

A STEREOTAXIC APPARATUS FOR BRAIN SURGERY AND HIGH FREQUENCY COAGULATOR WITH AUTOMATIC THERMOCONTROL

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Many kinds of operation methods and apparatuses have been reported for the stereoecephalotomy. These apparatuses are discussed regarding the stability and accuracy in inserting an electrode to the target and easiness to handle. Several methods for destroying target point are compared on preciseness in controlling size of lesion, complications and prognosis.

From this points of view a new stereotaxic apparatus and coagulator with thermo-controlling servomechanism were developed and the results of fifty operations performed with the apparatus presented here have been very satisfactory. In the paper, the details of this apparatus are described.

INTRODUCTION

It has recently been recognized that the stereotaxic method in brain surgery is an excellent approach for surgical treatment of Parkinsonism, involuntary movements, some types of epilepsy, pain and psychosis, because a very limited area of the brain tissue is effectively destroyed by a fine needle and the operative complication and mortality are kept to a minimum. A stereotaxic apparatus was first described by Horsley and Clark for animal experiments in 1908^{3) 15)} and was developed by Spiegel and Wycis for human surgical operation in 1947³²⁾. Since then, more than thirty different kinds of apparatuses have been designed for stereotaxic surgery^{6) 9) 14) 17) 19) 26) 28) 31) 35) 37)}.

The operative results reported by several authors are not always consistent. For example, the postoperative mortality varies from 0.2 to 10% from author to author. The prognosis after general neurosurgical operations depends mainly on the experience and skill of the operator as well as underlying pathological condition. Although experience and skill are necessary in the stereotaxic operation, success of the surgical procedure depends greatly on the determination of the target and its complete and accurate destruction with the

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aid of the stereotaxic apparatus. From such a point of view, the present apparatus is considered to be an excellent stereotaxic instrument.* Details of the apparatus and the results from fifty operations are presented in this paper.

OPERATIVE PROCEDURE

Stereotaxic insertion of the electrode

The technique for setting the electrode tip to the target point is essentially the same as that developed by Riechert *et al.*^{28) 29)}, *i. e.* the target is determined three-dimensionally in relation to the ventricle and is represented by an imaginary target in the phantom frame. The exact distances from certain points of the brain to the target are estimated by applying the values measured by Hassler^{12) 13)}.

The skull is fixed into a square frame with four pins as illustrated in Fig. 1. One of the x-ray tubes is adjusted so that the x-ray beam runs exactly

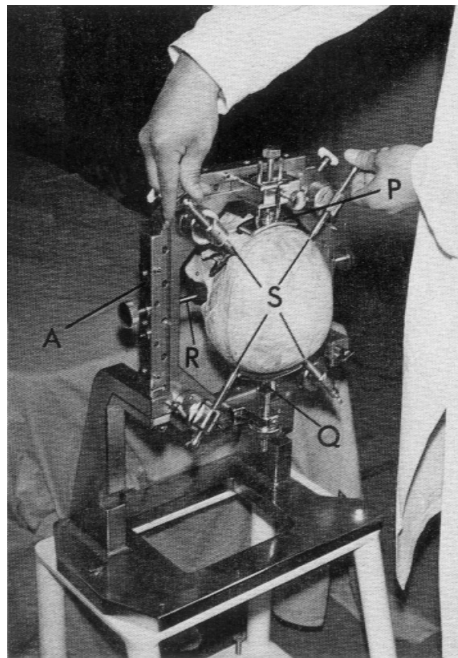


FIG. 1. Fixation of the skull in the patient's original frame. The skull is held temporarily in the original frame (A) at four points; forehead (P), occiput (Q) and bilateral external auditory meatus (R). The four fixing pins (S) are inserted into the skull with local anesthesia. The temporary fixtures are then removed and the skull remains supported by the fixing pins only.

