A CRYOSURGICAL SYSTEM FOR RETINAL DETACHMENTS AND TUMOURS*

S. P. AMOILS, F.R.C.S., *Johannesburg*

Cryogenic surgery, the use of cold for biological and surgical purposes, is not new. For more than 100 years there have been many who have sensed the possible usefulness of cold as a surgical tool.[1-4] During the past 20 years there have been classic advances in cryobiology as exemplified by the work of Luyet and Gehenio,[5] Kreyberg,[6] Rey,[7] Smith,[8] Parkes[9] and others who have clarified the effect of cold on biological tissue.

Extreme cold may serve as a valuable physical agent in surgery. It fulfils many of the criteria for an ideal method of destroying tissue. These criteria are: reversibility, constant reproducibility, haemostasis, sharp delimitation, flexibility, safety, simplicity and rapidity of application.[10]

Scholar[11] in 1910 reported freezing the sclera of a rabbit with carbon dioxide snow, thus producing an adhesive choroiditis with the formation of a chorioretinal scar. Bietti,[12] using dry ice and alcohol, attempted to determine the temperature within the eye at various distances from the applicator. In 1935 Deutschmann[13] used dry ice clinically to produce an adhesive chorioretinitis in cases of retinal detachment, with good results.

Due to the wor kof Lincoff *et al.*,[14] Amoils,[15] Shea and Dickson[16] and McPherson,[17] the use of cryosurgery in prophylactic treatment of retinal breaks and retinal detachment is now firmly established. Many basic advantages are inherent in this method of producing a chorioretinal bond.[18-21]

The main problem has been the bulky and unreliable instrumentation required to produce localized discrete areas of cryocongelation. It is only due to the introduction of a practical cryosurgical system[22] that the cryosurgical management of retinal disease is becoming universally adopted.

THE INSTRUMENT

Design Criteria for a Retinal Cryoprobe

In designing a retinal cryoprobe, the following criteria were borne in mind:

1. A minimum tip temperature of between −60°C and −70°C must be maintained when the probe tip is in contact with any portion of the eye, even when the probe is surrounded by blood.
2. Absolute reduplication of the lesions necessitates a constant freezing capacity with each application.
3. It is essential that the instrument be applied to the eye at ambient (room) temperature.
4. A freezing rate in excess of 50°C/second is desirable.
5. Automatic defrosting is required so that there is no manipulation of a finger lever while the probe is still frozen to the eye.
6. A thawing rate of less than 3 seconds is necessary.
7. Tip temperature should be variable between −70°C and −40°C.
8. A small, easily handled probe is essential.
9. A thin, coaxial, flexible cable with no cooling or atmospheric condensation on the exhaust line is desirable.
10. The contact area of the probe tip should be hemispherical in shape, and the diameter should not exceed 2·5 mm.
11. There should be no perceptible cooling of the probe handle.
12. No slow drop in coolant pressure should occur during surgery, as this causes loss of cooling efficiency. A large gas tank which can be used for at least 20 retina operations is thus required.
13. The same basic unit should be usable for cryo-extraction of cataracts.

Retinal Cryopencils

The cryopencils work on the Joule-Thomson principle, in which a sudden expansion of a compressed gas produces a rapid drop in temperature. The basic design of such a cryoprobe was described in 1965.[22,23] The first probes were built in collaboration with Prof. S. Smoleniec and Mr T. O'Duggan of the Department of Mechanical Engineering, University of the Witwatersrand. Subsequent development was done at the Massachusetts Eye and Ear Infirmary and Retina Foundation, Boston, USA.

Carbon dioxide under pressure is fed through the inner of two concentric tubes to a micro-orifice, where it expands to atmospheric pressure and impinges on the inner wall of the probe tip. The expansion of the gas results in a drop of temperature to −79·5°C, and the high-velocity flow ensures good heat transfer between the gas and the tip. Thus probe-tip temperatures of between −60°C and −70°C are achieved and maintained when the retinal pencil is in contact with tissue or fluid. Coupled with this is a remarkable cooling rate of 75°C/second.

After expansion, the gas, now at atmospheric pressure, is exhausted through the annulus formed between the concentric tubes. It then returns to the control unit for dispersion.

