A New Multipurpose Human Brain Depth Probe

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We have recently reported the details of construction of a new multipurpose brain probe. Although this has found significant use in animal studies, it was originally designed for chronic clinical implantation. In addition to the "usual" studies performed in depth electrography, such as the recording of spontaneous or evoked depth potentials and changes occurring consequent to depth stimulation, we have recently been interested in the use of other techniques to evaluate metabolic states in the living brain. There have been many reports built around the use of polarographic methods for evaluating cerebral oxygenation. Other polarographic techniques have been reported, principally for intravascular circulatory studies. Our probe has made it possible to apply many of these studies to brain tissue. We have also been interested in the use of alternating current impedance measurements as an index of certain anatomical and physiological characteristics of intracranial tissues.

With such a variety of studies in mind, it proved necessary to design a probe having a great number of contacts. Since one can never be exactly sure in advance where an area of interest might lie along the course of a depth probe, it is important to have more contacts than are needed so that the significant areas may be selected for study after implantation. In addition, this modification permits finely spaced measurements and the study of gradient fields within the brain. The basic design for the probe used in this study is shown in Fig. 1.

The 18 contacts are made by laminating 18 wires around a length of #24 stainless hypodermic needle tubing stock. Using high temperature electrical varnish, this probe has been heat-bonded as a unit and has one contact per wire. The electrical contact is made at a selected location by carefully cutting through the insulation. The wire, which is .0035 in. in diameter, is an alloy of 90% platinum, and 10% iridium; the latter gives rigidity and resiliency to the alloy. Each contact surface is 0.075×1.00 mm. All of the present probes are made with an increased density of contacts near the tip, with additional intercontact spacing further up the probe length. Through the hollow tubing core one may pass a guarded microelectrode, make injections into the tissue, or pass a coagulating electrode. The bare contacts are platinized which increases the electrical sensitivity of contact by about one hundred-fold over ordinary stainless steel. This sensitivity varies with frequency but is particularly important at the lower frequencies and DC.

The most common form of electrodes now employed consists of a bundle of wires tightly or loosely twisted together. When the number of wires is more than 8 or 10, the probe becomes stiffened so that it has the size and flexibility of a long, #20 needle. Although there are theoretical disadvantages to the use of a stiff probe, we have yet to observe any significant limitation related to this factor. Chronic implantations have been maintained from 2 weeks to 1 month. Three of our implanted patients have had grand mal seizures, occasionally accompanied by severe falls, but in none of these have we encountered any significant complication. We believe any possible disadvantage is outweighed by the availability of the large number of contacts and the ease of insertion and chronic maintenance.

Fig. 2 shows the parts for chronic implantation of the new probe. Fig. 3 shows the surgical steps involved in human implantation. A small circular cutter (looking like a cork borer) is used to incise the scalp, removing a skin plug 4 mm. in diameter. A small 2 mm. linear extension is made on either end of this round hole. This produces an incision resembling the Greek letter Phi (Φ). A simple prick punch is then used to
Fig. 1. Diagram of probe. The hollow stainless steel tubing stock core can be seen. The tips of the wires, cut off at the end, are insulated as shown. By cutting through the enamel of the wire at a selected point (\(*\)), a contact is established. Contacts may be cut anywhere along each wire. Probe contact spacing used in our clinical cases is shown. Recently we have varied the spacing from that shown to afford more contacts within the superficial cortex.

Fig. 2. Diagram of parts used for chronic implantation probes. A threaded-end, stainless steel cranial pin (A) has been driven into a hole predrilled in the calvarium. The retaining cup (B) is then screwed onto the pin. The probe (C) is inserted into the cup and locked into position by the retaining ring (D).