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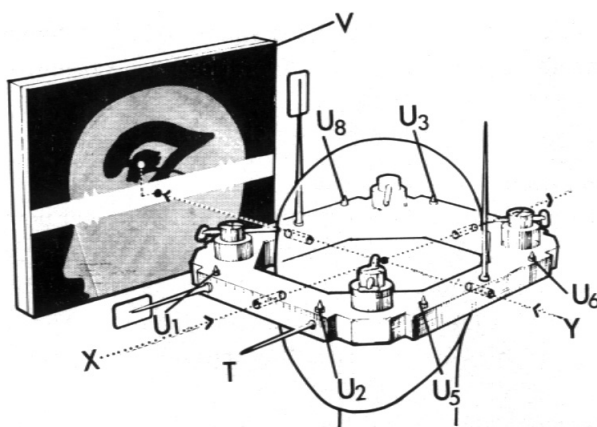


FIG. 2. The original X-Y plane of coordinates provided in the frame. X: sagittal axis of the frame which goes through a pair of center holes in the frame. Y: frontal axis of the frame which goes through a pair of center holes in the frame. T: sighting bar to align the optical axis of the x-ray tube with the center of the frame. U₁-U₈: datum cones for measurement of magnifying ratio and central axes on a x-ray photograph. V: x-ray film.

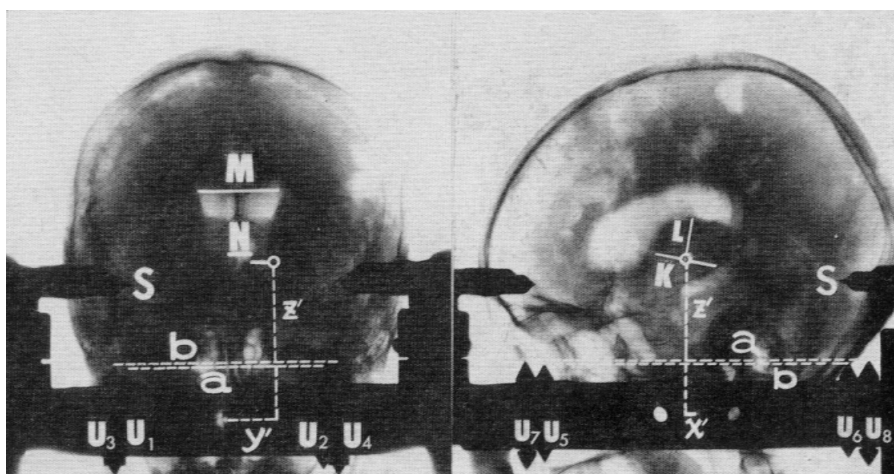


FIG. 3. Measurement of the relative position of target to the coordinate on the frame and of the magnifying ratio on the frame center line due to divergence of x-ray beam. The magnifying ratio is given by $(a+b)/200$ (mm/mm) in the anteroposterior and lateral x-ray photographs. (The real distance between two corresponding datum cones on the frame is 100 mm.) K: Foramen monroi-Comm. post. line. L: height of floor of ventricle from the line K at its middle point. M: width of ventricles at the lateral border of caudate nuclei. N: width of the third ventricle. S: fixing pins. U₁-U₈: datum cones (see Fig. 2). a: distance between U₁ and U₂ or U₅ and U₆ on the x-ray photograph. b: distance between U₃ and U₄ or U₇ and U₈. x', y' and z': position of target in the coordinate.

parallel to the sagittal axis of the frame (Fig. 2, X). The other tube is adjusted so that the beam runs through the frontal axis of the frame (Fig. 2, Y). The plane determined by those two axes serves as the original plane of the coordinates of the frame. X-ray pictures of frontal and lateral view of the skull are taken and the distance from the original point of this coordinate to the target point is measured on the photographs in three dimensions (Fig. 3). Errors occurring in these values due to the divergence of x-ray beams are corrected as shown in Fig. 3.

In order to determine the relative position of an imaginary target to the phantom frame, the values thus obtained are transferred to the coordinate of the phantom frame which is the same in configuration and size as that of the patient's original frame.

A semicircular arch with an electrode holder is attached to the phantom frame (Fig. 4). The arch and the electrode holder are manipulated so that the electrode tip will fit the target. Then, all of the sliding parts are locked in position tightly. After the relative depth of the electrode on the arch is read on the scale, the electrode is withdrawn and the semicircular arch is transferred to the original frame fixed to the skull. The electrode is inserted