Unit Construction

A pressure-regulating valve is mounted on the cylinder which contains the compressed carbon dioxide gas. This valve reduces the maximum pressure to 750 lb./sq.in. to ensure perfect operational stability, and allows probe temperature control by means of pressure variation. The gas is then piped to the control console through a screw connector (1) via a flexible armoured hose. In the console (Figs. 1, 2 and 4) the gas passes through a three-way solenoid valve (2) fitted with a silencer (3), which is controlled by a foot-switch.

The probe (Fig. 3) has a screw-in jack plug which fits into the console socket (4) and conducts the gas along a very thin high-pressure line (5) to a stainless-steel capillary-bore tube (6) with a micro-orifice (7) at its tip. The gas expands through this micro-orifice and cools the stainless-steel plate fitted with a thin silver cap (8) which makes contact with the ocular tissues. It is then conducted back via a stainless-steel tubular body (9) to a stainless-steel exhaust tube (10) and then via a coaxial silicone exhaust line (11) back to the console where it exhausts into the atmosphere.

*Date received: 25 July 1968.

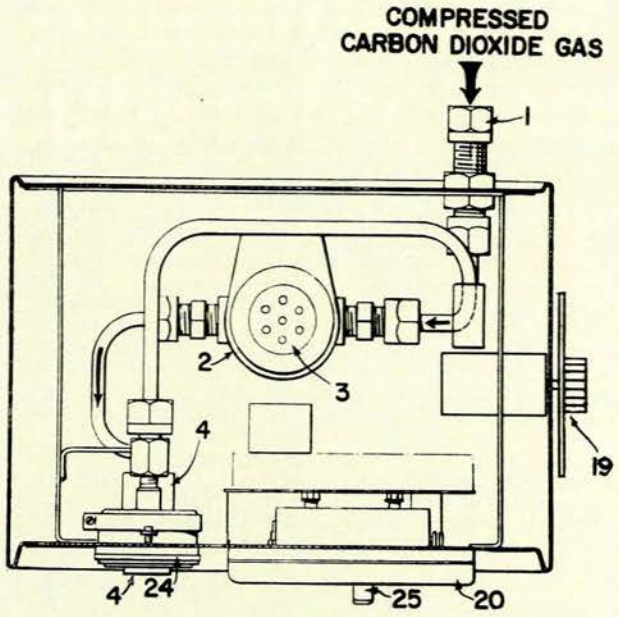

Fig. 1. Schematic view of interior of console from above.

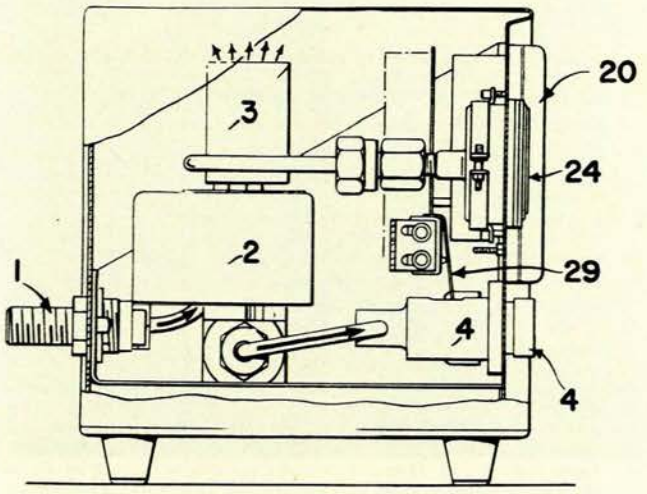

Fig. 2. Schematic view of console interior from the side.

An elastic safety sleeve (12) covers two large holes in the exhaust tube (13) and will allow escape of the gas through a safety vent (14), should the exhaust line inadvertently be clamped. It is set to release at 5 lb./sq.in., so that this is the highest pressure the outer casing need ever bear (8, 9, 10). This assures safety under all operational conditions.

A large heater coil (15), fed by 2 heater leads (16), is placed round the tapered silver ferrule (17) to ensure smooth operation and rapid defrosting. This heater keeps the probe body warm during the freezing cycle and is automatically kept switched on for 4 seconds after the gas flow has been interrupted. This is effected by a solid-state delay circuit incorporated in the console. An amber light (18) on the console face indicates that the heater is operational. An adjustable delay, controlled by a rheostat (19), can be incorporated. The delay time can then be varied from 0 to 10 seconds.

A thermocouple is placed in the tip to give the exact temperature of the contact point, and is connected to the temperature indicator (20) in the console by leads (21). The entire probe assembly is enclosed in an outer protective nylon sleeve (22) and a front end part (23).