dimple the surface of the skull. A \#54 metal drill (0.055 in. in diameter) is used to penetrate the calvarium. The angulation of the drill hole determines the direction that the probe will take when it is finally inserted; the hole must therefore be drilled with some degree of precision. Just as the drill enters the inner table, the chuck is opened and the drill left in place. The threaded steel pin is screwed onto the end of a special hammer having a 1 lb. captive, sliding weight. The captive hammer is held near and exactly parallel to the axis of the drill in the calvarium. An assistant removes the drill, the pin is then positioned exactly in the same axis at the entrance to the hole. By allowing the captive weight merely to fall, the pin is driven firm after about 6 blows. (The hammer's falling weight develops approximately 50 g's.) The captive hammer rod is unscrewed leaving the threaded pin in place. The threaded retainer cup is then screwed very tightly onto the pin. With the cup locked onto the pin, the dura is then penetrated using a \#20 hypodermic needle. The probe, previously sterilized by soaking for 30 minutes in 1:750 aqueous Zephiran, or by ethylene oxide gas, is rinsed, first in acetone, followed by saline and is then inserted and locked in place with the locking ring.
FIG. 3. The surgical steps for chronic implantation. The scalp is cut (A) using a circular scalp cutter resembling a cork borer. A regular machinist's prick punch is used to dimple the skull which is then drilled using a number 54 twist drill (B). It is important to hold the drill in the exact angulation required for the implantation. A captive hammer (C) with a one pound sliding weight, is used to drive the pin into the predrilled hole. The pin is screwed into the end of the hammer. The entire assembly is in place bilaterally at (D). An injection is being made through the hollow core of one probe while making recordings.

The technique of removing the apparatus at the conclusion of the study is the reverse of the above. It should be stressed however, that the locking ring must be unscrewed from the cup first, without the cup coming unscrewed from the pin. The cup may therefore have to be held with a hemostat as the ring is removed. Following the removal of the probe, a small amount of bone wax is pressed into the hole of the pin. This temporarily seals the entrance into the skull. The cup is then unscrewed from the pin. Whatever debridement or freshening of the wound surface may be necessary can be carried out without the possibility of contaminants entering the cranial vault through the hole in the pin. Following adequate cleansing of the area, the captive hammer is then screwed onto the threaded segment of the pin and with one simple sliding jolt of the weight the pin is extracted. (We use a free finger-and-thumb movement similar to that involved in shooting a billiard cue.) As a general rule the static pull necessary to remove the pin from the skull varies from 40 to 50 lbs. Without the use of the captive hammer it is rather difficult to pull the pin out of the skull.

Fig. 4 is a composite drawing showing approaches that we have used for study of patients having temporal lobe seizures. The shorter, more anterior, frontal probes are inserted with the tips lying near the orbital plates. The temporal probes, placed from above, pass through the temporal tip to enter the amygdala. The occipital approach gives one the opportunity of penetrating through
temporo-parietal fibers and much of the lateral hippocampus on the way to the amygdala. When the patient is being considered as a surgical candidate for removal of an irritating temporal lobe focus, two probes may be placed, one in each amygdala. At the same time, frontal probes may be placed. Depending upon the results of recordings and other studies made within the days subsequent to implantation, one may find the need for additional probe insertions. When the patient shows multifocal firing or when the anterior-posterior extent of the focus is to be studied, entry from the occipital area, passing through the temporal lobe and the hippocampus, may be desirable.

Fig. 5 shows a patient with a right temporal lobe focus studied using 4 depth probes. Unfortunately the 3 cm. intracranial length of the frontal probes proved a bit short for complete study. These photographs, however, serve to illustrate the simplicity of multiple implantation by this technique. The patient may "wear" these probes with comfort over a long period of time as recordings, stimulations and other studies are being conducted. Consequent to a series of studies, the tip of the right temporal lobe was removed in this particular patient. The pathology specimen showed a scar lying deep in the temporal cortical substance. The patient now remains free of seizures. Since the scalp surface area is unencumbered by bandages (the patient may wear a simple cap to hide the probe sockets) it is free for the placement of surface electrodes. This facilitates comparison of deep recordings with surface recordings.

In the case shown in Fig. 6, a 12-year-old boy had 4 implantations. The 2 more posterior ones were made of twisted bundles of stainless steel wires having 6 wires per probe. The 2 anterior ones are of the new design. This gave us the opportunity to compare the electrical activity of stainless steel contacts with the platinized platinum ones. The stainless steel electrode wires were placed by Dr. A. Earl Walker.

