A technique of sealing blood vessels requires the production of either an external or internal occlusion of the involved vessel. The ligature and the clip are examples of external sealing. Blood clotting is the familiar method of internal sealing and usually occurs in combination with some degree of vasospasm to produce the strength required to hold arterial pressure. Clotting within an adherent damlike wall such as that provided by Gelfoam may readily seal venous openings. Historically, the hot actual cautery or boiling oil was used to achieve hemostasis by forming a large tissue coagulum, which usually prevented bleeding until the entire dead mass sloughed away. Sometimes intravascular clotting occurred in a location sufficiently proximal to the slough that bleeding did not recur. A simple heated instrument will coagulate tissue and stop bleeding. If modern techniques were to be used to keep the instrument tip at the proper temperature and if the size was right, the actual cautery would effectively seal some blood vessels. The difficulty lies in the fact that the heat is externally applied and, as with any other form of external heating such as a frying pan or an oven, the cooking process proceeds from the outside inward. To alter this, Clark designed an electrosurgical device with a spark generator, which was first brought into an operating room in 1910. The device had a motor-driven rotating disk that acted as a static generator with a spark gap, a Leyden jar as a capacitor, and a resonating coil. The unit released a powerful discharge with which one could coagulate living tissue, but the device did not come into significant use.

In 1928, W.T. Bovie, a physicist and one of the earliest biophysicists, developed an electrosurgical unit in which a spark-gap generator provided an output of damped irregular waveforms, approximately 1 MHz in frequency; the unit permitted coagulation and, with the addition of a synchronous resonating circuit, also provided cutting ability. Cushing used this machine to revolutionize some removals in areas in which bleeding previously had not been controllable. Cushing's first publication regarding this technique began with a note by Bovie that is still remarkably erudite more than 65 years later. This basic system has been a mainstay of neurosurgery for many years.

Nearly 60 years ago, James Greenwood initiated the use of “two point” coagulation and conclusively demonstrated its superiority. Because all electrical flow requires a return path, Greenwood called the Bovie unit with its ground plate “bipolar” and called his own system “two point.” Over the years, it has become customary to call the Bovie system “unipolar,” whereas Greenwood’s two point unit is referred to as “bipolar.” In designing his unit, Greenwood divided a forceps and insulated the blades from each other. Using a switch, he attached one side of the forceps to the active side of the Bovie generator and the other side to the ground connector; he also disconnected the ground plate.

In 1951, while working with monkeys in Fulton’s laboratory at Yale University, I had to wait many hours after using the Bovie generator in craniotomy before cortical recovery was sufficient to allow recording. Because of my experience with the lack of current spread afforded by using bipolar stimulation in electrophysiology, I decided to develop a bipolar coagulator. I built a low-power spark-gap generator, empirically winding coils and transformers to achieve optimum coagulation, and made bipolar forceps by dividing and insulating the surgical forceps blades from each other. This solved my problem and the unit became my animal surgery mainstay in my Mount Sinai laboratory as well. Two years after I created my system,
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Dr. Leo Davidoff showed me Greenwood’s pioneering paper on two-point coagulation (of which I was unaware) and suggested that I bring my unit into the operating room. We found it as useful in the operating room as it had been in the laboratory. Because this occurred in an era before any government device regulatory process, I was able to have my unit manufactured (with some difficulty) by the Coles Corporation as early as 1955. As was the case in the Bovie units, in my first machines the power level was adjusted by varying the generator spark gap because the gaps burned away and required constant adjustment. After I designed a fixed spark gap, which required no adjustment despite years of use, a tapped output coil was used to provide accurate reproducible power steps. This improved version was produced by Codman and Shurtleff in 1966.

