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INTRACEREBRAL RADIO STIMULATION AND RECORDING IN COMPLETELY FREE PATIENTS

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Diagnosis and treatment of focal brain dysfunction associated with behavioral abnormalities are complex tasks which require more effective exploratory techniques. Intracerebral electrodes, electrocorticographical studies, and subsequent discrete neurosurgery have given the epileptologist and stereotaxic surgeon new possibilities for clinical investigation which as yet have been applied to only a small percentage of the patients suffering from neurological disorders including temporal lobe epilepsy and related episodic behavior problems. In these therapeutic studies, recordings and stimulations of any chosen cerebral structure can be performed over a period of days or weeks, and neuronal sites identified as triggers for abnormal electrical patterns associated with behavioral disturbances can be destroyed by electrolysis or resection. Unfortunately, in some patients episodic behavior disorders may be more disabling than their epileptic seizures, and focal lesions may improve one syndrome without modifying the other. Furthermore, recording and stimulation are usually performed under conditions which qualify their usefulness, because the patients' mobility is limited by connecting leads, and their behavior is likewise altered by the stressful and artificial environment of the recording room.

During the last few years, methodology has been developed to stimulate and record the electrical activity of the brain in completely unrestrained monkeys and chimpanzees (10, 13). This procedure should be of considerable clinical interest because it permits exploration of the brain for unlimited periods in patients without disturbing their rest or normal spontaneous activities. This paper reports instrumentation used and clinical application in four patients with psychomotor epilepsy in whom electrodes had been implanted in the temporal lobes. To our knowledge, this is the first clinical use of intracerebral radio stimulation and recording in man.

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The circuit for EEG recording is a modified version of the unit described by Meehan (21), and his help in providing us with information and with one of his units is gratefully acknowledged. The help of Mr. Per Hals in developing telestimulation instrumentation is also gratefully acknowledged.

METHODS

IMPLANTATION OF ELECTRODES

Electrodes were constructed and stereotaxically implanted according to methods previously described (20). The electrode assemblies, which were connected to a McPherson skull plug, consisted of a plastic stylet, 1.2 mm in diameter, with 15 stainless steel 3 mm wide contacts attached at 3-mm intervals, plus one thermistor and three other contacts at the tip. Using a McPherson type 2 stereotaxic machine (20), electrode assemblies were implanted bilaterally into the anterior medial amygdala of each patient.

RADIO STIMULATION

This system consists of two instruments: 1) the RF transmitter which measures 30 by 25 by 15 cm and includes the circuitry for controlling the repetition rate, duration and amplitude (intensity) of the stimulating pulse. The repetition rate may be varied in steps between 10 and 200 Hz and the duration between 0.1 and 1.5 msec. Single pulses may also be generated. Intensity control is accomplished by varying the frequency of the three subcarrier oscillators which operate in the 100 to 500 kHz frequency range. A 100 MHz oscillator is turned on and off by the pulse train from the subcarrier oscillators. The duration of this pulse train is determined by the pulse duration switch. These bursts of 100 MHz RF energy are received by 2) the receiver-stimulator which is carried by the subject, measures 3.7 by 3.0 by 1.4 cm, and weighs 20 g. The solid state circuitry is encapsulated in epoxy resin which provides it with very good mechanical strength and makes it waterproof. Space for the 7-volt Mercury battery is included in the size mentioned above. After RF detection, the resulting subcarrier frequency is demodulated into an amplitude. This amplitude controls the current intensity of the stimulation pulse by means of a constant current transistor in the output circuit of the receiver. This method makes the pulse intensity independent of biological impedance changes over a wide range. Under average stimulation conditions, the battery life is approximately 1 week. Operating range is up to 100 ft. Three channels of stimulation are available. The pulse intensity of each channel can be controlled individually from the transmitter. The pulse duration and repetition rate are the same for all three channels.