A pressure gauge (24) is mounted on the console front panel (Fig. 4). The master switch (25) and operating light (26) are located adjacent to the foot-pedal socket (27) and the thermocouple-heater socket (28). A micro-switch prevents any gas flow unless the plug-in jack is screwed in completely.

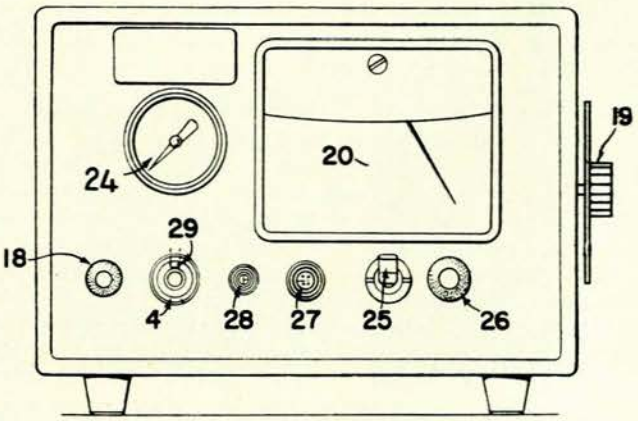

Fig. 4. Front panel of console.

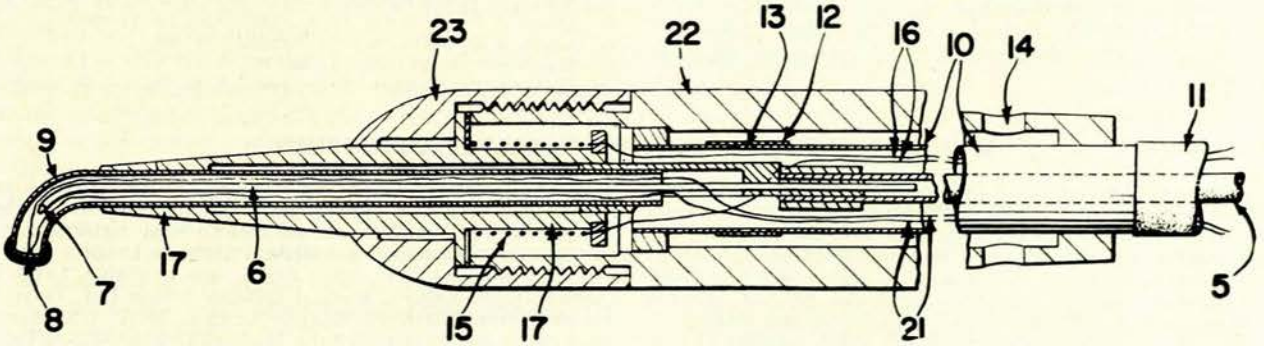

Fig. 3. Longitudinal section through retinal cryopencil.

COMMENT

This system of cryosurgical instrumentation has many advantages. The apparatus need not be large and the gaseous expansion principle gives very consistent and reliable freezing. A rapid freezing rate is assured due to the high-velocity gas flow over the thermal contact plate, which is the extreme tip of the probe itself. The large and robust heater coil, built into the probe body, operates during the freezing cycle, thus preventing cooling of the probe body or connecting hoses.

Automatic rapid defrosting is assured, as the heater operates for 4 seconds after the freezing cycle has been interrupted. The surgeon is not required to manipulate a hand lever while the probe is still frozen to the sclera; such manipulation could crack the sclera, choroid and retina if any shear stress were induced.

The coolant is commercial carbon dioxide gas, and 30 - 50 detachment procedures can be performed with one cylinder of gas.

In order to obtain rapid coverage of a scleral bed, only one or two lesions need to be monitored, since the extent of freezing is so consistent. There is no need to freeze sclera with the naked shaft of the probe to speed up the procedure. This latter action might result in over-freezing of the pigment epithelium, causing excessive pigment release and submacular pigmentation. The duration of freezing is measured from the moment of foot-switch depression, and there is no need to watch the temperature gauge. A coaxial cable is used to incorporate the gas delivery line inside the exhaust line.

The probe temperature can be varied from −70°C to −40°C by adjusting the pressure-reducing valve to values between 750 and 650 lb./sq.in.