Basic Principles of Electricity and Application to Electrosurgery

Passage of an electrical current through tissue produces heat in accordance with the distribution of the electrical power used. A simple battery, whether it be flashlight or automobile, emits a direct current: the current flows in one direction, from one terminal of the battery to the other at a fixed voltage, and is constant through time. Alternating current, which lights our cities, flows back and forth, changing its direction. Each direction change is called a cycle. One cycle per second is termed a Hertz. This smooth change of voltage from positive through zero to negative with time exhibits a sinusoidal wave form. The voltage is the root mean square of the peak-to-peak amplitude of the sine wave. This is analogous to pressure in a hydraulic system. Current, measured in amperes, relates to the number of electrons moving through space or matter in a unit of time. Power, measured in watts, is the product of voltage × amperage, at least in the case of direct current. For example, with a direct current source of power applied through a matched pair of electrodes, one on either side of a block of tissue, the distribution of the current flow will follow the geometry dictated by Ohm’s law. Current flow, and thus heat production, will be greatest in the straight path between the electrodes. Because surrounding tissue may act to prevent the loss of internal heat, the center may become the hottest and coagulation may occur from the inside outward. A direct current, unfortunately, is not a good coagulation method for use in living tissue. For one thing, stimulation of muscle and nerve tissue would produce gross movements. Electrolysis occurs, with a marked degree of hydrogen bubble formation at the negative electrode. Additionally, the quality of the coagulation is poor.

A low-frequency alternating current, such as that supplied from the power line at 50 or 60 cycles/second, is even worse. The degree of muscle and nerve stimulation is extreme for the amount of coagulation. Hydrogen bubbles are released at both electrodes alternately with oxygen bubbles during each cycle, and the incidence of local flame burning at points of sparking is even higher than with direct current. The situation changes in a number of respects as the frequency of an alternating current increases. At frequencies above 100 kHZ a simple alternating current produces little stimulation of muscle or nerve and little gas production.

All electrical current must complete a circle—it must have a return path just as in the case of the flashlight battery and bulb. With the Bovie machine, usually called unipolar, the return path is through the dispersive electrode, also known as the ground plate. The active electrode provides a high current per cubic millimeter because of its geometry, that is, it is very small compared to the large dispersive electrode. The amount of current that can flow at a given voltage depends on the resistance of the material through which it flows. “Resistance” is a term used in describing direct current. In describing alternating current, the equivalent term “impedance” is used because other factors determine how alternating current can pass through a material. Current flow differs for various conductors and shapes at different frequencies.

An electromagnetic field is produced whenever an electrical current passes through a conductor. With direct current this is a simple unchanging field with a north and south pole. With alternating current the field changes its polarity with each cycle. The electromagnetic spectrum of interest here is quite simple: 60 Hz is the power-line frequency used in the United States and 50 Hz is used in Europe and most of Japan. When electromagnetic forces are used to move air (loudspeakers), the audio spectrum runs from 20 to 20,000 Hz. Amplitude modulation (AM) radio broadcasting uses the frequencies from 550 to 1600 kHz; frequency modulation (FM) broadcasting spans the bandwidth from 88 to 108 MHz. Interestingly, macromolecular resonance, which is useful for electrosurgery, falls within the AM broadcasting band, whereas proton resonance, which is used in magnetic resonance imaging, falls within the FM broadcast band. With radio transmission, the energy is radiated from a resonated antenna and returned through the ground plane.

In Bovie’s original machine the coagulating current was generated by a variable spark gap with a resonant coil and condenser tuned to approximately 1 MHz, all fed by a high-voltage transformer. This system produced a new spark in the gap with each power-line cycle. This “rang” the resonant coil and condenser, producing an intermittent irregular series of damped waveforms. (A damped waveform is a group of cycles progressively decreasing in amplitude.) The multiple interruption permitted coagulation with little cutting tendency.

High-voltage alternating current in the range of approximately 0.5 to 3 MHz sustains a continuous fine arc between the active electrode and the tissue. Heat production is so complete and rapid that it smoothly parts the tissue; this is referred to as “cutting current.” There is considerable electrical current spread and heat production. If the sinusoidal radio frequency power is very markedly reduced, there will be insufficient power to cut and coagulation will occur. Unfortunately, this is a dangerous way to coagulate blood because the power difference is related to tissue volume, and if “cutting current” has been turned down to a degree at which a given electrode would coagulate, a partial contact with less area would have a higher current density and could now cut at the point of actual contact.

Even at high frequency, a pulsed waveform may still cause nerve and muscle stimulation. This is due to a
capacitive buildup of membrane potentials secondary to rectification at the tissue contact points. The stimulation may be minimized by control of the waveform of the individual pulses and is further controlled by an output series capacitor. Variations in the electrical design of the generators make a considerable difference in the results. A generator that has pulses on more than 30% of the time will tend to do more cutting while it is coagulating and thus will perforate vessels more often. If a significant sinusoidal component is present, cutting and perforating will occur. An ideal coagulating waveform is an arrhythmic waveform in which no two cycles are alike, there can be no true resonance (that is, no molecular resonance), and there is the lowest division of tissue. The two major requirements for coagulating are an arrhythmic waveform and damping. Of course, regardless of the type of current, frequency, or waveform, the amount of power per volume of tissue will make a great difference. Applied to a large ball electrode, the same power that will coagulate tissue will cut if applied through a fine blade or needle. If the electrode point is held well out of contact so that a long spark jumps across to the tissue, the result will be fulguration instead of coagulation or cutting. All the preceding discussion applies to the coagulating current, whether used as a so-called unipolar coagulator with a ground plate or as an isolated system with bipolar forceps.