ELECTROENCEPHALOGRAPHIC (EEG) TELEMETRY

A miniature FM-FM amplifier-transmitter combination and a telemetry receiver are used for this purpose. 1) The transmitting circuitry, carried by the subject, consists of an EEG amplifier with a gain of 100, input impedance of 2 MegaOhms, frequency response from 2 to 200 Hz, and a voltage-controlled oscillator (VCO) for each channel. The VCO operates in one of the frequency bands assigned for subcarrier oscillators by the IRIG standards. In these studies, a three-channel system was used which operated on IRIG channels 11, 13 and 14. The outputs of all three subcarrier oscillators were summed and connected to the single RF transmitter module. The miniaturized RF transmitter operates at 216 MHz and its range is 50 to 200 ft, depending on the environment. The size of the three-channel unit, including the battery, is 4.5 by 4.5 by 1.5 cm, and it weighs 50 g. The signals from the depth electrodes are received by the amplifier. The output signal of the amplifier controls the frequency of the subcarrier oscillator, and the oscillator output in turn controls the frequency of the transmitter. 2) After amplification of the received signal from the transmitter has been demodulated, the composite subcarrier signals are connected to the inputs of the three discriminators which then separate and demodulate their respective subcarriers to obtain the telemetered analogue information. In the instrumentation used in this instance, a 100-μv signal at the input of the EEG amplifier resulted in a 1-volt output from the corresponding discriminator in the receiver.

The analogue output signals from the receiver were connected to the inputs of an EEG recorder and a magnetic tape recorder. A microphone was also mounted in the room with the subjects and conversation was recorded along with the EEG on magnetic tape.

STIMOCEIVER

The integration of the three-channel units for radio stimulation and EEG telemetry constitutes the stimoceiver (*stimu*lator and EEG re*ceiver*). Several tests were conducted to ensure proper electronic and biological operation, as explained later. The complete instrument, which weighs only 70 g, can easily be taped onto the patient's head bandage (Figure 1). During part of her treatment, one patient wore a wig which covered her stimoceiver and all evidence of instrumentation.

ADDITIONAL EQUIPMENT

Conversations with the patients were tape-recorded and synchronized with the EEG recordings and moments of stimulation. During interviews with the first two patients, time lapse photography was used to record possible changes in facial expression or behavior, according to a method employed for studies in monkey colonies (9).

PHYSICAL LOCATION OF THE STUDIES

The first two patients were under treatment at the Boston General Hospital, and radio stimulations and recordings were performed in a curtained, shielded 12 by 12 ft room in which the patients could walk

