these areas (13 and 14) show hardly any simultaneous changes when led through the right ear alone (10th and 11th strips). The above-mentioned bursts occur only a few times during the entire record in other favored leads.

The minor and rare evidences present differentially in the electroencephalographic record (see Fig. 8) have been interpreted as probably suggesting the presence of a lesion situated anteriorly, deeply, and in the midline. Fig. 7 shows the routine skull roentgenogram indicating the presence of the lesion.

Case 4. R. F. was a 52-year-old white male admitted to the University Hospital on Aug. 16, 1946. For 6 months he had had "fainting" spells which were actually grand mal convulsive seizures. Following each seizure it was noted that there was some transient weakness of the left arm. He had had 6 of these attacks. On examination he exhibited mild confusion, loss of memory, and emotional instability. There was bilateral choked disk with hemorrhages and exudates. There was a central type of left facial weakness. Extensor plantar response was present bilaterally.
Electroencephalographic analysis disclosed a right frontal premotor localization, not deep with sparing of the temporal lobe (Fig. 9).

Fig. 9. Case 4. EEG on right, and diagrams on left. Stippled portions of diagrams indicate locus of the neoplasm.

A ventriculogram demonstrated a right posterior-inferior frontal space-occupying lesion (Fig. 10).

At operation a right sphenoidal ridge meningioma was removed.

Explanation of Fig. 9

The upper 6 electroencephalographic strips were taken simultaneously as were the lower 6 strips. These strips partially illustrate the alternate unilateral ground lead technique. Note the high voltage slow waves superimposed with alphas and sub-alphas in areas marked 13, 11, and 18' (strips 1, 2, and 3) when they are led across the lesion, and the high potential region through the right ear lead only (upper left diagram). Strips 7, 8 and 9 record waves of the same regions, 13, 11, and 18', when they are led through the left ear alone. Note then that the waves of 13 and 11 are slightly less in voltage, particularly from area 18'. When 18' skirts the high potential field (middle diagram), it shows much less slow wave change as it is led through the left ear (strip 9) than when it goes across the high potential region (upper left
diagram) being led through the right ear alone (strip 3). Note also that the left upper zygoma lead, 10, and the left anterior temporal lead, 14, when led through the right ear alone (upper left diagram) do not show as much slow wave change skirting the high potential field (strips 5 and 6) as the areas 13, 11, and 18' going across the field and through the same ear (strips 1, 2, and 3). This is so in spite of the shorter distance between the second group of leads and the right ear than the first group of leads and the same ear. The fact that leads 9, 13, 11, and 18' are close to the tumor region and show marked slow wave changes is only partially true because even a left hemispheric lead in the premotor area such as lead 12, which is quite a distance away from the involved region, shows the same slow wave changes as leads 9, 13, 11 and 18' if led across the involved region and through the right ear alone. This particular recording is not shown here. The last two strips, 11 and 12, illustrate how the left frontal area

![Fig. 10. Case 4. Ventriculogram showing marked displacement of ventricular system to the left—particularly the right frontal horn and third ventricle.](image)

(5) which showed occasional confusing marked slow wave changes (not shown) when parallel ground leads were used and when used bipolarly with other distant leads, shows only minimal changes when led through the left ear alone. The right frontal lead, 1, exhibits pronounced change in contrast when led through the left ear lead alone (strip 11). This helps to eliminate false parasagittal frontal localization.