Fig. 7 is a comparison tracing made on the patient shown in Fig. 6. The recordings were made on a 16 channel Grass Model 6 EEG machine with all channels operating at the same gain. The bipolar recordings were made using similar location and spacing of electrode contacts of stainless (A, B) and platinized platinum (C, D) electrodes. Lead solder scalp surface electrodes (E) were used. The re-
corded frequencies and amplitudes differed among the 3 types of contacts; the difference in the low frequency components of the wave forms was most striking. In the area of very low frequency delta rhythms (the right subfrontal area) polarographic studies of oxygen, carbon dioxide, and hydrogen indicated significant differences as compared to the rest of the brain. Here, at the time of surgery, a low grade cystic astrocytoma was found.
Stainless steel cannot suitably detect these very low frequencies. Stainless steel is stainless due to its natural coating of chrome oxide, a thin but good insulator. The difference is therefore easily explained by the much lower impedance of the new probe contacts as compared to those made of stainless steel.15

In the case shown in Fig. 8, a posterior approach was utilized in a 19-year-old boy whose problem was temporal lobe seizures. The probes found many bilateral foci. Note that since the scalp is not covered with bandages, surface electrodes are easy to apply; the patient is also more comfortable. These probes are protected by simple doughnut-
Comparison tracing made on the patient shown in Fig. 6. The recordings are bipolar using closely comparable levels of contacts for the two electrode types. All gains are set the same using a standard EEG machine. Signals recorded from the stainless steel depth electrodes (A, B), the platinized platinum depth electrodes (C, D), and the scalp surface using tin/lead solder electrodes (E) are shown. Platinized platinum is about two orders of magnitude (×100) more sensitive at EEG frequencies than stainless steel; even more as one approaches DC.

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type bandages worn only at night.

The case shown in Fig. 9 is that of an 18-year-old mentally retarded boy who was having almost continuous seizures of a mixed type. Both stainless steel and platinum probes were placed. The multiplicity of the foci was more apparent in the recordings made from the platinum probes than from the stainless type. The arteriogram is shown for anatomical localization of the intracranial circulation relative to the probes.

Fig. 10 shows a depth polarographic recording made using hydrogen. The gas was inhaled by the patient as a single breath for the determination of circulation timing. In normal gray matter and in highly vascularized structures in the head, the lung-to-brain circulation timing is approximately 3.5 sec. There are normal variations seen between gray, white and other structures. Contact No. 4, which was electrically silent in the spontaneous record, shows the rapid diffusion of hydrogen from the choroid plexus of the temporal horn. This location was confirmed by pneumoencephalography.

Fig. 11 shows an oxygen study made by
polarizing the contacts so that they became standard oxygen cathodes; $-0.65$ volts were applied. The same contacts were recorded as those shown in Fig. 10. The patient was given a mixture of 10 per cent carbon dioxide in oxygen to breathe. It can be noted that where the tissue has an abundant arteriolar supply, there is an undulating cycling of the

**Fig. 8.** A posterior implantation into the hippocampus and amygdala. The open scalp, without bandaging, facilitates surface recordings. (Case of Dr. R. G. Bickford)

**Fig. 9.** Bilateral implantations using new probes and twisted wire stainless steel types. The arteriogram, performed while tracings were being made, demonstrates the location of major intracranial vessels relative to the probes. (Platinum absorbs x-ray energy more effectively than stainless steel; the twisted wire types are therefore not visible in these films.)
Depth polarographic recording using hydrogen gas inhalation for circulation timing. Each electrode contact was referenced to a non-polarizable skin surface electrode placed on the right forearm. DC measurements between the reference and each platinum brain depth electrodes show changes in potential as the diffusing hydrogen gas reaches the depth contact. The numbers given indicate the location of electrode contacts along the length of an eighteen contact probe. (Point number 1 is at the tip.) Variation in circulation timing is seen in different intracranial structures.

oxygen tension for several seconds until arteriolar relaxation occurs. This is produced by the high concentration of carbon dioxide. Consequently, this relaxation, the oxygen tension rises. Again, certain characteristics can be seen in different structures of the brain.