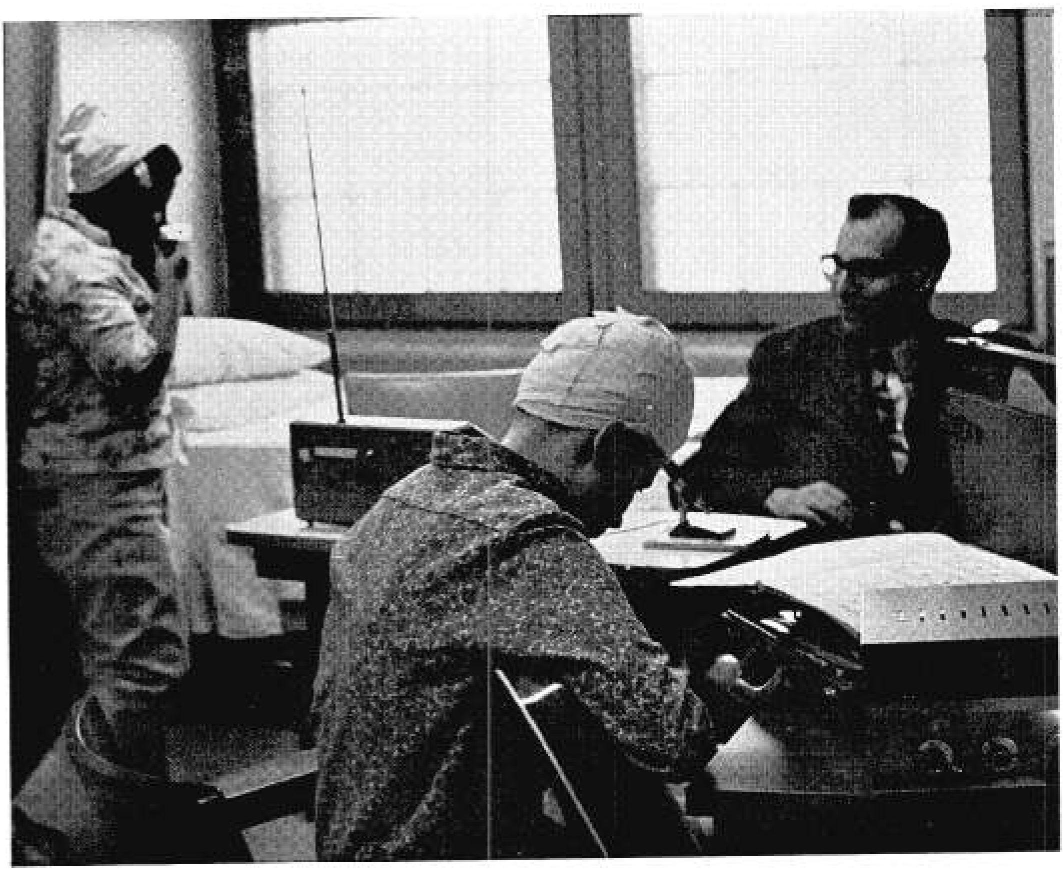

Fig. 1. Two patients instrumented for intracerebral radio stimulation and recording engage in spontaneous activities (one is playing the guitar) in the psychiatric ward in the presence of the doctor (VM). Explorations of the brain can be performed for as long as necessary without disturbing the patients.

around or remain seated. The other two cases were studied in their customary quarters within a closed psychiatric ward at Massachusetts General Hospital, and they could move freely around their bedrooms, bathroom, sitting room or dining room. Nurses and other patients were present during some of the recording and stimulation sessions, as seen in Figure 1.

EXPERIMENTAL DESIGN

The purpose of this study was to identify sites of abnormal intracerebral electrical activity and to test brain excitability in order to guide contemplated therapeutic surgery. Patterns of electrical activity were correlated with behavioral performance, and alterations of conduct evoked by brain stimulation were evaluated. Many hours of EEG recordings were taped and analyzed to determine the frequency, severity and propagation of spontaneous electrical discharges which could have pathological significance. Interviews were structured in order to elicit the patient's verbal expression without unduly influencing the ideological content. During these sessions, two intracerebral points were selected for more extensive study, and they were randomly stimulated at 3- to 5-min intervals according to a predetermined schedule. Neither the patient nor the therapist was informed of the exact moments of stimulation, and each point was stimulated seven times during three 60- to 90-min sessions. Tape-recorded conversations were transcribed, analyzed for number of words per minute and for ideological and emotional content, and correlated with the EEG activity recorded continuously during control periods and stimulations (17, 19).

Instrumenting the patient for telestimulation and recording is a simple and rapid procedure requiring only connection of the stimoceiver to the electrode assembly plug. The stimoceiver is so small and light that it can be concealed within the head bandage, as shown in Figure 1. The patient is thus continuously available, day and night, for brain exploration, and there is no interference with spontaneous behavior.

The entire instrumentation for these studies consisted of the stimoceiver, radio transmitter, FM receiver, electroencephalograph, tape recorder and oscilloscope. This equipment could be rapidly assembled in a small space and operates without any special physical or electrical requirements. These aspects are emphasized to indicate the feasibility of this type of research within minimum facilities of a hospital ward.

CONTROLS AND FUNCTIONAL CHARACTERISTICS OF THE STIMOCEIVER

Fidelity of recording: As demonstrated in previous animal experimentation (13), the traces obtained by means of direct wire connection with the brain were identical with tracings obtained from the same points by telemetry. In the present study this fact was also confirmed.

Noise of open input: Tests were made by disconnecting the instrumentation from the terminals of the implanted electrodes on the patient's head without removing the instrumentation. In this electrically adverse situation of open input, the noise level was below 15 μv. When the input of the EEG transmitter was connected with the calibrator, the noise level was below 5 μv, as shown in Figure 2*I*.

Movement artifacts: The leads connecting the terminal plug of the intracerebral electrodes with the telemetric unit were multistrand, Teflon-covered, unshielded copper wires about 80 mm long, attached to the patient's bandage. Normal activities including walking around did not produce observable artifacts.

Interference by extraneous noise: Most of the recordings, as in Figures 2, 3, and 4, were reasonably free of electrical interference in spite of the fact that no special precautions had been taken in the ward, and the rooms were unshielded. From time to time, however, brief periods of electrical noise appeared in the telemetric recordings, probably related to motors or other instrumentation in use at the hospital. These disturbances sometimes lasted for 10 to 15 sec.

Walls and obstacles: Suitable tests demonstrated that radio stimulation and telemetry could be performed through walls and closed doors which did not obstruct the transmission of RF energy. As an added precaution, receiving and emitting antennae were attached to the ceiling of the ward.

Cross-talk: Tests were performed to ensure the lack of cross-talk between the telemetric recording channels, and also between the channels of radio stimulation. During application of radio stimulations, however, artifacts appeared in the recordings, as seen in Figure 2*B*.

