CRYO-NEUROSURGICAL MACHINE SYSTEM, PROCESS TECHNOLOGY AND THEORY

INTERNATIONAL INSTITUTE OF REFRIGERATION COMMISSION C1
1÷5 JUNE 1981, WARSZAWA, POLAND

Quan-sheng Shu, Low Temperature Division, Zhejiang University, Hangzhou, China

Ai-Feng Xie & Xue-Ji Ma, Hanghou Radio Hanufacture

Shun-Shen Hu, Hangzhou Institute of Oxygen Plant

Xiang-Luo Tao & Shi-Ting Lu, Zhejiang Medical University

1. INTRODUCTION

In this paper a well designed cryoneurosurgical machine is described, the temperature of its probes can be displayed, recorded and automatically controlled during operation. The external diameters of these probes are Φ2.4, Φ3, Φ6 and Φ7.6 mm respectively. Both the temperature variation of brain and the corresponding heat transfer differential equation are also discussed.

It has been proved clinically that these gliomata of brain can be made demarcated from its surrounding tissue to help the complete removal of it, and bleeding can be lessened quite markedly by using this machine. Besides, it can help the surgeon to avoid some neurosurgical defects. Chosing suitable cryoprobe, it can be used for other cryo-therapeutics and cryophybiological experiments.

2. GENERAL SITUATION OF THE MACHINE

BY-II type cryoneurosurgical machine that we designed, can display record and automatically control the temperature variation in the neurosurgical operation. This machine is also equipped with externally clustered thermocouples in order to measure the temperatures of the deep brain tissue at various distances from the cooling surface of the probe tips. A series of special probes which are well vacuum insulated, except at the tip, have been developed. Their external diameters are Φ2.4, Φ3, Φ6 andΦ7.6 mm respectively. The interior field of the tips of these probes is provided with temperature sensors and heating devices, thus the temperature of the tip can be controlled from +20℃ to -196℃ automatically.

The liquid nitrogen in the Dewar bottle can be displayed by the capacitance type level gauge. The pressure feeding liquid nitrogen can be adjusted and maintained from 0 to 3 kg/cm^2 automatically. The machine can be operated by automatic program controlled system, by hand or by footboard switcher for different needs. The machine is shown in Fig.1 and flow diagram in Fig.2.

3. THE ULTRA-FINE PROBE

The way to solve cooling, insulation, rewarming, vacuum-sealed and electric insulation of the cryo-probe will be discussed briefly in the following/1-2/.

Keep vacuum of the ultra-fine probe

For example, the diameters of liquid nitrogen feeding tube, vapor returned tube and outer Jacket tube of the smallest areΦ1, Φ1.8 &Φ2.4 mm respectively. There is a high vacuum space between outer jacket tube and returned tube. Because the volume of vacuum space is very small, so the gas given up by the metal will make vacuum fail. We enlarged the hollow inner space of the handle of the probe as a large vacuum space, channeled to the original small vacuum space and put the charcoal adsorbent around the cold gas returned tube.

The metal wall of the tube while being evacuated can be heated to above 300℃. The pressure of 5×10^{-6} mmHg can be reached. A hign vacuum can be maintained for above two years.

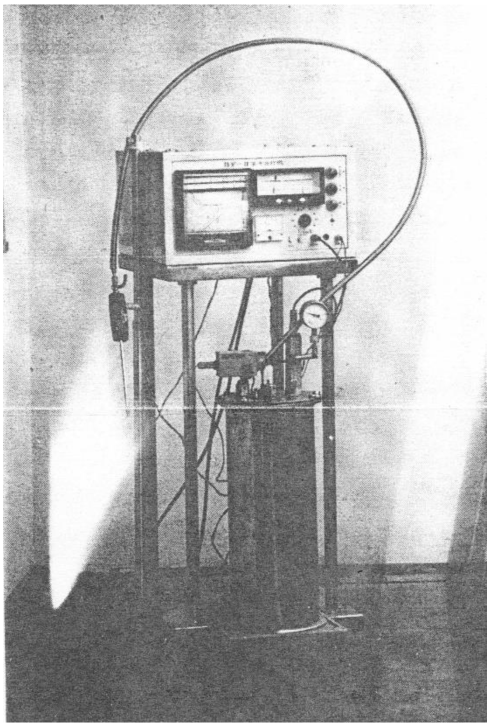

Fig. 1. The BY-ii type machine

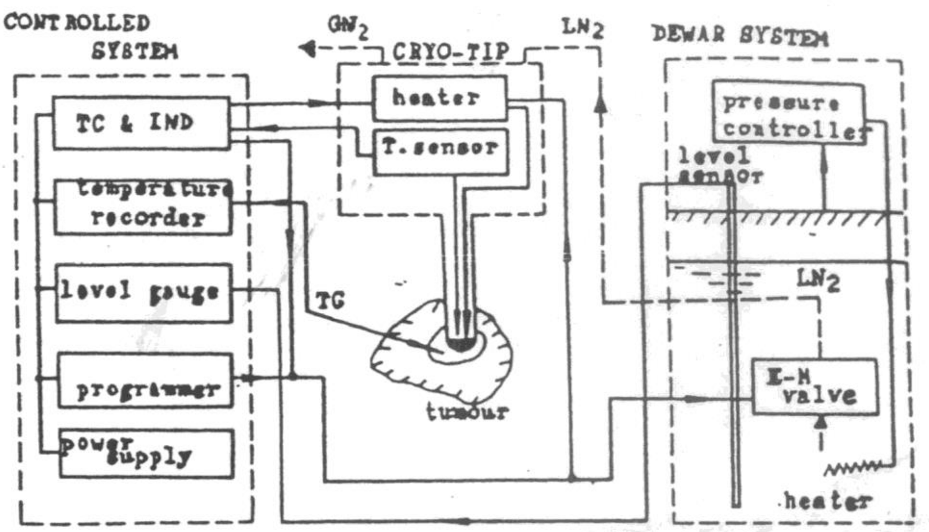

Fig.2. The flow diagram for BY-II machine

Microheater

There is a special high power microheater in the probe tip. It can undergo the frequent temperature variation between -196℃ and 20℃, It can make the temperature of the tip change from -196℃ to 20℃ within less than 25 seconds.