Fig. 12 shows a rhesus monkey with a probe in place. The same equipment is used for placing a probe in the animal. Three satellite screws are placed in the skull approximately 5 to 7 mm. away from the pin. The pin and the 3 screws are locked together by working a small amount of fast-setting dental cement over them. This gives a firm base anchoring the pin to the animal's thin calvarium. Chronic implantations of several months' survival have been obtained easily using this technique.

Discussion
We have so far placed brain probes in 8 patients with a total of 16 implantations. All but 2 of these were done on a chronic basis with probes staying in from 2 weeks to 1 month. One of the 2 done acutely was for localization of rhythms during a thalamotomy. The other was an acute placement for the study of depth electrography in a patient who was being artificially maintained on a respirator, and who was thought to be clinically dead but still maintained a pulse and

Fig. 11. An oxygen polarographic recording of the contacts used in Fig. 10 above. Certain characteristics occur in different structures of the brain.
Fig. 12. A chronic implantation in a rhesus monkey. The probe is inserted in the same manner as for clinical implantation. Three satellite screws must be placed nearby in the cranium and firmly combined with the cranial pin, by the use of acrylic cement.

had bilaterally downgoing toes on plantar stimulation. A single right frontal probe was placed in about 5 minutes. Recordings demonstrated neuronal death, an absence of all cortical function.

Patinized platinum contacts are superior to those of stainless steel for the measurement of spontaneous potentials. Approximately the same parameters are required for stimulation using either type. Polarographic and DC studies are only possible using the precious metals; platinum is the best of these. By patinizing the platinum we have obtained a surface which apparently is preferable to all others previously used. By expanding the armamentarium of techniques, using polarography and altering current impedance measurements in conjunction with the standard studies obtained through ordinary recording methods and then subjected to computer analysis, we expect to improve on the validity of depth probing by establishing diagnoses as well as structural localizations.

Summary

We have described a new brain depth probe for use in man. Its advantages include the following: 1. It is small (.75 mm. in diameter). 2. It can be made with multiple contacts at variable spacing. 3. It exhibits more sensitivity than that of stainless steel electrodes. 4. In addition to standard studies, it can be used for DC and polarographic studies (oxygen cathode, etc.). 5. No shielding from electrical interference is required and it is extremely stable. 6. No bandaging of the scalp is needed. 7. With careful handling it can be reused many times. 8. It is easily inserted and removed; it is comfortable. 9. The anatomical locations are easier to calculate; increased absorption of x-ray by platinum makes it more visible than stainless; the exact location of each contact along the probe length is known. 10. Other electrodes or chemicals may be passed down through the hollow core. 11. Mechanical and electrical fittings are more reliable and safer than those used with stainless steel probes. 12. Tissue cannot entwine itself in the probe surfaces. 13. The cranium remains effectively closed throughout the entire clinical study.

There are some disadvantages: 1. The probe is relatively stiff. 2. It is more expensive than simple twisted wire types. 3. The overall length can be selected in advance but not adjusted while being implanted. 4. The scalp opening often becomes more indurated than with the more flexible twisted wire type. 5. Direct lateral temporal implantations are not recommended.

We believe that the proven and projected uses of this depth probe far outweigh its limitations.

References

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Addendum

As of March 17, 1966, 15 patients had been implanted with a total of 28 probes. Four cases were acute. Probes have been reused 4 to 6 times. Chronic implants have been maintained from 1 to 6 weeks. Recordings were often begun on the day of implantation. In a recent case, essentially continuous spike firing was found in an area of cortical scarring extending only 13 mm below the pial surface. Local bipolar electrical stimulation and I.V. Metrazol provoked seizure propagation. Only at the onset of clinical seizure did the scalp surface electrodes show abnormality; resting and sleep E.E.G. scalp records were consistently free of spike discharges. Probe contacts placed in the contralateral hemisphere and those placed deep to the focus recorded normal activity except during seizure propagation or post-ictally. This case emphasized the value of multiple contacts with cortical representation.