The Bovie type of coagulator, standby of the neurosurgical operating room for half a century, passes its coagulating current into the patient through the small active coagulating electrode, and out through a large ground plate. If the ground plate were as small as the active electrode, each would coagulate equally. Additionally, the Bovie machine’s output is not isolated. That is to say, its patient-ground connection has a fairly low impedance to the machine chassis and power-line ground. This makes the system vulnerable to current spread to other grounding points on the patient, such as metal parts of the table or monitoring equipment.

Current flow from the active electrode to the ground plate passes through all intervening conductive media at a rate proportional to their conductivity, but decreasing in current density as it moves farther from the point at which the small electrode is applied in accordance with the obvious geometry. This, of course, means current flow passes through main trunks of blood vessels, whose branches are being coagulated, through neural structures and cerebrospinal fluid as well as muscle and bone. There is a considerable amount of current and heat at distances of even 1 to 2 cm from a small point of coagulation. For this reason the use of unipolar coagulation has been restricted, particularly for work around the spinal cord or brainstem. For microsurgical techniques in neurosurgery to be really developed, a constantly clear bloodless field is essential. Bipolar coagulation using properly designed instrumentation is able to provide this type of hemostasis with ease and safety as well as to permit other significant changes in handling tissue to be discussed later.

**Leakage of Current**

In a human with a coagulating electrode on the brain and a ground plate on the back, the impedance at 1 MHz is approximately 1500 ohms. The impedance between the tips of the bipolar forceps on the brain averages approximately 150 ohms. With these parameters, only 10% as much power is needed to coagulate vessels at the brain surface using the bipolar unit than is needed using the unipolar unit with ground plate. Although Greenwood used his system with the ground plate disconnected, because the Bovie machine was not isolated (even without the ground plate), there was significant leakage from one side of the forceps to the patient. Nevertheless, the impedance between the forceps tips was only one-tenth of the impedance to ground. At worst, only 10% of the current leaked to ground. So despite the fact that the system was not isolated, Greenwood’s unit had only a modest leakage of current and it did indeed work, being reasonably safe and effective for human use.\(^{4,6}\) Nevertheless, potential dangers did exist: for example, if only the active side of an unisolated unit were to contact a delicate area, the current would flow to any ground as in a unipolar coagulator. Accordingly, all properly designed bipolar coagulators are required to have isolated outputs with minimal leakage of current to any ground.\(^{12}\) Using the isolated bipolar technique, current flows only between the forceps tips. To summarize, in a unipolar system all current flows to ground from the forceps; in an inadequately isolated bipolar unit, most of the current flows between the forceps tips with some flow to ground as well; in the true bipolar system, current flows only between the forceps tips. The restriction of the geometry of current flow permits the use of the bipolar system in the most delicate areas, in which unipolar currents would be completely unacceptable.

A direct method of determining the leakage of various bipolar coagulators is rather simple to use. The coagulating forceps may be mounted so that one blade touches the cortex of an anesthetized animal (the rat is eminently suitable). The coagulator is turned on and run through its range of outputs, allowing 1 or more minutes at each step and then reversing the electrode connections and repeating the process. Evans blue dye introduced through the carotid artery is then used to perfuse the brain hemisphere. The absence of an opening in the blood-brain barrier is proof of the safety of the current leakage level in the tested coagulator.