Blocking time after stimulation: The amplifiers of the telemetric units recovered from the over-voltage block immediately after stimulation, and the delay in onset of EEG recording was very brief, as shown in Figure 2*B*. In general, recordings were obtained from points adjacent to the stimulated leads

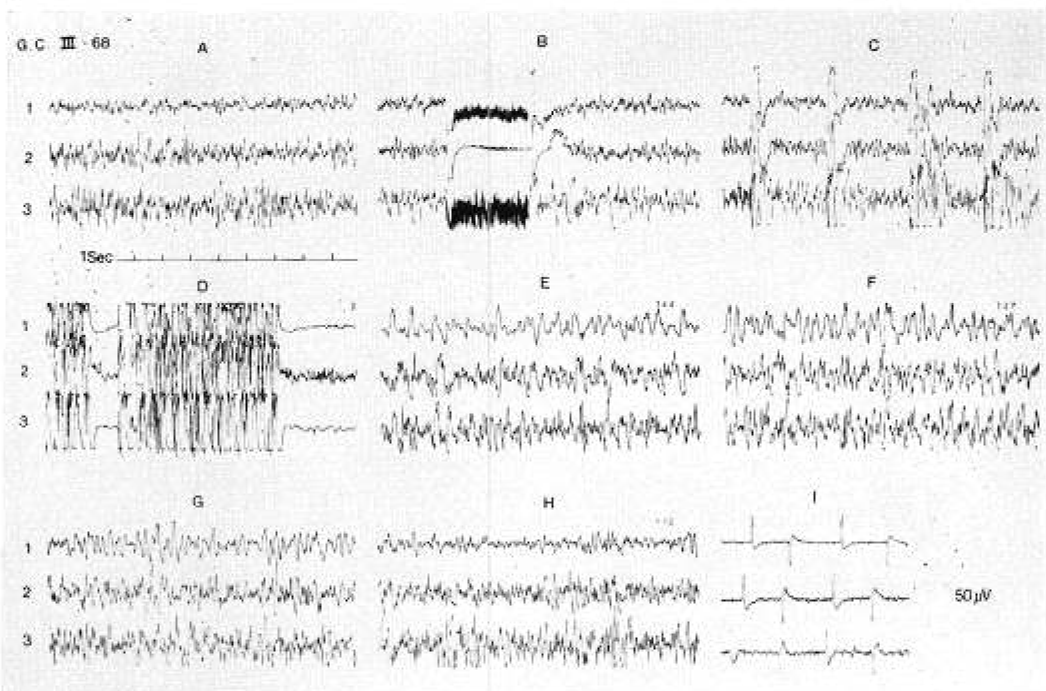

FIG. 2. *A*, Control. Recordings from the left temporal lobe in patient G. C. Linkages are: channel 1: 3–4 (amygdala); channel 2: 8–10; (hippocampus); and channel 3: 15–16 (optic radiation). Observe the lack of poststimulation disturbance. *B*, Artifact of stimulation through contact 9 with 0.8 mA, which was below the AD threshold, demonstrating the brief duration of blocking time for telemetric transmission. *C*, Single pulses of 1 ma applied through contact 9 (hippocampus) induced high voltage activity in links 16–17 and the perception of funny feelings. *D*, Electrical seizure evoked by radio stimulation of contact 9 with 1 ma caused a complete behavioral inhibition without observable motor manifestations. *E*, Sixty seconds after stimulation, slow activity is prominent, especially in channel 1, while the patient thinks that she is going to faint (she did not). *F*, One hundred seconds after stimulation, high voltage sharp waves dominate the three channels and the patient feels frightened. *G*, One hundred forty seconds after stimulation, abnormal high voltage is still present in channel 1, and the patient reports a sensation of "floating around." *H*, Five minutes after stimulation, spontaneous activity is similar to controls, and the patient behaves and speaks normally. *I*, Telemetric calibration with 50 μv was applied to each channel independently.

to avoid direct interference between inputs and outputs in the instrumentation. One cerebral contact could be shared by recording and stimulating units.

Monitoring of stimulation: In animal experimentation, prior to releasing the subject for telestimulation, we always monitor on the oscilloscope the voltage and milliamperage of cerebral radio stimulations. In two patients we performed similar oscillographic monitoring. It should be clarified that in the completely free situation there is no direct monitoring of the actual intensity used, but as the output is constant current, reliability of electrical parameters is ensured.