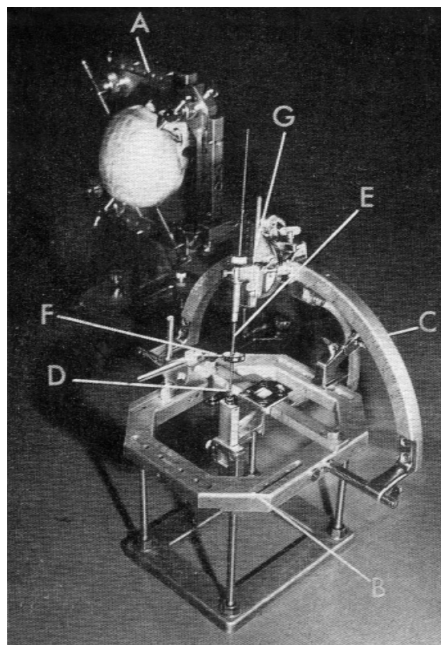


FIG. 4. A target point measured on x-ray photographs (Fig. 3) is transferred to the phantom frame (B). The semicircular arch (C) is fixed on the phantom frame so that an electrode (E) can reach the imaginary target (D) through the center of the burr hole indicator (F). A: patient's original frame, G: electrode holder.

into the brain through the electrode holder to the same depth as previously determined on the phantom frame and AP and lateral x-ray photographs are taken to confirm the position of electrode tip in the brain.

High Frequency Coagulator

The coagulator consists of three components: a high frequency generator with an out-put power controller, a thermometer and a timer (Fig. 5). The high frequency generator generates sinusoidal waves of 300 ± 10 kc and its

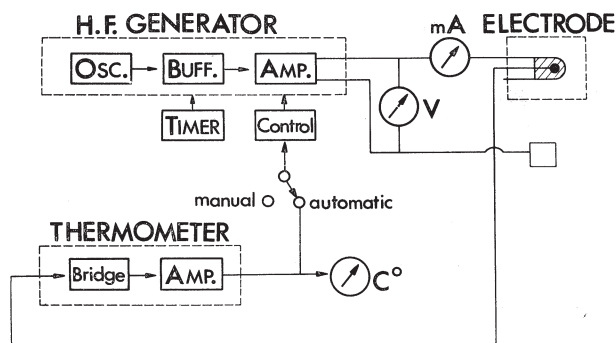


FIG. 5. Block diagram of HF coagulator. Amp.: amplifier, Bridge; bridge circuit containing a thermistor in an electrode tip, Buff.; buffer stage, Control.; controller of output power, Osc.; high frequency oscillator, Timer; timer to adjust duration of coagulation.

output power can be manually set up to 15 watts in connection with a suitable load. A thermistor is mounted in the electrode tip and connected to a thermometer which is graduated from 0°C to 100°C . The output of thermometer is fed to the controller of generator so that the temperature at the electrode tip is maintained within the pre-set range. When the temperature at the electrode tip reaches the pre-selected degree, the timer begins to run. After the desired period of coagulation lapses the output of the coagulator is turned off by a signal from the timer. The size of the coagulated lesion can be controlled by both the temperature and the duration of coagulation. In the event of an emergency, such as overheating caused by a malfunction of the coagulator, or trouble in the coagulator itself, the high frequency current to the electrode is immediately discontinued automatically and a warning lamp is lit.

Coagulating electrode

1) Standard electrode (Figs. 6, a and 7)

The electrode consists of a stainless steel tube (300 mm in length, 2.0 mm in diameter) and a hemispherical gold tip (4.0 mm in length) with a built-in thermistor. The entire electrode surface is insulated except at its gold tip.

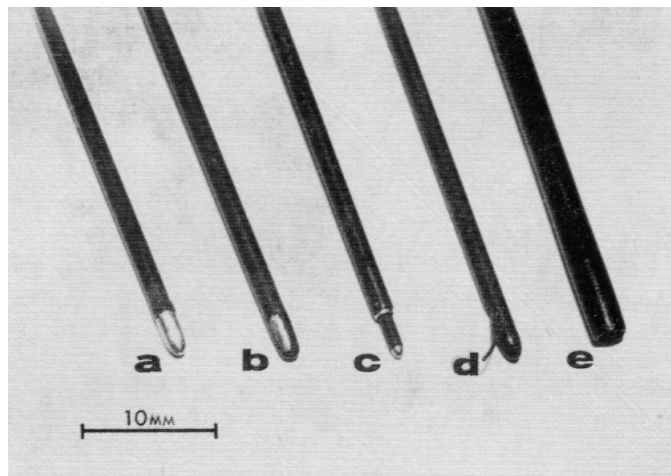


FIG. 6. Various types of electrode tips. a: standard coagulating electrode with thermistor. b: one-side coagulating electrode with thermistor. c: coaxial stimulating electrode. d: branched electrode for coagulation. e: guide tube.