Using the general and the specific techniques, it is found that the lesion particularly involves the areas marked 1, 13, 11, and 9. Area 18' was partially eliminated from consideration (strip 9). Two short-distance triangulations between 1, 13, 11, and 9 were done (not shown) indicating clearer reversal of phase of slow waves at lead 1 although the distances between all leads were about the same. Then by using the nasal lead, 20, bipolarly with lead 1 (not shown), the slow wave changes were found to be occasionally less than when lead 1 was used with other leads simultaneously (e.g. lead 19 or other closer leads). This indicates that the lesion is not immediately subjacent to lead 1 but quite close to it, that it is more towards leads 13 and 11 than lead 20. Formerly it was found that 4–2 lead combinations rarely showed any significant change. From all these bits of evidence it was concluded that the lesion was located in
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the right fronto-premotor area, not immediately subjacent to lead 1, that the temporal lobe was spared, and that it was subcortical but not deep enough to involve the corpus callosum or other deeper regions. If it were quite deep, area 14 when led through the right ear would have shown more slow wave changes than it actually did (Fig. 9, strip 6), since the path of the potential traverses deeper cortical areas, the corpus callosum, and sub-callosal regions.

Case 5. L.D. was a 41-year-old white male admitted to the University Hospital on Aug. 26, 1946. He had a 7-week history of headache, blurring of vision, loss of memory, confusion and paresis of the right arm and leg. All had been rapidly progressive. Examination disclosed ex-

Fig. 11. Case 5. Electrode diagram and EEG. The upper 6 strips were taken simultaneously as were the lower 6 strips.

treme drowsiness, bilateral choked disk, and paresis of the right arm and leg. X-rays disclosed extrasellar erosion.

Electroencephalographic analysis was interpreted as showing a deep parasagittal frontal premotor chiefly right-sided localization of an infiltrating neoplasm (Figs. 11, 12, and 13).

A ventriculogram was interpreted as showing questionably two lesions, one parasagittally situated on the left and another in the inferior right frontal region (Fig. 14).

At operation an extensive parasagittal callosal and right frontal glioblastoma multiforme was disclosed.

Explanation of Fig. 11

The use of a common bipolar lead at the midline parietal region, 18, connected with the posterior and anterior leads on homologous areas is shown. The first 4 strips immediately rule out the presence of a cortical lesion posterior to the interaural plane (parietal, occipital and posterior temporal regions) and rule in the presence of a lesion in the right frontal region, lead 1, and equivocally in the left frontal region, lead 5 (5th and 6th strips). The 9th strip again proves the lesion to be in the right anterior region, probably laterally and not medially. The 7th and the 8th strips indicate that the lesion is probably not on the surface in the right or in the left hemisphere (see explanation of Fig. 12). The combination of the 11th and 12th
strips (right frontal with a posterior lead and the same region with the nasal lead) suggests a choice between the anterior or posterior extension of the lesion in reference to lead 1. (It is assumed from previous recordings that lead 18 was not involved and of course the nasal lead, 21, could not be involved). The amplitude difference in the 11th and the 12th strips is due to the long-distance effect (18–1) and short-distance effect (21–1). The 180 degree phase difference of high voltage slow waves as between 18–1 and 21–1 is genuine and not instrumental. It suggests that the 21–1 line of potential skirts the anterior border of the high potential region which is established by 18–1 and other neighboring leads to be present slightly posteriorly or laterally. From these electroencephalographic strips it is possible to say that at least some part of the lesion is more toward the premotor region than the frontal pole.

Explanation of Fig. 12

The electroencephalographic strips 1 and 2 of Fig. 12 show in common bipolar recording that the slow waves were present in bilateral premotor areas. Strip 3 shows definitely that the left anterior region is involved. Strip 4 shows that the deep parasagittal region is also involved. Strips 5 and 6 in combination suggest that probably the lesion is more toward the premotor region than the frontal pole, but this evidence is not as strong as that presented in strip 12 shown in Fig. 11. Strips 7, 8, and 9 show results of triangulation, giving a 180 degree phase reversal of slow waves in lead 16' but not in leads 19 or 20. The latter fact suggests that the lesion is near 16', and that either there is a likelihood of a cancelling-out effect in push-pull as between two homologous areas 19 and 20 or that the lesion is not immediately subjacent to 19 or 20. Strip 10 (lead 22-left ear) shows some slow wave changes but not as marked as in strip 5, indicating variable performance of the same lead. Strip 12 definitely suggests that lead 5 is involved when led through the left ear. This corrects the previous impression (Fig. 11) that the lesion existed only on the right side and confirms the impression gained from other strips that the left side was also involved.
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Explanation of Fig. 13

The first strip of Fig. 13 shows that slow waves are found in the occipital protuberance lead 17 and the midline parietal lead when they are led across the interior of the brain through

Fig. 13. Case 5. Right lower skull diagram shows position of leads on left side and position of lesion as interpreted from ventriculogram (Fig. 14), though it gives the false impression that it is on the surface.