Safety in stimulations: In patients walking around while instrumented with stimoceivers, there is a theoretical risk that they might receive extraneous electrical signals. In our stimulators this risk is avoided because of the specificity of the frequency-modulated coding needing to activate them. In addition, by construction the maximum amount of current that the stimoceiver can deliver is 2 ma.

CLINICAL APPLICATIONS OF THE STIMOCEIVER

1) L.K. This 35-year-old white male design engineer had experienced attacks of staring and automatisms for 10 to 12 years. He also had frequent episodes of rage during which he assaulted and injured his wife and children. His driving was precarious because he became enraged if other cars cut in front

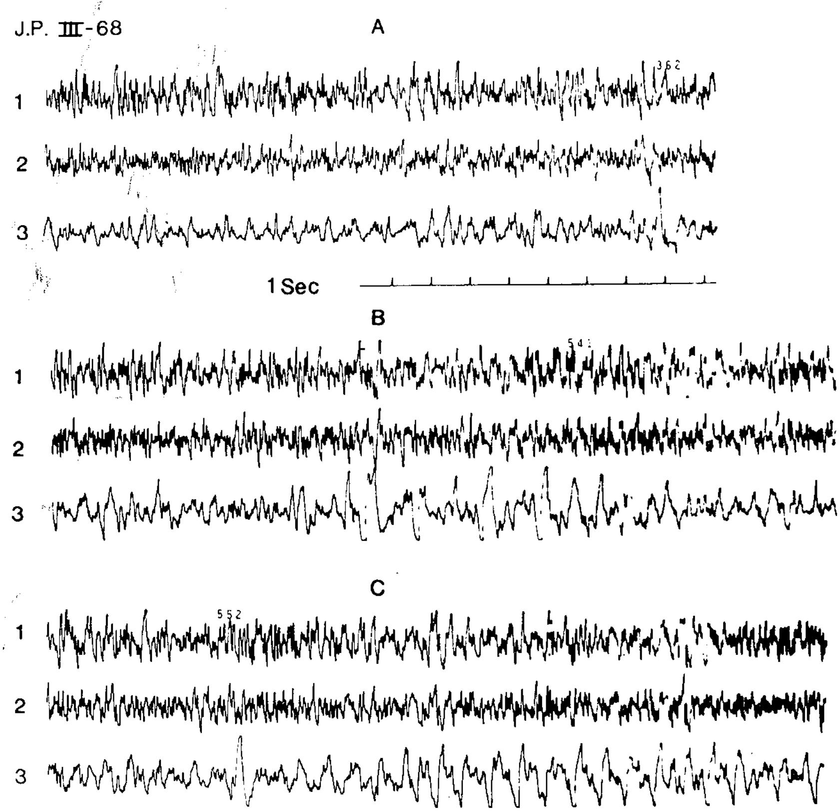

Fig. 3. Recording from the right side in patient J. P. Linkages are: channel 1: 2–5 (amygdala); channel 2: 6–9 (anterior part optic radiation); channel 3: 15–17 (posterior part optic radiation). *A*, Control; *B*, spontaneous aimless walking around the room for several minutes coincided with high voltage sharp waves in channel 3; *C*, similar high voltage activity appeared in channel 3 when a flashlight was waved in front of the patient's eyes. Calibration as in Figure 2.