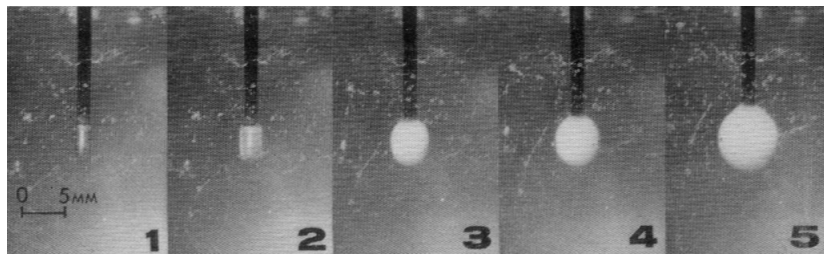


FIG. 7. Coagulation of the egg-white by a standard electrode. 1) 30 sec. at 55°C. 2) 22 sec. at 65°C. 3) 30 sec. at 65°C. 4) 60 sec. at 65°C. 5) 30 sec. at 95°C.

2) One-side electrode (Fig. 6, b)

This electrode is similar in configuration and size to the standard one with only a quarter of circumference of the tip uninsulated. With this electrode only the area adjacent to the non-insulated side of the tip will be coagulated.

3) Branched electrode (Figs. 6, d and 8)

This type of electrode is designed to coagulate a focus situated laterally so distant from the tip of the inserted electrode that it can not be coagulated with the aforementioned one-side coagulating electrode. After the electrode is inserted into the brain, a flexible steel wire is pushed out 3-7 mm laterally from the electrode tube through a small hole near the blind end of the tube. As this electrode lacks a thermistor in the extended tip, high frequency coagulating power is fed to the electrode manually, instead of being servo-

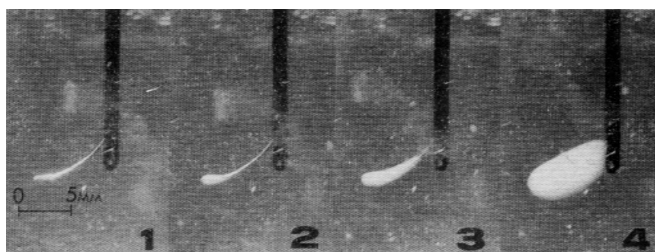


FIG. 8. Coagulation of the egg-white by a branched electrode. The voltage and current fed to the electrode in 1) to 4) are the same as those in 1) to 4) of Fig. 7 respectively. 1) 30 sec. 2) 22 sec. 3) 10 sec. 4) 30 sec.

controlled.

RESULTS OF OPERATIONS

Fifty cases were operated from July 1964 to June 1965. The results so far obtained are indicated in the table. No operative mortality occurred. In one case, light hemiparesis was complained after the operation which was undertaken in order to relieve pain due to a sarcoma.

TABLE

	No. of cases	Not effective	Effective	Excellent	Target
Parkinsonism	31	1	4	26	{VL and {Pall. int.
Choreo-athetosis	3	2	1	0	VL
Torsion dystonia	3	0	1	2	VL
Cerebral palsy	2	1	1	0	VL
Psychomotor epilepsy	3	0	2	1	Fornix
Psychomotor grand mal	3	1	2	0	Fornix
Pain	3	0	2	1	{VP, DM and {CM
Psychosis	2	*			DM
Total	50	5	13	30	

* Evaluation of results was considered difficult, as the results were available for the preceding half year only.

DISCUSSION

Exact approach to a target

Several different types of operative apparatuses and of methods of destruction have been developed. Those stereotaxic apparatuses will be classified into the following five types:

1) Those in which a holder of a coagulating electrode is fixed to the soft tissues covering the skull. The path of the electrode axis is corrected with an aid of x-ray photography and the electrode is directed precisely to the target in the brain. This was initiated by Clark and is now called Spiegel and Wycis' Type or Narabayashi's type. The methods of Wada³⁹⁾, Bailey and Stein²⁾ are included in this type.

2) Those in which a holder is imbedded into the skull itself. It is fixed to the surrounding part of the trephine hole instead of being fixed to the soft tissues. This has been modified by Guiot (Gillingam⁸⁾), Austin and Lee¹⁾, Cooper⁴⁾, Handa¹⁾, Sano³⁰⁾, Nishimoto and Tsubokawa.

