Studies on coagulation and the development of an automatic computerized bipolar coagulator

Technical note

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A new computerized bipolar coagulator is described in which tissue heating is switched off automatically when adequate vessel occlusion has been achieved, thus preventing overheating, undue tissue damage, cutting, and sticking of the forceps. Experiments with radiofrequency (rf) heating of albumin or arteries revealed an impedance minimum at the moment of coagulation. The attainment of this impedance minimum is transmitted electronically via a microprocessor to the coagulator, which automatically shuts off the rf energy supply. In experiments, adequate artery strength and avoidance of the drawbacks of conventional coagulation methods were achieved when rf heating was shut off soon after the impedance minimum was reached. Neither irrigation for cooling nor cleaning of the forceps tips was necessary. Electronic feedback through the same cables as used for coagulation enabled the use of conventional bipolar cables and forceps. The bipolar coagulator described can also be used for conventional bipolar coagulation under visual control. The microcomputer enables: 1) automatic coagulation cycles that start when tissue is picked up in the forceps and stop automatically on completion of the seal; 2) the change of power setting from a pedal and activation of automatic cycles by the pedal as described above or surgeon-controlled coagulation, which facilitates the use of alternative debriement with inactive forceps; 3) cable testing; and 4) negligible disturbance of the intraoperative monitoring equipment.

KEY WORDS • coagulation • bipolar electrocoagulation • diathermy • neurosurgical apparatus

The use of bipolar diathermy to seal off bleeding arteries is associated with the well-known problem of switching off the power at the right moment during the short period of coagulation. If power is switched off too early, the vessel will not be sufficiently coagulated and, if too late, cutting and charring will occur and the forceps will stick to the tissue. Upon withdrawal of the forceps, rebleeding may occur. Furthermore, build-up of charred tissue on the tips makes frequent cleaning necessary. This renders the procedure unsafe and time-consuming. The exacting demands of neurosurgery have resulted in a variety of methods being developed to reduce these drawbacks; improvements include automatic thermocontrol,7 automatic irrigation of the tissue,1 and the use of heavy metal in the forceps points.3 A fast to-and-fro movement of the bipolar forceps tips during heating at a high power setting while irrigation is applied by an assistant to slow the heating rate of the tissue has frequently been practiced.

These procedures improve the results but considerably complicate hemostasis. The necessity for an assistant to manage the switch further lessens the surgeon’s control over the procedure. The aim of the present work was to find a method to switch off the current during bipolar radiofrequency (rf) heating of arteries at a fixed point in the coagulation process when adequate vessel occlusion had been produced and before sticking of the forceps and charring of the tissue, and to adapt the procedure to the variable demands of micro- and macroneurosurgery.

Materials and Methods

The coagulator described here* has a bipolar generator with a built-in computer, and was used together

* The computerized bicoagulator is available in the United States under the trade name CBC-1 and in Europe under the name COA-COMP. The machine is distributed in the United States by Radionics Inc., Burlington, Massachusetts.
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Fig. 1. Diagram showing the set-up used to measure the correlation between impedance, temperature, and coagulation during radiofrequency heating of albumin.

Fig. 2. Diagram showing the set-up used to test and record the pressure strength of coagulated arteries in vitro.

with test electrodes for impedance measurement during heating of albumin or coagulation of arteries. Experiments were performed with albumin to illustrate the coagulation process. An rf current of 512 KHz was used at a constant voltage and at sufficient power to obtain coagulation within about 1 second. The computer in the coagulator was programmed to deliver instantaneous values of the electrical parameters to the recorder for later analysis (Fig. 1).

Impedance and Temperature Monitoring

Heating of Albumin. Two steel electrodes were coated with Epoxy, leaving an uncoated 2 × 3-mm area at the tip. The electrodes were mounted at a distance of 2 mm apart. During coagulation of albumin, light transmission between the electrodes was measured with a photocell and a light source in order to monitor the coagulation process (Fig. 1). The temperature between the electrodes was monitored by means of a thermocouple.

