United States Patent

Bryne

[15] 3,651,813

[45] Mar. 28, 1972

[54] CRYOSURGICAL DELIVERY AND APPLICATION OF LIQUEFIED GAS COOLANT

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[73] Assignee: **Brymill Corp.**, Vernon, Conn.

[22] Filed: **Oct. 8, 1969**

[21] Appl. No.: **870,399**

Related U.S. Application Data

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[52] **U.S. Cl.**.....**128/303.1**, 128/173

[51] **Int. Cl.**.....**A61b 17/36**, A61m 11/04

[58] **Field of Search**.....128/303.1, 173 R

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[57] **ABSTRACT**

A self-contained, mobile, compact, untethered cryosurgical instrument is provided in which liquefied gas coolant in a container with heat conducting walls is pressurized by ambient temperature for delivery to a lesion to be necrotized. The coolant is discharged in a controlled spray in one embodiment; the delivery tube includes a vent tube coaxially spaced therefrom in other embodiments. Freezing to tissue is overcome with "Teflon" coatings.

11 Claims, 10 Drawing Figures

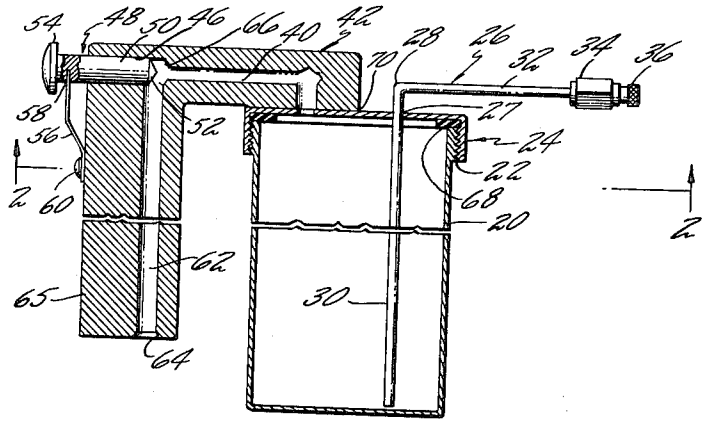


FIG. 1

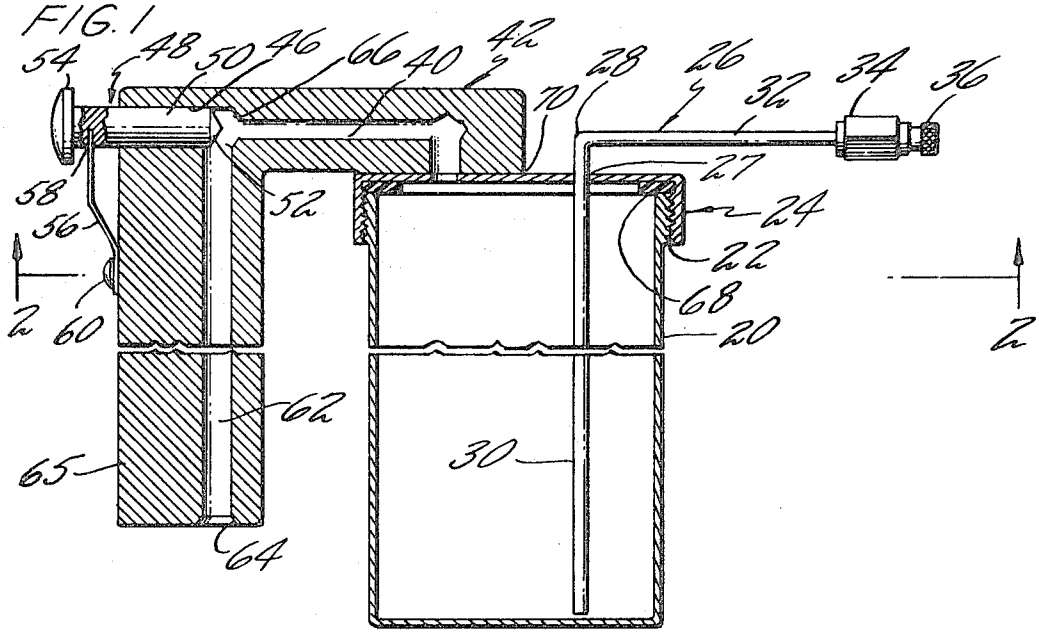


FIG. 2

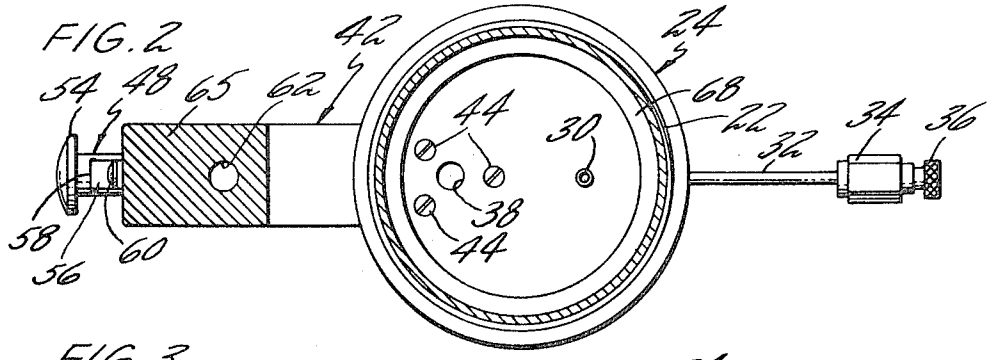
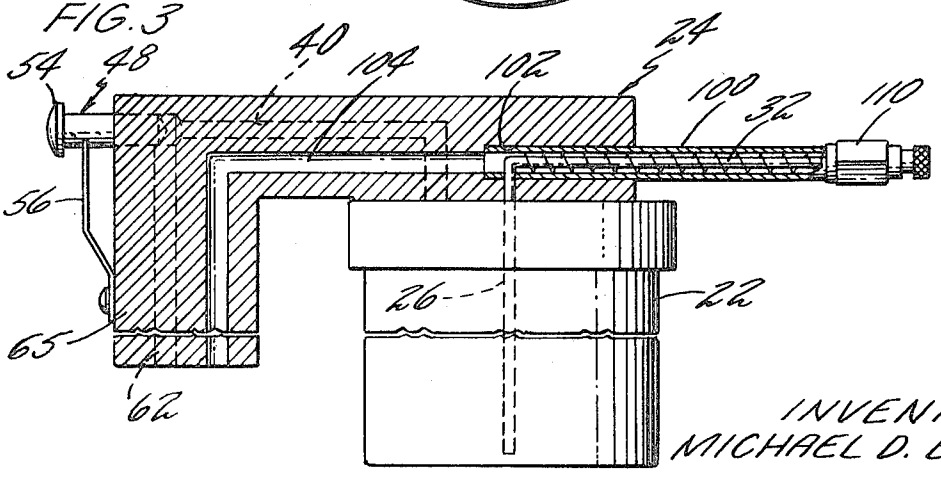