3) Leksell's type¹⁷⁾ 18).

Those in which a frame is attached to the skull. A semicircular arch is tightly locked to the frame and the target in the brain is brought to the center of the semicircular arch with the aid of x-ray photography. The electrode is inserted through the electrode holder which is tangentially mounted on the semicircular arch.

4) Talairach's type³⁴⁾ 35).

Two pieces of similar lattice boards which are perforated in arrays at 3 mm intervals are held upright in parallel on the skull frame. Each piece stands 30 mm distant from the other. An x-ray beam is projected perpendicular to the boards and a pair of holes in the two boards through which the x-ray beam leads exactly to the target are selected as the guide holes to insert an electrode through them.

5) Riechert's type²⁸⁾ 29) 22).

A phantom frame with an imaginary target is used, which is the same as the original frame attached to the patient's skull in configuration and size. The relative direction and position of an electrode which tip is at the position of imaginary target to the semicircular arch mounted on the phantom frame is determined. The arch is transferred from the phantom frame to the patient's original frame and the electrode is inserted into the brain according to the calibrated data on the phantom frame. The apparatuses of Jinnai¹⁶⁾ and of Takebayashi³⁶⁾ are under this category.

Each apparatus has its own advantages and disadvantages. Any apparatus in stereotaxic surgery should:

1) Be as light and simple to manipulate as possible.

2) Require a minimum x-ray photographing,

3) Be firmly fixed to the skull, because it is necessary to keep a precise correlation between the skull and the apparatus. Fixation of them should not become loose throughout the operation even with involuntary movement. It is desirable that the apparatus gives the least possible discomfort to the patient.

The electrode should:

4) Be directed to the target at each insertion with an accuracy of less than

± 1.0 mm deviation,

- 5) Be inserted from any point over the skull at any selected angle, and
- 6) Be micro-adjustable longitudinally mm by mm.
- 7) Allow a number of electrodes to be inserted into the respective targets at the same time by means of the stereotaxic apparatus, and
- 8) An operator, without previous training, by using this apparatus can insert the electrode tip and reach exactly the target.

The apparatus recently designed by us is considered to meet sufficiently all of the above requirements. In particular:

1) The apparatus is made of an aircraft aluminum alloy and weighs approximately 4 kg. For the purpose of holding the electrode tip with an accuracy of less than 0.5 mm deviation and of making the apparatus withstanding long use, it is considered impossible to make the apparatus lighter in weight.

2) The skull of the patient is firmly fixed under local anesthesia with four fixing pins (Fig. 1). During and after operation, the patients do not suffer from any pain. Even for those who are suffering from serious tremor and involuntary movement, only local anesthesia is required.

3) The insertion of the electrode into the target is conducted exactly under aid of both anteroposterior and lateral x-ray photographs only. After the electrode is inserted, the photographs are taken once more to ascertain if the electrode is located exactly at the target. In our experience in 50 cases, all electrodes arrived at the target with an accuracy of less than ± 0.5 mm deviation at the first trial of insertion, excepting one which deviated by 2 mm due to an error in the process of calculating the position of target.

When the measurement of position of target point on a set of anteroposterior and lateral x-ray photographs is accurate enough, the exact insertion of electrode into the target is possible even in the first case of experience.

4) It is important to insert the electrode into the brain along the longitudinal axis of nuclei or along nerve tracts so that the blocking effect may effectively be attained by the destruction of the smallest possible focus. For destruction of Pall. int., for instance, the electrode is inserted nearly horizontally or parallel to the skull base, and for V. L. (V.O.) of Thalamus, the electrode is inserted nearly perpendicular to the base of the skull. In determining the angle at which the electrode is inserted, care should be taken to avoid the parts where blood vessels concentrate. With the apparatus it is possible to insert the electrode to any site in the brain with desired angle as shown in Fig. 9.

5) The possibility in longitudinal microadvance of the electrode in the vicinity of the target is very useful for destroying two or three foci in line with the target. With the apparatus electrical activity of a single neuron in the brain could be recorded by a microelectrode.