Fig. 14. Case 5. Ventriculogram showing displacement of ventricular system compatible with a parasagittal lesion predominantly left-sided, and displacement of right frontal horn and third ventricle to the left compatible with a right inferior frontal lesion.
the nasal lead picking up slow wave changes from the involved regions in the depth of brain, though in themselves the occipital proterubance and midline parietal areas are clear (not shown here). The 3rd strip suffers from short-distance effect; nevertheless it shows some changes. Because of the distance effect it is not strictly comparable to the 4th strip though 9 and 10 are homologous areas. The 4th strip indicates that when the upper left zygoma, lead 10, is recorded through the right ear lead it picks up slow wave changes from the interior of the brain indicating that the lesion has depth extension or deep spread effect. Strip 5 indicates minor changes, but strip 6 leads the left premotor area potentials across the interior of the brain through the right ear bringing out some prominent slow waves. Though distances between lead 19 to the right ear and lead 20 to the right ear are not comparable, this discrepancy is not enough to minimize the value of slow waves in the lead 20-right ear recording.

From all electroencephalographic evidences gathered from different types of recording (Figs. 11, 12, and 13) and in spite of the clinical evidence of a left-sided lesion, it was concluded that the lesion was a parasagittal one involving the fronto-premotor area, lying more toward the premotor region than the frontal pole and having a definite preference for the right side, that it was a large lesion having very deep extension, and that probably it was an infiltrating and edematous neoplasm.

This conclusion arrived at from electroencephalography was corroborated by the ventriculographic and operative findings.

COMMENT

In Cases 1 and 2 only certain phases of the conventional localizing techniques have been used. Depth and precise extent of a lesion cannot accurately be determined by this method. In Cases 3, 4, and 5 a combination of the special techniques discussed has accurately revealed not only the depth but the antero-posterior extent of the lesions as well.

Irregular high voltage 1 to 3 per sec. delta waves are usually associated with a neoplasm. These waves are supposed to arise from the cortex, although a lesion may be some distance away from it, indicating the influence (mechanical, vascular, etc.) of the lesion on the neighboring brain tissue and therefore upon the spontaneously beating cortical cells.

The question is not settled, however, as to whether the ionic disorganization surrounding a lesion is relayed to the cortical cells presenting an electroencephalographic picture in which the original cellular beats become only graphically masked, or whether such disorganization intrinsically changes the beat of the cortical cells themselves.

All localizing electroencephalographic techniques assume the presence of ionic disorganization without inquiring into the mechanism of its origin, transmission, or spread, and only attempt to utilize it for detecting the involved areas. The three-dimensional technique empirically facilitates this detection by directing the spherical vectors through the areas in which the ionic disorganization (delta waves) originates or into which it strongly spreads. If the delta waves did not spread three dimensionally, skull leads could not pick them up, arising as they do in the cortex below.

Much more work is necessary before it is possible to predict accurately the nature of the lesion causing ionic disorganization though at times some idea is obtainable from the electroencephalogram alone as to the broad classifications into which the lesion may fall pathologically.
SUMMARY

A three-dimensional system of localizing electroencephalographic techniques using alternate unilateral ground lead, common bipolar lead, and nasal lead individually or in combination is described. These special techniques have been of particular value in narrowly localizing different types of lesions, including parasagittal lesions and lesions of varying depth. The techniques are illustrated by a few cases culled from a series of 300 cases (193 verified brain tumors) in which electroencephalographic localization utilizing the techniques discussed has been done.

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