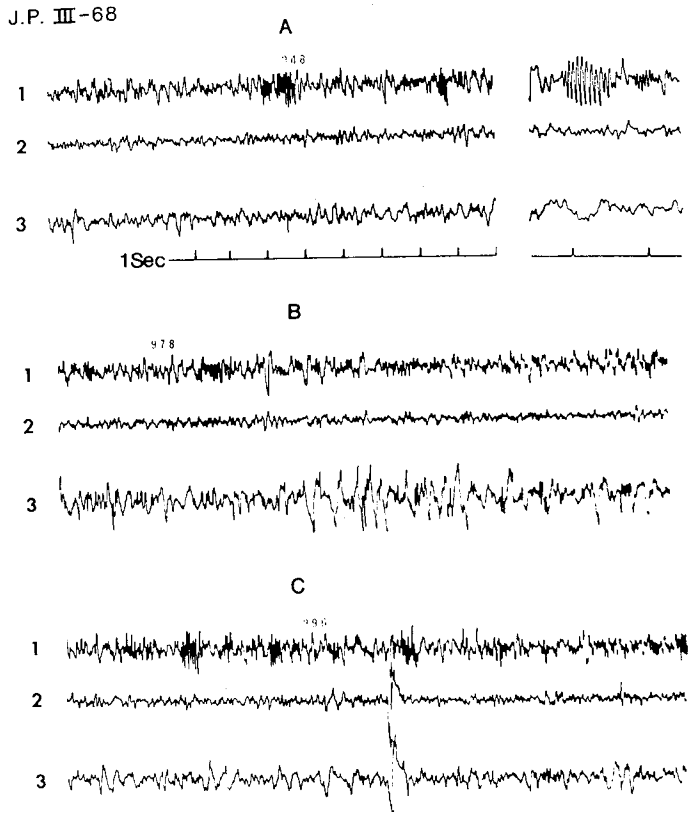

FIG. 4. Recording from the right side in patient J. P. Linkages are: channel 1: 3–4 (amygdala); channel 2: 6–7 (anterior part optic radiation); channel 3: 15–16 (posterior part optic radiation). *A*, Spontaneous bursts of about 16 cps appeared in channel 1 and were more prominent when the patient was psychologically excited. The *upper right insert* shows similar bursts recorded at greater speed. *B*, Sudden spontaneous arrest of speech coincided with bursts of spike activity in channel 3. *C*, Spontaneous over-friendliness of the patient culminated in an attempt to kiss the therapist. No correlation with electrical changes in the brain was detected. In spite of the considerable motor activity of the patient, the recording is almost free of artifacts. Observe also the increase in bursts of rapid activity in channel 1. Calibration as in Figure 2.

of him and he would go miles out of his way to force them off the road.

The EEG revealed temporal lobe spiking more prominent on the right side. Pneumoencephalogram disclosed dilatation of the right lateral ventricle, and recording from inlying temporal lobe electrodes showed marked EEG abnormalities. Telemetered recordings were done to correlate the results of amygdala stimulation, EEG recording, and behavior without risking the danger of displacing the intracerebral electrodes by sudden, untoward movements of the patient which could not be compensated for with the usual method of EEG recording by means of direct leads.

2) *M.R.* This 25-year-old white male suffered from encephalitis as an infant and a severe head injury in the Navy. Following this he had 4 years of staring spells and automatisms. He was the driver of a car involved in a serious accident and had a police record for vagrancy and violence. He began assaulting his medical attendants on the neurology service of a local veterans' hospital and had to be confined in a mental institution while awaiting surgical evaluation.

The EEG showed bilateral temporal lobe abnormalities. Electrodes were implanted in both amygdalas and depth recordings revealed abnormalities particularly prominent on the right side. The clinical problem here was to decide if and where in the amygdala a focal destructive lesion should be made. The telemetered recording and stimulation allowed us to correlate the patient's behavior and electrical abnormalities without the structured rigidity of the EEG recording room.

3) *J.P.* This 20-year-old white female had a history of encephalitis at the age of 18 months. In addition, she had experienced temporal lobe seizures and occasional grand mal seizures for 10 years. She also had frequent rage attacks which on more than a dozen occasions resulted in an assault on another person. On one occasion she inserted a knife into a stranger's myocardium, and another time she inserted scissors into the pleural cavity of a nurse.

The EEG showed occasional temporal lobe spikes and depth recordings revealed dramatic electrical abnormalities in both amygdala and hippocampus. The use of stimoceivers proved to be of crucial importance in selection of the temporal lobe site for a destructive lesion because it was difficult to confine the patient in the EEG recording room during a rage attack while recordings were easily made by telemetry.

4) *G.C.* This 14-year-old Negro girl was brought up in a foster home and was of borderline intelligence. On two separate occasions her violent behavior resulted in the death of a young foster sibling, and she subsequently assaulted a 7-year-old child at the state hospital where she was confined.

The EEGs, ventriculograms and arteriograms appeared normal, and extradural plates beneath the temporal lobes recorded normal brain waves. Depth electrodes were placed in each amygdala through the posterior approach. Recordings from the hippocampus showed marked focal electrical abnormalities. Telerecordings and telestimulations were used because of this patient's unpredictable behavior. She could not be relied on to sit quietly with the conventional EEG recording system. Stimulation in her right hippocampus produced a clinical and electrical temporal lobe seizure. In retrospect, the patient claimed to have had a number of these before electrode implantation but she had not communicated this information to her physicians.