Although the advantages of bipolar systems have been disputed, their clinical superiority has clearly led to their wide acceptance. A laboratory comparison between bipolar and unipolar coagulation can demonstrate the difference. On one side of the rat brain, several surface vessels can be sealed using the unipolar system at the lowest possible power setting; on the other side of the brain, stroking with bipolar forceps set at the lowest bipolar coagulating power can coagulate all the surface vessels. After Evans blue dye is injected, it is clear that the unipolar system causes damage extending deep into the brain, the result of electrical current and heat spread. The bipolar system causes superficial damage, essentially the result of deliberately destroying all the cortical vascular supply. However, if the bipolar coagulator and the unipolar coagulator are set at the same output power, all the energy will be concentrated between the bipolar forceps tips, whereas the same energy will be dispersed from the contact point to the ground in the unipolar connection. At any setting at which the unipolar unit will coagulate, the bipolar unit will be overpowered. If we set the bipolar device to the level at which it can properly operate and compare it to the
other system, we find that the unipolar unit at the same power will not coagulate at all. The comparison between devices needs to be made at the lowest power at which each can properly coagulate a surface vessel. Even in the rat, damage from the unipolar system is far greater than that from the bipolar system. In the human, coagulation with the bipolar system ordinarily requires only approximately 5% of the power required using the unipolar system.

Regulation of Current

Constant-current stimulators are the generators most frequently used for electrophysiology today. This is the diametric opposite of the generators used for power distribution in our cities. Our cities are supplied with constant voltage. Within limits, the voltage at every outlet remains the same, no matter how many lights are being used, and each single bulb burns at the same brightness. The voltage remains constant regardless of the load. Constant current, on the other hand, keeps the total current the same by varying the voltage to meet the changing load. If 10 lamps were to be placed across a line at which previously one had burned brightly, the total current drawn would remain the same, and each lamp would produce only a dim glow. The maintenance of constant voltage is essential to the power distribution in a city, and it is called “regulation.”

Regulation, or maintenance of constant voltage, is a function of generator impedance. The lowest possible generator impedance gives the least change in voltage with a varying load. Great sums of money and much engineering skill go into designing well-regulated generators and power systems to provide the lowest generator impedance so that reasonably constant voltage can be obtained. A low generator impedance in the coagulator permits the same voltage settings to work with differing electrode sizes and different tissues, as well as to work under saline irrigation. Provision of the lowest possible generator impedance is synonymous with the best regulation.

For the coagulator constant voltage is critical. If there were a constant-current coagulator, whenever saline flowed over the field, little current would be left for coagulation at the forceps tip because most of the current would flow through the saline. Very fine-tipped forceps would receive much lower voltage. Broad-tipped forceps would receive a high impedance and would therefore be fed a high voltage to achieve the current setting, whereas a broad-tipped forceps would receive much lower voltage.

The factors required for a superior bipolar generator can be summarized as: 1) proper waveform; 2) lowest possible generator impedance; 3) isolated output; 4) rigidly stabilized voltage output; and 5) control totally in the hands of the surgeon. Achieving these most important criteria, as well as adequate reproducible controllable power levels, reliability, simplicity of use, and safety, has been a design exercise over the years.

Spark-gap generators produce a sloppy, asynchronous, fairly random damped series of spikes in each burst. The bursts repeat at power-line frequency but with considerable irregularity. The duty cycle, the arrhythmicity, and the individual spike frequency can be determined by the inductance and capacitance of the circuitry and the transformer design. This very waveform variability is the reason for the good coagulation produced. The minimal macromolecular resonance decreases tissue perforation and division. However, the initial spike of each damped train is always much higher in voltage than the rest of the train, as a requirement for striking the arc in the internal spark gap of the generator, also true in the Bovie system. This high-voltage initial spike is responsible for the undesirable sparking at the forceps tips, which results in excessive tissue charring, eschar buildup and sticking, and video and monitoring equipment interference.

As commercial electronic-tube or solid-state coagulators were developed, they generally provided either damped trains of sine or square waves, or simply repetitive pulses. The synchronization of these pulses or waves increased undesirable cutting or perforating of vessels being coagulated as a result of molecular resonance. In addition, their high output impedance (usually over 500 ohms) prevented their effective use in an irrigated or bloody field. For this reason, I continued to use the CMC-I spark-gap generator for many years, as did most neurosurgeons.

Advances in solid state electronics made feasible the design of a solid-state microprocessor–controlled unit, the CMC-II. The microprocessor could be programmed to simulate the aperiodic waveform of the spark-gap systems, but with the leading spike reduced to be proportion- al to the remainder of the damped asynchronous train. The aperiodic waveform results in the elimination of molecular resonance, whereas control of the first spike of each train results in a marked reduction in sparking of the forceps and interference with other equipment. The most effective, nonperforating, strongest coagulation pattern and the lowest temperature spread were determined by progressively varying the parameters of the generator microprocessors. The coagulation waveform finally determined has fairly complex parameters. The basic frequency varies from 0.8 to 1.2 μsec in groups varying from 8 to 12 cycles, each successive cycle diminishing in amplitude by a randomized amount. These groups recur in series of 8 to 12, each group diminishing also in amplitude. Each series recurs every 8 to 12 msec, all asynchronously randomized. These parameters markedly reduce the tendency to stick or char and improve the ability of the generator to coagulate smoothly and effectively at lower voltages without the need to pulse the forceps.