Electric connection without wires

since the space between tubes is so small, that it is almost impossible to fix two heating leads for heating and thermocouple. We use returned and feeding tubes of liquid nitrogen instead. For electric insulation, a very thin layer of the special plastic (0.05 mm) was sintered around outer surface of liquid nitrogen feeding tube. At the entrance of liquid N_2 there is a special shaped teflon collar.

soldering in vacuum

In order to get a good vacuum-seal, all seams of the cryo-probe as a whole can be soldered at once in vacuum.

Needle for temperature measurement

The special multipoint temperature sensor in a fine hollow stain-less tube is developed. The signal can be indicated, recorded and fed back to the machine to control the neurosurgical operation.

4. A TRANSIENT THERMAL FIELD

It is obvious that, when a cryosurgical probe have been inserted into tissue and brought it to a cryogenic temperature suddenly, a transient thermal field will be developed in the media. The freezing front will propagate through the tissue until a steady-state condition is reached. It is important to know the rate or propagation and the ultimate range of freezing. In biological tissue a partial differential equation describing heat transfer can be written as follows:

$$\nabla \bullet (K\nabla T) + M_b C_b (T_b - T) + S_m = \rho c \frac{\partial T}{\partial t} \quad (1)$$

Where, (1) $\nabla \cdot (K \nabla T)$ indicates the conductive portion of heat transferred by conduction occurring in the tissue. (2) $M_b C_b(T_b\text{-}T)$ indicates the portion of heat transferred due to blood flow. (3) S_m is the portion of heat transferred due to metabolism portion, it may be a function of temperture, time and position. (4) $\rho c \frac{\partial T}{\partial t}$ represents the increase (or decrease)of internal energy of a small region of tissue. If a steady state is reached, $\rho c \frac{\partial T}{\partial t}$ =0. The details of solution of phase change problem were given in references /3-4/ which we have published. The temperature variation in brain be recorded during an actual operation is shown in Fig. 3.

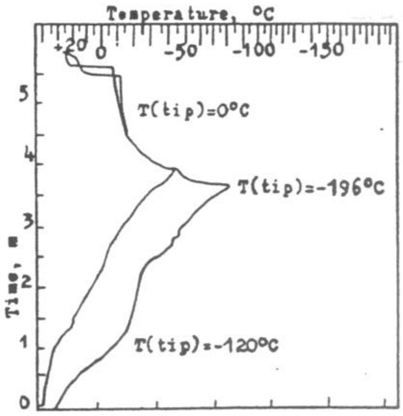

Fig.3. The recorded temperature-time curves of the various depth of the man's brain tissue during operating by BY-II.The right curve is the temperature of a point that is 5mm from the surface of the tip, the left curve is 10mm.

5. CLINICAL CONCLUSION

After craniotomy, the tumour is exposed, frozen solid for two or three minutes by the use of a cryoprobe inserted into the center of the tumour, and removed en bloc while the probe is pulling out. Gliomata, which ordinarily are gelatinous and difficult to manipulate, may be transformed into solid more easily handled tissue, and the line of demarcation between tumour and normal brain tissue become more clear to facilatate identification and separation. When the tumour is situated in important functional area or deeply in the brain, it is better to remain a small part of residual tumour rather than to remove it completely. In order to kill the residual tumour cells in this area, the cryoprobe can be placed closely to the tumour to freeze for 2-3 minutes, then after thawing, it can be frozen again.

Clinically, there have been more than thirty cases with brain tumour to be removed by cryogenic freezing extraction. These patients aged from 19 to 69 sufferred from various types of brain tumours, such as glioma, meningioma, metastatic cancer etc. The operation were done under local anethesia, genaral anethesia or acupuncture anethesia depending on the patient's conditions. Hydrocortisone or mannitol were administered intrarenonsly during the operation and postoperatirely. There were no severe cerebral edena, tumour bed bleeding, wound infection and operation death.

We are very grateful to president Zhou Shen-Tin, prof. Ma Yuan-ji and prof. Chen Yun-Xia for their guiding.

NOMENCLATURE

∇ del operator, cm^{-1}
k thermal conductivity, cal/g • k • s.
T temperature of unfrozen phase, k
T_b arterial systemic blood temperature, k
M_b blood mass flow rate, g/cm^3 • s
C_b specific heat of blood, cal/g • k
C specific heat of unfrozen, cal/g • k
S_m metabolic heat generation rate, cal/cm^3 • s
ρ tissue density, g/cm^3
t time, s

Figure 4 Extracting the man's brain tumour with the cryoprobe. The temperature variation of the deep brain tissue of various distance from the tip can be monitered with two (or three) needle thermocouples beside the probe

REFERENCES

[1] E.E.SIWIEC, S.D.Augustynowicz, c/52,XV International Congress of Refrigeration,Venezia 23-29 Sept.19/9

[2] Shu Quan-Sheng, Cryogenic Engineering, published by The Chinese Publishing House of Science,1977.

[3] Cai Xi-Hou, Shu Quan-Sheng, Cryosurgery and Cryogenics, published by Shanghai Publishing House of Science and Tecnnique,19/8

[4] Shu Quan-Sheng (edited), Cryogenics and Their Applications, to be published by the Chinese Publishing House of sience.