

a trough through which cooling or warming liquids are passed from two reservoirs. The reservoir temperatures are kept at 2 C and 45 C with the flow arranged to integrate with the stage and progress of the surgical procedure. Roller pumps are used to transmit blood from an extra corporeal storage container to the body vascular system via the cooling (or warming) system, and to maintain circulation during the operation.

The body temperature is reduced to about 10 C, resulting in complete cardiac cessation, as well as apparent cessation of all other vital functions. This procedure has been used successfully for surgery lasting one hour or more. As noted it is used only in highly selected cases where other less drastic techniques are unsatisfactory, and is fraught with higher danger to the patient.

Many problems naturally exist in these applications of refrigeration anesthesia, being mostly in regard to patient safety, the best method of cooling (rapid or slow), optimum temperature for carrying out operating procedures, correlation with length of operating procedure, etc.

Actually all of these relate to the stage of development of the technique, and depend upon the accumulation of considerably more satisfactory information for future success.

Responsibility for the success of this anesthesia procedure rests squarely upon the physician-anesthetist who watches over the patients' vital signs before, during and following the operation. In addition to the experience needed for this delicate task, information from several recording thermometers to monitor the temperature of various areas of the body is valuable.

Local Hypothermic Anesthesia

Similar methods of ice packing or circulated cooling fluid are used for local anesthesia, principally for extremity amputation. The method is similar in all respects except that only the limb is encased, rather than the whole body, and a tourniquet is applied shortly after the cooling is begun, since the human body has great capacity to compensate for local external temperature changes. General anesthesia is not required. Refrigeration usually takes two to four hours for the production of anesthesia, depending on the area to be anesthetized. When ice alone is used, frostbite does not generally occur, and the skin temperature does not usually fall below 4 C. Care must be taken with mechanical refrigeration that these conditions are reproduced. This type of anesthesia is usually reserved for the elderly or poor risk patients, who have additional ailments which preclude the use of other anesthesia.

In summary, it may be stated that hypothermia may be induced locally, or applied to the entire body, inducing analgesia (insensibility to pain). Current interest in physiological problems and clinical application is responsible for continuing study. Although knowledge of this subject is far from complete, it is apparent that general hypothermia:

1. May be induced by cooling the blood stream or cooling the body surface.
2. Dangerously enhances ventricular fibrillation (independent heart muscle fiber action resulting in incoordinate contraction) in man, especially at temperatures below 25 C.
3. Depresses the respiratory center.
4. Lowers pulse rate, blood pressure and cardiac output.

5. Is reversible by rewarming, if not carried below a critical level.
6. Lowers oxygen demands by the tissues and therefore may be used to protect the brain while circulation is totally occluded during open heart operations; and the liver, kidney, or spinal cord during occlusion of the arterial blood supply to these parts.

REFERENCES

1. L. C. Gage: Hospital refrigeration needs (*Industrial Refrigeration*, August 1957, p. 30).
2. S. W. Chase and C. H. Herndon: The fate of autogenous and homogeneous bone grafts (*Journal of Bone and Joint Surgery*, Vol. 37-A 1955, p. 809).
3. P. H. DeVries, L. L. Kempe, and W. O. Brinker: Sterilization of Bone Transplants by Cobalt-60 Radiation (University of Michigan Medical Bulletin, Vol. 21, 1955, p. 29).
4. R. A. Kilduffe and M. DeBakey: *The Blood Bank and the Techniques and Therapeutics of Transfusions* (C. V. Mosby Publishers, St. Louis, 1942).
5. E. L. DeGowin, R. C. Hardin, and J. B. Albever: *Blood Transfusion* (W. B. Saunders, Philadelphia, 1949).
6. R. L. de C. H. Saunders: Preservation of cadavers by plasticization (*Anatomical Record*, Vol. 115, 1953, p. 43).
7. W. O. McQuinn: Anesthesia in cardiac surgery (*Archives of Surgery*, Vol. 61, 1950, p. 892).
8. F. J. Lewis and M. Tausif: Closure of atrial septal defects (*Surgery*, Vol. 33, 1953, p. 52).
9. J. W. Dundee, T. C. Gray, P. R. Mesham, and W. E. B. Scott: Hypothermia and autonomic block in man (*British Medical Journal*, Vol. 11, 1953, p. 1257).
10. C. E. Drew, G. Keen, and L. B. Benazon: Profound hypothermia (*Lancet*, Vol. 1, 1959, p. 745).