6) For treating epilepsy, multiple recording of subcortical EEG from many foci in the brain is necessary. With additional electrode holder, several

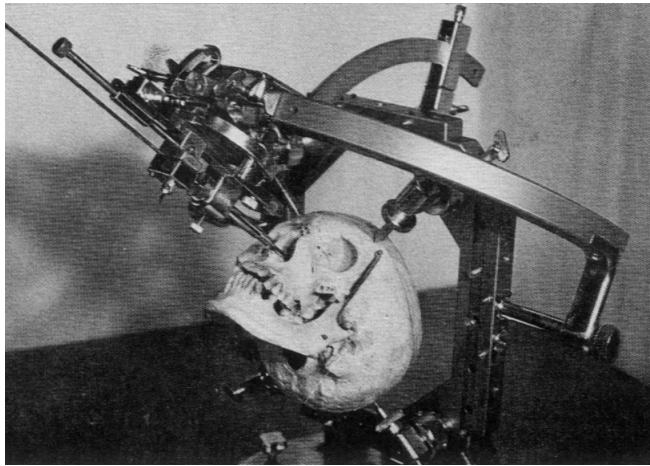


FIG. 9. Transnasal operation of the pituitary gland. The electrode can be inserted in any direction from almost any site of skull to the target.

electrodes as many as ten can be inserted to targets with an accuracy of approximately ± 1 mm deviation.

Destruction of the target

Nerve fibres and cells at the target should be broken down in compliance with the following requirements.

- 1) A focus can be coagulated in any desired size from 2 mm to 10 mm in diameter with an accuracy of approximately ± 1 mm deviation.
- 2) A coagulated focus should be clearly defined. No tissue outside the focus should be affected.
- 3) Risk of contingent bleeding or thrombus due to the severance of the blood vessels should be minimized.
- 4) Breaking or blocking should not be temporary in its effect.
- 5) Effect of breaking should be proved during the operation.

Tentative breaking should be reversible and "try-out" should be possible.

With these requirements in mind, the following evaluation of major breaking techniques is done.

a) Mechanical destruction

Brain tissues are destroyed by using wax (Narabayashi²⁵), rubber ball (Cooper), incision of such tissue as Lamella medialis (Sano). Wertheimer⁴⁰ (1960) has reported 8 deaths of 61 cases of brain tissue destruction by leucotomy, so that the destruction by incision is considered very dangerous. By using oil-wax it is not always possible to form the focus desired. Skill is required in this method because such substances are influenced by temperature. This method has, however, the advantage that the destroyed part of the brain can

be observed for life by x-ray photographing.

b) Chemical destruction:

Brain tissues were destroyed by injecting absolute alcohol. Previously it was adopted rather extensively by Spiegel and Wycis, and Cooper. But it is not accepted so widely now because the chemicals spread irregularly into the adjacent tissues around the target and the focus is not formed in the desired shape. This method may be applicable to pharmacological treatment by injecting some chemicals into a small region of the brain in conjunction with the stereotaxic surgical treatment.

c) Electrical destruction:

This includes thermal coagulations by direct current (Spiegel and Wycis, and Sano), low frequency current (Gildenberg) and high frequency current (Riechert and Leksell). Direct current involves electrolysis in the tissues and it is impossible to form a focus large enough in size through a monopolar or a bipolar electrode with direct current. It is also very difficult to control electric power fed to the electrode to coagulate a certain size of tissue by means of adjusting the tension or amount of the electric current alone because of the impedance difference among individuals and different structures of the target.

As the size of coagulated focus is not only the function of electric power

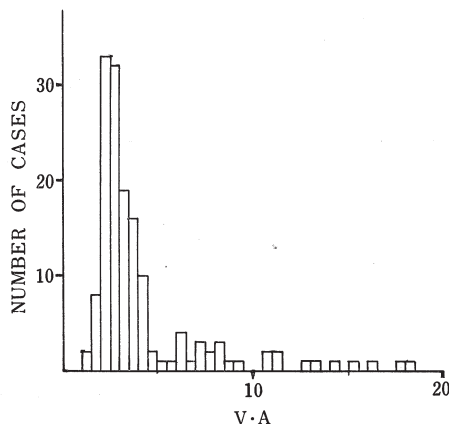


FIG. 10. Large variation in the surface value of electric power necessary to maintain the temperature of electrode tip at 70°C to coagulate different targets in the brain. abscissa: product of tension (V) and current strength (A) of high frequency current applied. ordinate: number of coagulation.