RECORDING AND STIMULATION

In the four patients, recording of spontaneous electrical activity showed typical patterns which in general permitted the identification of each linkage in different recordings, indicating the reliability of the information. The activity of each linkage indicated the existence of autochthonous electrical generators rather than the predominance of widespread pacemakers. This fact is demonstrated in Figures 2, 3 and 4, which show the lack of synchrony among the waves in the three channels, contrasting with the simultaneous detection of single shock stimulus artifact which appeared in Figure 2*C* and also contrasting with the correlation of patterns during the evoked after-discharges which spread to the three channels (Figure 2*D*). We do not know the extension of the electrical fields generated within each cerebral structure but recordings indicate that the localization is rather precise because a clear pattern, such as the 12-cps bursts in Figure 4*A*, was detected exclusively in channel 1.

One of the main objectives in telemetric recording of intracerebral activity is the search for correlations between electrical patterns and behavioral manifestations. Computer analysis of the tape-recorded information is the best method for this purpose, and its results will be reported in the future. Visual inspection of ink writing recording may also give valuable data, as indicated in the following examples.

In patient J.P., spontaneous, brief periods of aimless walking around the room coincided with an increase in high voltage sharp waves, as shown in Figure 3*B*. At other times, spontaneous inhibition of speech lasting for several minutes was accompanied by a burst of spike activity localized to contacts 15–16, as seen in Figure 4*B*. Psychological excitement of the same patient was related with an increase in the number and duration of 16-cps bursts (see Figure 4). Emotionally charged conversation often modified the recordings from the amygdala, but this result was not as evident as the above mentioned changes. The possible significance of these correlations was increased by the fact that other behavioral manifestations did not produce detectable electrical changes. The patient walked around the room, used the toilet, read papers, and conversed without visible alterations in the telemetered depth recordings.

Radio stimulation of different points in the amygdala and hippocampus in the four patients produced a variety of effects including pleasant sensations, elation, deep thoughtful concentration, odd feelings, super relaxation, colored visions and other responses. In this article we will discuss only the following selected results:

During a recorded interview in patient G.C., point 9, located in the left hippocampus, was radio-stimulated for 5 sec with 100 cps, 0.5 msec, and 1 ma, resulting in an electrical after-discharge (Figure 2*D*) involving the amygdala, hippocampus and optic radiation, which lasted for 25 sec. During this time the patient's conversation stopped completely and she was unresponsive, without exhibiting motor convulsions, automatisms or other visible disturbances. When the after-discharge was over, the patient resumed conversation, remembered her speech arrest, but was not able to explain it. Spontaneous electrical activity of the brain was considerably modified for more than 2 min after stimulation, as shown in Figure 2 (*E*, *F*, *G*). During this period, the patient expressed the successive sensations of fainting, fright and floating around. These "floating" feelings were repeatedly evoked on different days by stimulation of the same point even in the absence of after-discharges. Single shocks applied to the hippocampus induced bursts of high voltage activity in the optic radiation and were accompanied by the perception of "funny feelings."

In patient J.P., crises of assaultive behavior reminiscent of her spontaneous bursts of anger could be elicited by radio stimulation of contact 3 in the right amygdala. Seven seconds after the onset of radio stimulation with 50 cps, 1.0 msec, and 1.2 ma, the patient interrupted spontaneous activities such as guitar playing, and in a fit of rage threw herself against the wall (never attacking the interviewer), paced around the room for several minutes, and then gradually reassumed her normal behavior. This effect was repeated on 2 days with similar results. During this elicited rage, no seizure activity was evident in the depth recording. The fact that only one contact gave this type of response suggested that the surrounding neuronal field was involved in the behavioral problems of the patient.

DISCUSSION

Important limitations of standard electroencephalographic recordings are as follows: 1) psychological stress of the recording room; 2) time required to attach leads to the patients; 3) restrictions imposed on individual mobility by the connecting leads; 4) limited period for the acquisition of data; and 5) the slim likelihood of taking recordings during spontaneous electrical or behavioral crises, which could provide the most important information for the patient's diagnosis and treatment.

These handicaps are eliminated by using telemetry. Extensive information has been published about different systems for radio telemetry in biological studies (4, 7, 15, 24). The disparity between the large number of technical papers and the few reports of results indicates the existence of methodological problems. There is some data on telemetered EEG obtained during space flights (1, 23); preliminary descriptions of scalp EEG studies in humans have been reported (6, 18); and there is also a technical paper on telemetered scalp EEG in disturbed children (25). Data is presented here to demonstrate that telemetry of EEG has already attained a degree of sophistication, miniaturization and reliability that render it suitable for widespread clinical application in both standard scalp and intracerebral electrical studies.