Surgical Results

To date, 800 operations have been performed over the last 2 years at the Massachusetts Eye and Ear Infirmary with this apparatus. These include cryo-applications to full- or partial-thickness sclera in both primary retinal detachment procedures and re-operations. Transconjunctival prophylactic treatment of retinal breaks and lattice degeneration was also carried out.

Tumours such as retinoblastoma and retinal angiomata[24] were treated, using a triple freeze-thaw technique, to include the entire tumour, with excellent results. All areas of the tumour and a rim of adjacent normal tissue were frozen for at least one minute, and after slow thawing the procedure was repeated twice.

Cyclocryocongelation, using a 4-mm. diameter probe and a triple freeze-thaw method, and the effect of multiple freeze-thaw cycles on non-functional glaucoma drainage blebs show promise.

Because of its simplicity, low operational cost and reliability, this system of cryosurgical instrumentation has proved very satisfactory. To date, more than 500 such units have been in constant use for up to 2 years throughout the world, both for the treatment of retinal disease and for the cryo-extraction of cataracts.

SUMMARY

The Joule-Thomson principle with carbon dioxide gas is utilized in the construction of a cryosurgical system for the treatment of retinal disease. Tip temperatures of between −60°C and −70°C are maintained anywhere on the globe, and absolute reduplication of lesions can be produced by the constant freezing capacity inherent in the system. Cooling rates in excess of 75°C/second with an automatic defrosting system and a thawing time of less than 3 seconds are generated in a small, easily handled probe. The probe contact diameter is only 2·5 mm. No drop of cooling efficiency occurs during surgery, as a constant gas pressure is maintained. Probe temperature can be regulated between −70°C and −40°C if so desired. This system has proved of very great value in the treatment of retinal breaks with and without detachments, as well as in the treatment of retinal tumours.

This work was supported in part by USPH Grant No. NB 05691 from the National Institute of Neurological Diseases and Blindness, National Institutes of Health, and the South African Council for Scientific and Industrial Research.

REFERENCES

1. Arnott, J. B. (1951): *On Treatment of Cancer by Regulated Application of an Anaesthetic Temperature*. London: J. & A. Churchill.
2. Balthasar, K. L. (1957): Dtsch. Z. Nervenheilk, **176**, 173.
3. Poppe, J. K. (1942): Surgery, **11**, 460.
4. Zimmerman, H. M. and Dussorde Barrine, J. E. (1935): Arch. Neurol. (Chic.), **33**, 123.
5. Luyet, B. J. and Gehenio, P. M. (1940): *Life and Death at Low Temperatures*, p. 500. Normandie, Missouri: Biodynamica.
6. Kreyberg, L. (1957): Proc. Roy. Soc. B, **147**, 546.
7. Rey, J. R. (1959): Techn. hosp., **141**, 33.
8. Smith, A. U. (1957): Proc. Roy. Soc. B, **147**, 533.
9. Parkes, A. S. (1957): *Ibid.*, **147**, 424.
10. Cooper, I. S. (1964): Cryobiology, **1**, 44.
11. Scholar, F. (1935): Klin. Mbl. Augenheilk., **94**, 349.
12. Bietti, G. B. (1933): Boll. Oculist., **12**, 1247.
13. Deutschmann, R. (1935): Klin. Mbl. Augenheilk., **94**, 349.
14. Lincoff, H. J., McLean, J. M. and Nano, H. (1964): Trans. Amer. Acad. Ophthal. Otolaryng., **68**, 412.
15. Amoils, S. P. (1966): Proc. Roy. Soc. Med., **59**, 1056.
16. Shea, M. and Dickson, D. (1966): Canad. J. Ophthal., **1**, 138.
17. McPherson, A., ed. (1968): *New and Controversial Aspects of Retinal Detachment Surgery*, chapt. 15, pp. 186-201. New York: Hoeber.
18. Curtin, V. J., Fuzino, T. and Norton, E. W. D. (1966): Arch. Ophthal., **75**, 674.
19. Kirkconell, W. S. and Rubin, M. L. (1965): *Ibid.*, **74**, 399.
20. Amoils, S. P. and Haining, W. M. (1969): *Ibid.* (in the press).
21. Amoils, S. P. and Honey, D. P. (1969): *Ibid.* (in the press).
22. Amoils, S. P. (1965): Amer. J. Ophthal., **60**, 846.
23. *Idem* (1966): S. Afr. Med. J., **40**, 797.
24. Amoils, S. P. and Smith, T. R. (1969): Arch. Ophthal. (in the press).