FIG. 3



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FIG. 4

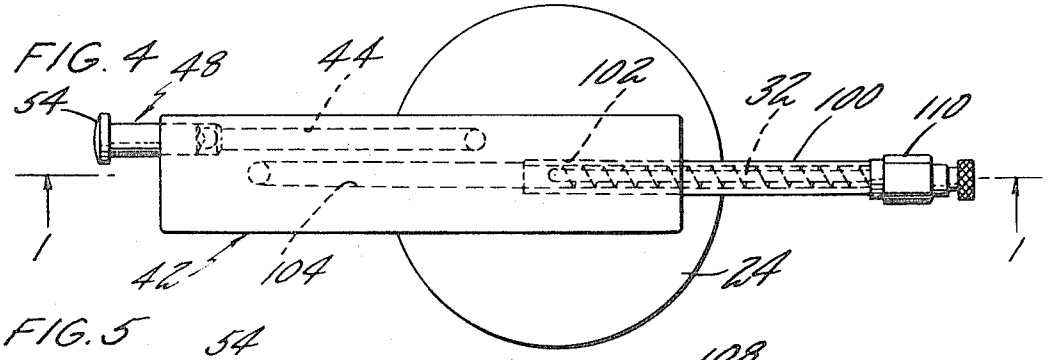


FIG. 5

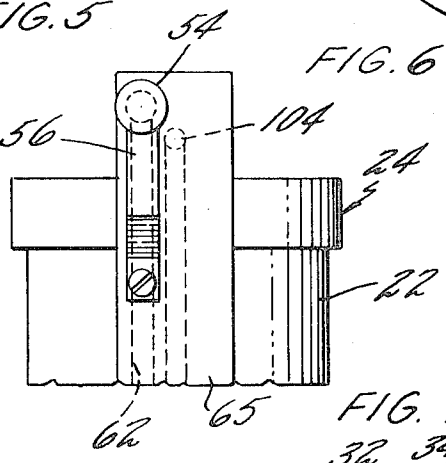


FIG. 6

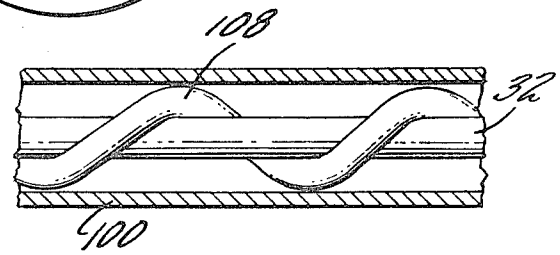


FIG. 7

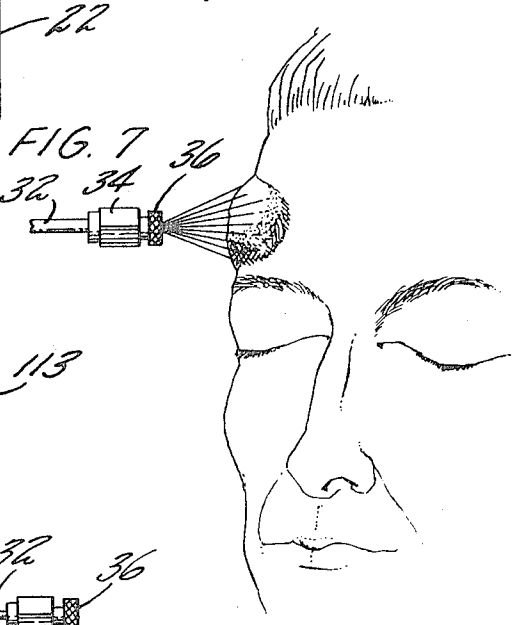


FIG. 9

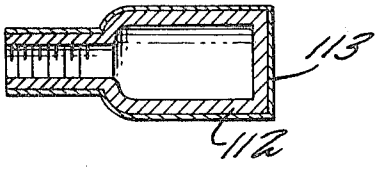
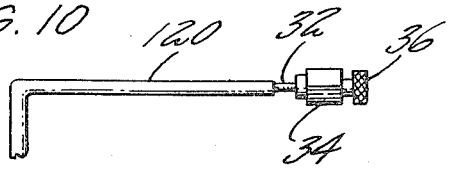


