ANALYSIS AND CHOICE OF PROMISING TRENDS IN THE DEVELOPMENT OF CRYOGENIC MEDICAL EQUIPMENT

G. A. Kiseleva

Methods for cryogenic treatment of biological tissues have received comprehensive study in recent decades. In some cases cryosurgery has been shown to be superior to other surgical methods because it provides bloodless operation, sharply defines the borders of the treated area, and has anaesthetic and anti-inflammatory effects. The high efficacy of the method combined with its sparing action opens up promising prospects for future application and generates a need for new devices which would meet the requirements of clinical practice and research.

It should be noted that the technical literature on cryogenic engineering assigns terms containing the component "cryo" to the temperature range from 120 K (−153°C) to close to absolute zero (−273°C). Temperatures from 0°C to −153°C are referred to as refrigeration technique, in disagreement with terms accepted in the medical literature.

To provide expert choice of promising trends in cryogenic technique for medical purposes and to reduce the cost of design work, it seems reasonable to review the relevant literature to determine the most appropriate design that would be consistent with the technological capabilities and personnel skill of potential manufacturers, while taking into consideration the present economic status of defense industry facilities.

Medical cryogenic devices can be based on open-circuit, closed-circuit, or semiconductor cooling systems, solid refrigerants, sublimation cryogenic accumulators, etc.

The cooling efficiency of the device depends on its system. Condensed gases or gaseous mixtures can be used as cryogenic agents. The choice of a particular cooling system and cryogenic agent depends on the specific medical requirements.

Some existing cryogenic devices require only minor modification of a few units to fit medical purposes. For example, the Krioélectronika-1 domestic cryogenic device should be supplied with a more powerful and sound-proof compressor. However, sound-proofing of compressors and reduction of their energy consumption proved to be unresolved problems for many industries, including the pharmaceutical industry, where artificial cooling is used for preparing and storing drugs.

Design of domestic medical cryogenic devices falls into two basic groups [1, 2, 5]: in one case a refrigerant-containing vessel is connected to the working part of the device by a transfer line, and in the other a refrigerant-containing vessel is an integral part of the device. Liquid nitrogen stored in Dewar flasks is routinely used as a cryogenic agent, the capacity of the flask particularly determining the duration of continuous operation of the device. Liquid nitrogen is chosen as a cryogenic agent both for economical reasons (it is less expensive than other cryogenic agents) and for safety.

Consider as an example one such device, the Kriolor-Zhl apparatus developed at the Scientific-Manufacturing Association "Orion" in 1976. The Ministry of Health of the USSR approved its application in medical practice, but serial production of the device has not been established. The Kriolor-Zhl apparatus is designed for otorhinolaryngology, and it could be used for cryotonsillectomy (Fig. 1). Liquid nitrogen from the vessel (4) under working pressure (A) is applied to the operation field through a removable nozzle (1). This design allows temperatures from −150°C to −180°C to be obtained on the working part of the device (under zero thermal load). The cryogenic agent transfer is regulated by a manual pressure regulator (3), and gaseous nitrogen is transferred through a transfer line. A heat-insulating handle protects the surgeon's hand from cooling.

Method for low-temperature treatment and working temperature depend on the capability of the refrigerating device and its specific application.

According to [2], for example, optimum working temperature for cryogenic extractors is from −30°C to −50°C. Experiments of L. Kh. Shotter (1977) showed the eyelid average rupture strength to be 18 g, while a frozen cryogenic extractor...
Fig. 1. Schematic diagram of the Kriolor-Zh1 apparatus: 1) removable nozzle; 2) high pressure receiver; 3) manual pressure regulator; 4) Dewar flask with liquid nitrogen; 5) handle; 6) low pressure receiver; 7) reverse flow transfer line; A) working chamber with gaseous nitrogen under working pressure.

grips an eye lens with a force reaching 140-150 gf. Experienced surgeons extract the lens by gentle rocking for 5-8 sec with extracting force of not more than 2-4 gf. Otherwise, if a lens is extracted in one stroke, the eyeball membrane can be damaged because of the high adhesion force between the eyeball and extractor (40-50 gf).

Therefore, the efficiency of the surgeon's and therapist's work could be improved by providing them with special cryogenic devices for special purpose with working parameters variable over a wide range.

An algorithm can be composed for the preliminary requirements which should be met by the cryogenic devices used in clinical practice of ophthalmology and general surgery:

- minimum weight and dimensions, and simple design combined with high reliability over the whole service life;
- the ability to regulate the working regimes;
- time interval for reaching minimum temperature regime;
- cooling rate (change in cooling temperature with time);
- stability of cooling temperature;
- duration of continuous operation (single filling);
- ability of the device to implement various methods of cryogenic therapy, surgery, etc.

On reviewing the literature and patent documentation on the subject, it may be concluded that medical application of restriction microcoolers opens up promising opportunities in microsurgery. The microcoolers were formerly used mainly in defense-oriented microelectronics [1] rather than in domestic medical devices.

Operation of restriction microcoolers (cryogenic microrefrigerators) is based on the Joule—Thomson effect (gas temperature decrease during its passage through hydraulic resistance, i.e., a restrictor). Restriction microcoolers can contain either a closed-circuit loop with compressor (Fig. 2) or an open-circuit loop with a gas cylinder as the source of compressed gas (Fig. 3). The following condensed cryogenic agents with positive throttle-expansion effect at ambient temperature are used in restriction microcoolers: carbon dioxide, air, nitrogen, nitrous oxide, and some others. Basic parameters of gases used in restriction microcoolers [3] are given in Table 1.

Restriction refrigerators compare favorably with cooling devices of other types by simple design, low mass, small dimensions, and short start-up time (from fractions of a second to several minutes), but they have low thermodynamic efficiency (as a result of irreversible gas expansion) and high gas consumption. High degree of purification of the cryogenic agent should be provided for when developing the microcooing devices; the necessary degree of purification can be achieved using zeolite filters and "tablet"-filters. Use of zeolite inlet gas filters would provide reliable operation of both projected domestic microcooling apparatuses and currently used foreign devices.