The microprocessor is also programmed to stabilize the constant output voltage, providing better regulation and lower output impedance than any other method. It also turns off the power if the forceps are short circuited. Additionally it provides the cutting waveform, delivers the speech announcements, and controls the irrigation. It would be possible to program for constant current, but the irrationality of choosing this mode has already been noted. The unit could also have been programmed for other types of output control, such as thermistor control or impedance-shifted output. A thermistor could be incorporated in the forceps tip to measure temperature; however, saline irrigation, which is an essential feature of the microsurgical technique, precludes the use of such a temperature level device with forceps. Although the forceps may be quite cool and immersed in saline, the vessel being coagulated may well be more than adequately heated. The thermistor would not read the internal tissue temperature, but only the temperature of the metal element, and could raise the power far too high.
In my opinion, the same considerations apply to controlling the voltage by measuring impedance during coagulation. In addition to saline lowering impedance and keeping the power high, coagulum on the forceps can sufficiently raise the impedance to turn off the coagulator as though the vessel were sealed when, in fact, little had been accomplished. Additionally, if a large vessel or tissue mass is coagulated as the outer surface is coagulated, impedance would rise, voltage would be lowered, and coagulation would not be completed. Although these controls could readily be programmed in the microprocessor, I have found them deleterious and I would stress the need for the surgeon to control the parameters of switching, power level, and irrigation, rather than leave them to any other control system.

Although the bipolar coagulation techniques used by different surgeons may vary, I always prefer to work under gentle irrigation, using the lowest effective power level. Coagulation is done smoothly, without pulsing the forceps. The vessel is held gently to avoid shorting the forceps tips. The forceps are kept scrupulously clean and smooth, and the tip size is selected to correspond to the size of the vessel being sealed. Large thin-walled vessels should be stroked with a broad-tipped forceps to shrink them slowly before closing. In the same manner hemangioblastomas can be stroked and progressively reduced in size, permitting bloodless atraumatic removal.

Bipolar Cutting

I began using bipolar cutting in 1988. My bipolar cutting system operates in quite a different manner from the familiar unipolar cutting of the original Bovie machines. Although both unipolar and bipolar cutting are performed using an approximately 1-MHz sine wave, in unipolar cutting the power is presented to a fine-tipped active electrode at a very high voltage with the return to a proportionately large indifferent plate. This voltage drops precipitously when the active electrode is brought into firm contact with tissue or under saline. Customarily, for the fastest unipolar cutting, the power is turned on before the electrode contacts the tissue. A spark then jumps to the tissue as the electrode approaches, the impedance remains high, and the tissue is vaporized just prior to contact with the electrode, thus maintaining the high voltage necessary for this type of cutting. Unipolar settings of well over 1000 V are applied at the electrode with powers of several hundred watts or more available. Even with the power levels turned down, the initial voltage is still very high, although it is shunted down as soon as the tissue is touched.

The bipolar cutting system is designed on the basis that there is no appreciable spark and that the forceps will cut while in contact with the tissue and under saline irrigation. It is fully isolated as a true bipolar system. The voltage is kept quite low and the extremely low impedance of the generator minimizes the voltage drop from open circuit to full load. Accordingly, this technique provides for cutting, not on the basis of vaporization by an advancing spark, but rather on the basis of a true molecular resonance by the sine wave cutting current dividing the tissue without sparking.

The more vascular the tissue, the easier it is cut, although the first units did very well on soft neuromas. If the tissue is totally avascular, it has very little conductivity and can be either difficult or impossible to cut using this first bipolar technique, even with the added conductivity of the saline. To overcome this limitation, development in 1992 of the CMC-III model provided a more sophisticated, computerized digital control system with a lower output impedance and a higher voltage cutting availability. The higher voltage permits cutting dense avascular tissue with or without irrigation. As an extra advantage, the lower output impedance gives even smoother coagulation and the microprocessor more tightly regulates the output voltage, maintaining constancy in the face of widely varying loads.