Animal Preparation and Heating of Arteries. Pigs, each weighing 15 to 25 kg, were anesthetized with intra-

muscular ketamine (15 to 20 mg/kg of a 50-mg/ml solution) and intravenous methohexitone chloride (3 to 5 mg/kg of a 50-mg/ml solution) and azaperon (0.05 to 0.1 mg/kg of a 2-mg/ml solution). The animals were normoventilated with O₂/N₂O at a 1:2 ratio and the pCO₂ was maintained at 4 to 4.5 kPa. The distal portion of the femoral arteries was used for impedance monitoring and pressure testing. The tested segments had an outer diameter of about 1.5 to 3 mm. The vessel diameters were measured at a normal blood pressure. Coagulation was applied at locations about 10 mm apart. For coagulation of arteries, we used bipolar forceps. In some trials, a 0.5-mm diameter thermoprobe was introduced in vivo through a hole in the arterial wall and advanced to a position between the forceps points to achieve simultaneous temperature and impedance monitoring during heating.

Pressure Testing of Coagulated Arteries

After coagulation, the arterial segments were numbered, excised, stored in saline, and tested within 30 minutes after removal. Saline was infused into the coagulated arterial segments at a rate of about 8 ml/min by means of a constant infusion pump and a Y-tube where one arm was ligated to the artery and the other was connected to a pressure transducer (Fig. 2). The pressure that caused rupture was easily identified on a continuous pressure-time recording at the point where the rising pressure suddenly decreased. The strength of the arterial wall was measured by making similar pressure tests on excised segments ligated with a thread ligature.

Histopathological Analysis

The coagulated specimens were fixed in paraformaldehyde and stained with van Gieson's technique.

Results

Impedance Monitoring During Radiofrequency Heating

The electrical impedance behaved in a specific and quite reproducible way when albumin was heated (Fig. 3). The region where coagulation takes place can be found where light transmission drops to almost zero. From Fig. 3, it is also evident that the minimum value of impedance occurs at the point where coagulation takes place. The temperature at this interval is about 60° to 80°C. It is also noteworthy that coagulation occurs less than 1 second after the power is switched on.

Impedance measurements during rf heating of arteries showed results similar to those for heating of albumin. Again, the impedance had a minimum value at the moment of coagulation (Fig. 4).

† Malis medium bipolar forceps manufactured by Codman & Shurtleff, Inc., Randolph, Massachusetts.
Pressure Resistance of the Coagulated Artery

Healthy arterial walls withstood a pressure higher than 1500 mm Hg, more than 10 times the normal blood pressure. When the heating was switched off at the impedance minimum, 1.5-mm diameter arteries ruptured at a mean pressure of 260 ± 152 mm Hg (± standard deviation) in 10 trials. When the impedance minimum +1 second was the point at which heating was discontinued, these arteries resisted a mean pressure of 460 ± 190 mm Hg in nine trials. When coagulation ceased at the impedance minimum +2 seconds, the mean pressure at rupture was 490 ± 180 mm Hg in 10 trials, similar to that obtained at the impedance minimum +1 second. It was not possible to coagulate safely arteries with a diameter larger than 2 to 2.5 mm.

Histological Analysis

The adventitia of the coagulated arteries was thickened at the coagulation site. The collagenous tissue in the vessel wall increased to about twice the normal volume. The collagenous fiber structure was generally preserved, although there were small scattered areas of lost fiber structure when coagulation ceased at the impedance minimum +1 or 2 seconds. The muscular tissue was slightly thickened. The intimato-intima contact line was irregular but visible within the constricted part of the vessel. In vessels exposed to coagulation at the impedance minimum +2 seconds, the intima contact line was more irregular and often difficult to distinguish.

Discussion

Coagulation of albumin and arteries revealed that the impedance minimum correlated with the moment of coagulation. Impedance alterations have been reported previously in connection with coagulation of proteins, however, those reports apply to stereotactic lesions where the coagulation times (10 to 100 seconds) are much longer than in bipolar coagulation. The impedance showed reproducible behavior, decreasing during heating up to about 60°C (probably related to the augmented ion mobility in the tissue at a higher temperature) and increasing again at 60°C to 80°C, when coagulation takes place. This is probably attributed to "trapping" of ions within the denatured protein meshwork. Dessication of the tissue from boiling at 100°C also increases impedance.