FIG. 10



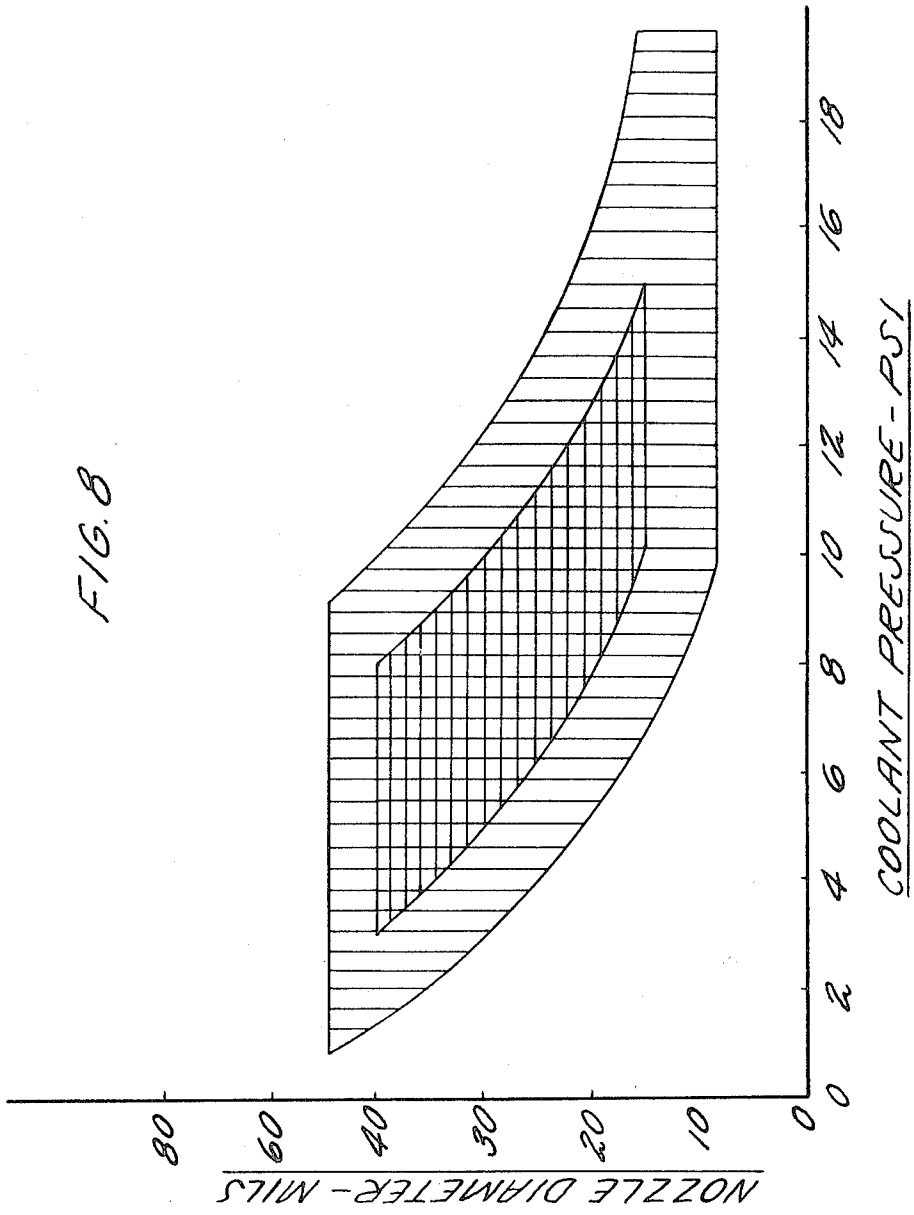

NOZZLE DIAMETER - MILS
80
60
40
30
20
10
0
2
4
6
8
10
12
14
16
18
COOLANT PRESSURE - PSI

FIG. 8

CRYOSURGICAL DELIVERY AND APPLICATION OF LIQUEFIED GAS COOLANT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a division of my copending application Ser. No. 683,351, filed on Nov. 15, 1967.

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to cryosurgery, and more particularly to the delivery and application of liquefied gas coolant to living tissue in order to necrotize the same.

2. Description of the Prior Art

It has long been known in the prior art to use liquefied gas (such as helium, nitrogen, oxygen, air, freon, zenon, carbon dioxide, etc.) to freeze healthy or diseased tissue, and thereby necrotize the tissue. For instance, one well-known use of liquefied gas in cryosurgery is the removal of lesions, both on the skin or internally. Usually, the object is to remove the lesion by destroying the tissue; in other cases, the object is the destruction of the tissue while maintaining adjacent portions of the tissue structure in place, such as in the walls of vital organs. As used herein, lesion means both diseased and healthy tissue which is to be frozen; the destruction of lesions includes removal of healthy tissue for cosmetic purposes, and killing of tissues as a complementary modality to surgical procedures.

Heretofore, the liquefied gas has been delivered through an insulated tube to an applicator. The delivery of the liquid to the applicator has been accomplished by using pressure within the reservoir containing the liquid to force the liquid out of the reservoir. The creation of pressure within the reservoir has been achieved in several different ways. A first and perhaps most widely used method of creating pressure in a liquefied gas container is to place an electric heater within the reservoir of the liquid, thereby raising the temperature of the liquid to its boiling point so that a gas pressure is created. The liquefied gas, as it vaporizes, creates sufficient pressure to force the liquid out of the reservoir. A different type device utilizes external gas pressure (such as a separate tank of compressed dry air, or other suitable source of compressed gas) to force the liquefied gas coolant out of the reservoir.

All of the before described devices require connections either to a source of fluid pressure or to electrical energy, or on the other hand, are bulky due to the need of a heat exchanger or batteries. Additionally, the need for adjunct equipment makes such devices expensive, complex and cumbersome. Such devices are not well adapted to portable office use for small dermatological applications, nor for certain internal applications which involve small spaces or tortuous routes. Furthermore, cumbersome devices of the type described tend to absorb too much space in already overcrowded operating rooms.