In the last decade, depth recording in man has become a major therapeutic tool in various medical centers (2, 3, 5, 16, 22, 26–28). The usefulness of intracerebral electrodes would be significantly increased if stimulations and recordings were performed by remote control. This technique, in addition to being more comfortable for the patients, would permit more detailed exploration and prolonged studies including periods of normal sleep.

Electrical stimulation of the brain, which is a standard procedure in neurosurgery, has been proposed by some authors as a therapeutic technique (16, 22, 27). For this purpose, programmed radio stimulation of ambulatory patients would be obviously advantageous.

The combination of both stimulation and EEG recording by radio telemetry offers a new tool for two-way clinical exploration of the brain, and it may be predicted that in the near future microminiaturization and more refined methodology will permit the construction of instruments without batteries and small enough to be permanently implanted underneath the patient's skin, for transdermal reception and transmission of signals through several channels. Part of the basic circuitry for this purpose has already passed satisfactory testing in our laboratory. While the use of cardiac pacemakers is well established in clinical medicine, methodological problems in the development of a similar instrument for cerebral pacemaking are far more difficult because of the requirements of multichanneling, external control of several parameters of stimulation, and the far greater functional complexity of the brain in comparison with the heart. These technical problems, however, are soluble, and the possibility of clinical application should attract the interest of more electronic and medical investigators.

Experimentation in animals has demonstrated the practicality of long term, programmed stimulation of the brain to inhibit episodes of assaultive behavior (8), to increase or decrease appetite (14), to modify drives (10) and to modulate intracerebral reactivity (9). Some of these findings may be applicable to the treatment of cerebral disturbances in man.

With respect to the electrical information obtained in our four patients, analysis of their telemetered EEG supports the assumption that depth recordings reveal local activity rather than diffuse volume conductor fields in the brain, in agreement with previous work obtained by direct leads (12). The considerable independence of the electrical activity of different intracerebral points indicates that this electrographic information has anatomical significance. Caution is necessary, however, in a calculation of the origin of apparently abnormal waves, such as the burst recorded from channel 1 in Figure 2*A*, which could originate in the neuronal field around the contacts or could reflect merely the activity transmitted from a distant cerebral area, as demonstrated in animal experiments (11). The distinction between reactive and propagated activity which can be made by studying recorded electrical patterns may help to evaluate the origin of abnormal intracerebral activity.

SUMMARY

A new instrument called "stimoceiver" has been developed for the simultaneous multichannel recording and stimulation of the brain by FM radio waves in completely unrestrained subjects. This instrument is

small enough to be worn comfortably and permanently by the patient.

Clinical application of the stimoceiver is reported in four patients with psychomotor epilepsy who had electrodes implanted in the amygdala and hippocampus for therapeutical reasons. The advantages of this methodology are: 1) the patient is instrumented for telestimulation and recording simply by plugging the stimoceiver into the electrode socket on the head; 2) the instrumentation does not limit or modify spontaneous behavior; 3) the patient is continuously available, day and night, for intracerebral recording or treatment; 4) studies are performed, without introducing factors of anxiety or stress, in the relatively normal environment of the hospital ward and during spontaneous social interactions; 5) cerebral explorations may be conducted in severely disturbed patients who would not tolerate the confinement of the recording room; 6) the lack of connecting wires eliminates the risk that during unpredictable behavior or convulsive episodes the patient may dislodge or even pull out the implanted electrodes; 7) programmed stimulation of the brain for therapeutic reasons may be continued for as long as necessary.

In four patients telemetric information obtained supports the following conclusions: 1) depth recordings reveal local activity rather than diffuse volume conductor fields, giving anatomical significance to the data; 2) abnormality in spontaneous behavior, including aimless walking, speech inhibition, and psychological excitement, coincided with abnormal EEG patterns: 3) arrest reaction accompanied by an after-discharge was evoked in one patient by radio stimulation of the hippocampus, and during the subsequent 2 min, abnormalities in brain waves coincided with successive sensations of fainting, fright and floating around; 4) assaultive behavior, reminiscent of spontaneous crises, was elicited in another patient by radio stimulation of the amygdala, and this fact was important in orienting therapeutic surgery.

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