FIG. 11. Lesions in a cat's brain 7 days after coagulation (Klüver-Barrera's stain). A: Frontal section of the brain fixed by 10% formaldehyde solution. B₁: The lesion in the left side of A was coagulated at 95°C for 30 sec. B₂: The small area outlined in B₁. Blood vessels are torn and some haemorrhage is observed. C₁: The coagulated area in the right side of A (30 sec at 70°C). C₂: The small area encircled in C₁. In contrast with the lesion in B, no haemorrhage can be found.

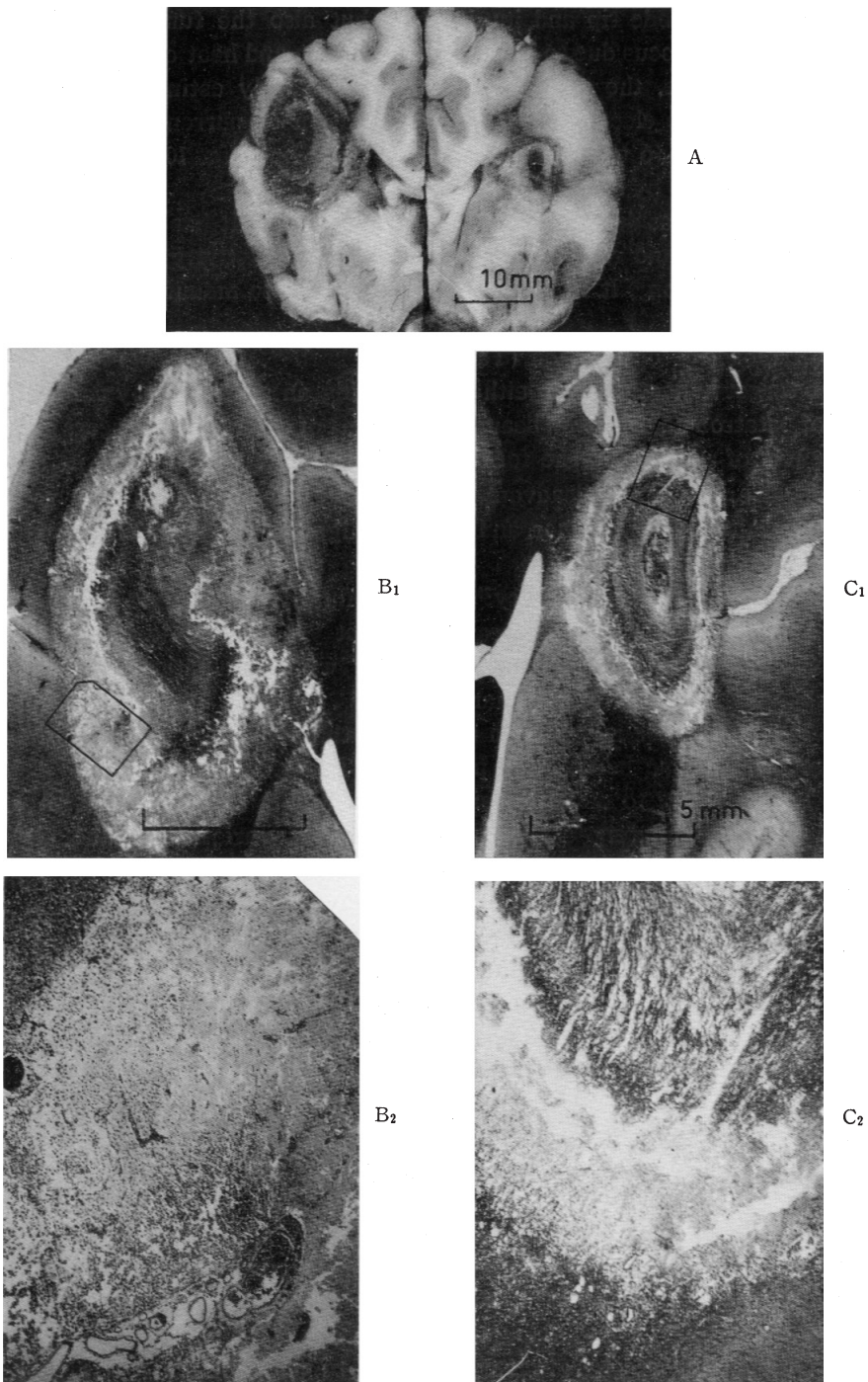


FIG. 11

spent at the electrode tip and its duration but also the function of heat dissipation from the focus due to the blood circulation and heat conduction through the adjacent tissue, the size must be more precisely estimated by the local temperature at the electrode tip and the duration of current supply than the electric power fed to the electrode and its duration (Fig. 10).