In this regard the forceps should be scrupulously clean and absolutely smooth for either coagulation or cutting. A pitted or abraded forceps surface coagulates poorly and tends to build coagulum and produce dangerous sticking. A newly developed tungsten alloy forceps tip material has a surface polish and hardness far better than one made of stainless steel, titanium, or even nickel, as well as a much higher melting point. These new forceps show no wear or change after long testing and appear to me to be the best answer to forceps tip metallurgy. Approval from the Federal Drug Administration has now been received, which will permit their availability.

I use bipolar cutting current for removal of tumors in two ways. In the first, sharp forceps can be used to make almost parallel orange slice–type cuts and to lift out the segments. It should be noted that this type of cutting is always performed with the finest tip forceps because adequate cutting depends on a high concentration of current at the point of the forceps tips to divide the tissue smoothly. In the second, bipolar forceps with loop tips have now become a major technical aid in the coring of tumors. As the paired loop tips are brought together in the tissue, the cutting current removes neat cylindrical cores of tumor, permitting virtually bloodless decompression. For fine dissection of small amounts of tissue along the capsule or along adjacent neural or vascular structures, 3- or 5-mm loops are used. For coring very large tumors, a 7-mm loop can be used. The power level depends on the consistency of the tumor and the size of the loop. For a soft acoustic neuroma, a setting of 45 Malis units does well, perhaps increasing to 50 at locations at which the neuroma is more fibrotic. For most meningiomas 60 is better and for a very tough fibrous meningioma a setting of 70 is usually used. Surprisingly, calcified craniopharyngiomas cut well and fragment at 40 or 45.

The fastest and smoothest cutting is achieved by placing one blade of the loop forceps against the tissue and then bringing the opposite loop toward it. The bipolar current is totally without a neutral setting; thus it does not matter which blade one starts with because the other one will always cut to it. Of course, this is different from bipolar coagulation in which both tips of the forceps are usually placed against the tissue at the same time.

A comparison was made retrospectively using Mount Sinai Hospital operating room records to determine the changes in operating time related to bipolar cutting. To provide a reasonable case match the review was limited to acoustic neuromas and angle meningiomas. One hundred fifty microsurgical removals were logged: 75 of these
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were selected from the period just before the introduction of bipolar cutting; the second 75 were selected from operations that were performed with bipolar cutting. There were no deaths, infections, or serious complications in either group and all removals were total. The important differences were in the length of time of the surgery and blood loss. In the acoustic neuroma surgeries in which bipolar cutting was used, intradural operative time was under 2 hours; in the same type of surgeries performed before bipolar cutting, operative intradural time was between 3 and 4 hours. In meningioma surgeries, intradural time in the group operated on with bipolar cutting was just under 3 hours, whereas in the group operated on earlier it averaged 5 hours. No intraoperative transfusions were required. No patient who underwent operation with bipolar cutting required blood postoperatively, whereas in the other group several patients required a postoperative blood supplement.

Importance of Irrigation

I started using irrigating bipolar forceps in the animal laboratory in 1955 because I had no surgical assistant, but I did not use it in the operating room in the mistaken belief that resident involvement would be more focused if the assistant had to irrigate. Automatic irrigation was introduced with the appearance of the CMC II and continued with the CMC III. Sterile saline is pulsed from a fine channel added to the bipolar forceps, synchronous with the electrical output, but separately regulated in volume according to the surgeon’s preference. With the ability of the units to coagulate or cut under saline, this permits the irrigation still improved the result, cooling the area as well as further decreasing any chance of the forceps adhering to the tissue.

Conclusions

Modern microprocessor-controlled solid-state bipolar coagulating and cutting systems contribute significantly to the performance of major neurosurgical procedures, decreasing operative time and blood loss while facilitating successful outcome. Generator designs providing the lowest possible output impedance, rigidly stabilized voltage, isolation from ground, the most sophisticated waveform for coagulation, and total control by the surgeon are the most important considerations. New tungsten alloy tips (essentially permanently smooth), cutting loop forceps, and automatic regulatable irrigation at the forceps tips have also improved the ease of this surgical technique.

Disclosure

Dr. Malis is a principal stockholder and director of the Valley Forge Scientific Corp., manufacturer of the Malis bipolar generators. He is also consultant to the Codman Corp., from which he receives royalties for the sale of his instruments.

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