The pressure tests of coagulated arteries demonstrated that the strongest seals were obtained when the power was switched off shortly after the impedance minimum. If coagulation was prolonged further, strong seals were obtained but the problem of the forceps sticking to the tissue became more serious. Switching off the heating at the impedance minimum produced seals that resisted about twice the normal systolic blood pressure; when the power was turned off 1 second after the impedance minimum, seals occurred that withstood three or four times that pressure. More prolonged power resulted in a marginal gain in seal strength but had the adverse effect of the forceps sticking to the artery. Experiments (F. Harris, Valleylab Inc., personal communication, 1977) have shown that sticking of the forceps became less marked at a temperature below 120°C. When the collagenous fiber structure was lost.
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due to high-temperature coagulation, or if the tissue was carbonized, the strength of the arterial wall diminished. Our histological analysis demonstrated that the collagen of the arterial wall was largely intact at the impedance minimum +1 second. Veins can be coagulated safely up to a diameter of 3 to 4 mm.2

The finding of an impedance minimum during heating of proteins at the moment of coagulation prompted the development of the new computerized bipolar coagulator. The microprocessor provides electronic feedback of the condition of the arterial wall during heating and causes an automatic break-off when the artery has a strong seal; this is a great improvement over the visual feedback and manual shut-off required with conventional bipolar diathermy. Accurate visual control is difficult without some side effects occurring, due to the short coagulation time. The adverse effects of conventional bipolar diathermy are thus reduced with this system, including insufficient heating or overheating resulting in a weak seal or sticking of the forceps, cutting, rebleeding, or charring. With the new device, neither irrigation for cooling nor cleaning of the forceps tips is necessary, as the rf energy supply is shut off automatically at the desired temperature of about 70° to 90°C. This automatic “temperature control” combined with the controlled current leak to ground from the forceps points, and the fact that heating is confined to the tissue between the forceps points results in negligible heating and injury of adjacent tissue. Conventional bipolar forceps and cables are used since the energy supply and electronic feedback are conducted through the same line, thus avoiding the expense of a dual system. This is a major advantage compared to other suggested methods employing less available, more complicated, and more expensive equipment.17

The only requirements that must be satisfied for the machine to work well is that tissue is picked up gently between the forceps tips and that the tips are kept relatively steady at a certain distance apart during the very short heating period. Pressing the tissue too hard between the forceps tips will cause a short circuit and consequently no heating. Irrigation or changing the distance between the forceps tips during heating might disturb the computer’s ability to detect the impedance minimum. The microprocessor of the generator can also adapt the generator to variable neurosurgical conditions. An automatic start and cessation of coagulation is used in macroscopy. For microsurgery, inactive forceps debridement alternating with a surgeon-initiated start is generally preferred. The microprocessor therefore provides a choice of options including a pedal-initiated or an automatic start, infrared transmission from the pedal for simplified management and cleaning, and cable and generator testing, thus giving the surgeon better control over coagulation. No additional personnel is needed for power-setting or managing the switch. Due to the automatic power shut-off, the choice of power is less critical with this computerized coagulator. However, if the power level chosen is too high, resulting in coagulation occurring very quickly, the microcomputer will not be able to stop the power emission fast enough to avoid cutting. This effect can be utilized for dissection of intramedullary and brain-stem tumors. Small blood vessels and fibrous bands can be divided at the time that hemostasis is achieved.

Besides being adapted to neurosurgical working conditions, the computerized bipolar coagulator complies with all desired characteristics of bipolar coagulators. The coagulator has been used in more than 15,000 neurosurgical operations in Sweden, and surgeons who have tried the technique do not as a rule wish to revert to conventional bipolar coagulation methods requiring manual and visual control.

References

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