d) Destruction by freezing:

This method was designed by Cooper⁵⁾ and Mark. It has a great advantage in getting a mild and reversible suppression of the activity of the target for tentative destruction. It is, however, very difficult to manufacture such equipment.

e) Radioactive destruction (Talairach, Leksell¹⁸⁾, Hoshino¹¹⁾)

The target is destroyed by either implanting an isotope or by concentrating firing of betatron and electron beams. The effect of destruction appears gradually in a couple of weeks and the focus and lesion can not be formed in a predetermined size. They are disadvantage of this method, but it would be applicable to treat pituitary gland tumor and other malignant tumors with isotopes implanted stereotactically in them.

f) Ultrasonic destruction (Fry²⁰⁾, Oka²⁷⁾, Miura²¹⁾, Nakashima²⁴⁾, and Ueki³⁸⁾.

It is still in the stage of research and not yet for practical use.

Our high frequency thermal coagulator with automatic thermoregulator has the following three major characteristics.

I. *By a thermistor* mounted in the tip of the electrode the temperature of the electrode tip can be adjusted precisely. Therefore,

1) It is possible to make a lesion of 2 to 10 mm in diameter with an accuracy of approximately ± 1 mm irrespective of variation in the electrical impedance or/and the heat dissipation in anatomically and physically different structures in the brain tissue of different individuals.

2) When the temperature is kept under 70°C, the tissue adjacent to the lesion are not microscopically affected at all (Fig. 11, C).

3) Under 70°C, nerve cell protein is coagulated at first with little effect on the blood vessels, so that no bleeding occurs, because there is no damage to the blood vessel wall as illustrated in Fig. 11, C.

4) If a short circuit takes place in any part of the electrode or on the cable from the coagulator to it, the temperature does not rise even if excessive electric current is supplied. Such incidental troubles can be monitored.

II. *By the automatic thermoregulator:*

1) The operator can pay his full attention to any change that may occur on the patient without adjusting or watching the equipment while the power is being supplied.

2) Overheating at the electrode tip due to operator's error is prevented by the servomechanism.

3) Excessive current, which might be caused by malfunction of the apparatus is automatically shut off.

III. *300 kc is chosen*, because tissue in contact with the electrode tip will not stick to it at all after coagulation at such rather low frequency. Therefore, when the electrode is withdrawn damage of the tissues or blood vessels by plucking out a piece of tissue stuck to the electrode and resulting incidental unexpected bleeding can be avoided.

SUMMARY

A new stereotaxic apparatus and high frequency coagulator with automatic thermoregulator has been developed. The results of fifty operations with this apparatus have been very satisfactory. The characteristics of this instrument are as follows:

A) Insertion of electrode:

1) The head of the patient can be held so firmly that even an operation on patient with marked tremor or other kinds of involuntary movement can be conducted under local anesthesia only.

2) The electrode tip can be driven exactly to the target point with a standard deviation of less than ± 0.5 mm.

3) Insertion of electrode into the brain from any direction is possible. Transnasal approach to the pituitary body is also feasible.

4) Using an accessory electrode holder, several electrodes can be inserted into the brain from any desired direction in the stereotaxic manner for multi-channel recording or coagulation (*e.g.* for treating epilepsy).

5) Only a pair of anteroposterior and lateral x-ray photographs is enough to conduct an electrode to the target. After insertion of the electrode, additional x-ray photographs are desirable to confirm the position of electrode tip.

6) Even if the operator has not had previous experience with the apparatus, he can introduce exactly the electrode into the target by stereotaxic means since his first trial with this apparatus.

B) Coagulation by high frequency coagulator with automatic thermoregulator; Due to the automatic thermocontrol system with a thermistor mounted in the electrode, the temperature at the tip of the coagulating electrode is indicated and whole process of coagulation progresses automatically after the temperature and duration of coagulation have been pre-selected, so that the target can be coagulated in the desired size. Overheating at the electrode tip is prevented by the thermocontrol system and the warning signals.

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