BIBLIOGRAPHY

1. W. H. L. Dornette: The use of temperature monitoring devices in anesthesia (*Anesthesia and Analgesia Current Research*, Vol. 35, 1956, p. 584).
2. B. Fisher, C. Adams, R. Wilde, and E. R. Fisher: The sterilization and storage of lyophilized blood vessels (*Annals of Surgery*, Vol. 143, 1956, p. 73).
3. E. W. Flood: *Freeze-Drying* (Reinhold Publishing Co., New York, 1949).
4. E. W. Flood and G. W. Hyatt: Preservation of bone grafts by freeze-drying (*Surgery*, Vol. 31, 1952, p. 716).
5. E. R. Hipp and G. R. Minor: A freeze-dried artery bank (*Virginia Medical Monthly*, Vol. 82, 1955, p. 125).
6. R. E. Horton: Storage and use of arterial grafts (*British Journal of Plastic Surgery*, Vol. 7, 1955, p. 9).
7. T. Komoda and M. Morio: Experimental study on the specimen contamination in electron microscopy (*Journal of Electron Microscopy*, Vol. 9, 1960, p. 77).
8. H. B. Lehr, W. S. Blackmore, P. N. Sawyer, F. Clausen, and J. Johnson: An apparatus for the preparation of homologous arterial grafts by freeze-drying (*Surgery*, Vol. 37, 1955, p. 576).
9. H. T. Meryman: Freezing and drying of biological materials (New York Academy of Sciences, 1960).
10. W. W. Mushin: *Anesthesia for the Poor Risk* (C. C. Thomas Publishers, 1948).
11. J. P. Reidy: Homogeneous bone grafts (*British Journal of Plastic Surgery*, Vol. 9, 1956, p. 89).
12. L. R. Sauvage, S. A. Wesolowski, and R. D. Pine: Review of the principles and description of manifold type vacuum systems (*Surgery*, Vol. 37, 1955, p. 585).
13. E. T. Smith: Five years experience with refrigerated bone (*Southern Medical Journal*, Vol. 49, 1956, p. 704).
14. E. W. Flood: Chapter on quick freezing and freeze-drying process (*Biophysical Research Methods*, F. M. Uber, editor, Interscience Publishers, 1950).
15. R. W. Virtue: *Hypothermic Anesthesia* (C. C. Thomas Publishers, 1955).
16. S. A. Wesolowski, L. R. Sauvage, and R. D. Pine: Quantitative observations during the freeze-drying processing of arterial segments (*Journal of Thoracic Surgery*, Vol. 30, 1955, p. 9).

CRYOGENICS

Liquefaction of Helium; Liquefaction of Hydrogen: Problems and Properties, Liquefaction Cycles and Equipment; Measurement of Low Temperatures; Thermal Insulation: High Vacuum Reflective Insulation, Conductivities of Supports, Multiple Layer Insulation, Unevacuated Porous Insulations, Evacuated Powders, Rigid Foam Insulation; Properties of Structural Materials: Specific Heat, Thermal Expansion, Thermal Conductivity, Mechanical Properties; Cryogenic Fluid Properties

ALTHOUGH man has been interested in the nature of things at very low temperatures from early times it was about the first of the 20th century that any real investigations were made. The liquefaction of hydrogen (-423 F by James Dewar in 1898) followed soon by the liquefaction of helium (-452 F by Kammerling Onnes in 1908) made it possible to study nature near absolute zero (-460 F). Before this it was possible to reach temperatures only as low as -300 F to -350 F using liquid air or one of its primary constituents, oxygen or nitrogen.

Up until World War II research and development in the field of cryogenics were carried on only in a few of the major universities in the United States and Europe and in a few government laboratories. A great upsurge in cryogenic research took place about 1947. This was made possible, partly by the Collins helium liquefier (developed by S. C. Collins at Massachusetts Institute of Technology) and partly by the growing interest in uses of liquefied gases. The few commercial interests in this field up to this time were primarily centered in production and uses of liquid oxygen and liquid nitrogen. This area also has exhibited a tremendous expansion in the last fifteen years.

As a result of investigations, developments, and increased interest in applications in the very low temperature ranges, the new field of cryogenic engineering has emerged. It is generally associated with the development, production, and use of equipment in the temperature range of -250 F to near absolute zero. It includes the measurements of properties of engineering materials; chemical and physical processing of bases; the liquefaction of gases; pumping, transport, storage and use of liquefied gases; and development of a wide range of equipment, instruments, gadgets, and techniques for such work.

Probably the most important field of application for cryogenics today is in the missile and rocket industry for defense and space programs. There are many other important developments, however, that have accounted for the great interest in this field and its growth to a billion dollar a year industry.

The name cryogenics was coined from the Greek, cryo- (kryos) meaning icy cold, and genic (genes) to become or produce. It is appropriate in that it refers to the coldest area known in nature. Fig. 1 illustrates this temperature range, separating it from the range generally referred to as ultra low temperature.

This chapter presents the fundamental principles and con-

siderations in the liquefaction of helium and hydrogen as compared to the simple Linde cycle used in the liquefaction of air or either of its constituents, nitrogen or oxygen; describes the basic methods of temperature measurement in the cryogenic temperature range; covers the principal methods of insulation and temperature isolation; and discusses the basic properties of many engineering materials at low temperatures. The chapter also includes a number of tables and graphs of cryogenic data that are considered most helpful to the refrigerating engineer who may occasionally encounter problems in the cryogenic engineering range.

LIQUEFACTION OF HELIUM

The normal boiling point of helium is 4.2 K (-452.1 F) and the critical temperature (the highest temperature at which the liquid phase can exist) is only 1 K deg (1.8 F) higher. Other properties of helium are indicated in Figs. 2 and 3. In the temperature-entropy diagram of helium Fig. 2, lines of constant pressure and constant enthalpy have been added and in Fig. 3 lines of constant temperature have been superimposed upon an enthalpy-pressure diagram.

Many ordinary refrigerants condense at room temperature

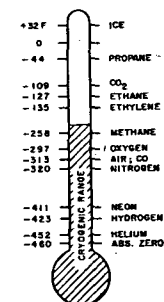


Fig. 1 . . . Cryogenic Thermometer Showing Normal Boiling Temperatures At Atmospheric Pressure