Another characteristic of previously known cryosurgical devices is the need to have a long delivery tube which must be insulated in order to achieve an adequate percentage of liquid nitrogen delivered to the application-end (the distal end) of the device. The insulated delivery tubes which have been found to be practical in the prior art usually comprise coaxial evacuated Bellows-type tubing, which is usually comprised of stainless steel. Therefore, these tubes are quite stiff and offer substantial resistance in mobility to the surgeon using the device. It can readily be understood that it is essential that the surgeon be able to position the device very accurately in order to freeze the selected area without freezing adjacent areas. For instance, a lesion on an eyelid presents a near probability of doing great damage to the eye unless precision application is possible. Therefore, the positioning of the equipment relative to the patient is critical. Moreover, many lesions are of a very complex shape, and must be addressed from different angles in order to adequately treat all of the portions thereof. Furthermore, anatomical irregularities of the body relative to the positioning of the lesion make mobility of instrumentation critical. It is therefore apparent that the stiff delivery tubes

known to the prior art hinder the surgical usage of the equipment, and render it difficult to provide adequate lesion removal. Certain other devices have attempted to overcome stiffness by using flexible plastic tubing; however, at temperatures capable of freezing human tissue, these devices become stiffer than the evacuated metallic types, and are therefore relatively useless.

So great is the problem with insulated delivery tubes that various devices have been composed for overcoming the need for such delivery tubes. One such device provides liquid nitrogen in a probe handle, and utilizes an external source of compressed gas which will not freeze much above liquid nitrogen temperature to be cooled by the nitrogen and mixed with nitrogen gas so as to provide a cold gas application to the tube and applicator tip which is cooled sufficiently so that when the applicator tip is applied to a lesion, it will freeze it. However this device, though providing a flexible tube, is nonetheless tethered and the device itself is so large, relative to the amount of nitrogen in it, that its application is limited to the removal of extremely small lesions. Furthermore, the device is so complex as to render it extremely difficult to construct, and it may also have a tendency for unreliable operation.

A different problem in the cryosurgical freezing of tissue is a need for good heat exchange. Most devices known to the prior art utilize liquid nitrogen to cool a probe, and the probe in turn is applied to the lesion. This has taken a variety of forms, and in the more sophisticated cryosurgical apparatus known to the prior art, the probe applicator tip is sprayed with liquid nitrogen fed through the inner tube of a coaxial tube assembly, the outer tube venting the nitrogen gas away from the area of the applicator tip.

A severe limitation on devices of the prior art is that the heat removing applicator has been rigid and unable to conform to the contours of living tissue. Additionally, the amount of liquid coolant required to cool an applicator is so great that large lesions could not be accommodated except with huge, cumbersome apparatus. Further, large lesions require numerous applications of prior art devices in order to cover the area with an adequate degree of freezing. Thus, the prior art is inadequate in terms of application means and techniques in cryosurgery.

The coaxial systems of the prior art including liquid feed, gas vent lines and vacuum insulation are impossible to manufacture below a given size. As the diameter of the coaxial tubing is reduced, the ability to destroy tissue is markedly decreased. Therefore, such devices are extremely limited in the nature and size of lesions that can be removed thereby. It is therefore apparent that the use of probe-type cryosurgical instruments known to the prior art is severely limited in cases where the tissue that is to be destroyed is enclosed within a body cavity, such as the larynx, pharynx, bladders, bronchi or other locales where the cryosurgical instrument must be used in conjunction with other instrumentation, such as a laryngoscope, a broncoscope, or a cystoscope.

A related problem is the need to provide electrical heating to the probe tip in any case where wet tissue (which includes most nondermatological applications of the device) is being frozen. This is required because the probe tip actually freezes to the tissue due to the formation of ice at the surface of the tissue which is being destroyed. In order to remove the device from the tissue it is necessary to melt the ice which binds the device to the tissue. Therefore, such devices require not only a coaxial combined feed and vent tube assembly, but also require the presence of an electrical heater and the electrical conducting lines in the probe tip itself. This not only further complicates the apparatus, but requires an increase in size such that all of the problems described hereinbefore are further compounded.

SUMMARY OF THE INVENTION

Objects of the invention include:

Application of substantially liquid, nonsplashing liquefied gas coolant to living tissue for the necrotization thereof;

Provision of means for confining to a localized area, liquefied gas coolant in the application thereof to living tissue;

Provision of cryosurgical applicators capable of insertion into, and routing adjacent to, living tissue without the freezing of or adherence to the tissue;

Cryosurgical destruction of wet tissue without the freezing of instruments thereto;

Provision of a cryosurgical instrument capable of implementation with application tubes as small as 10 thousandths of an inch in diameter.

In accordance with the present invention, there is provided a cryosurgical application and delivery instrument having a coating of nonsticking fluorocarbon, such as "Teflon," which substantially eliminates sticking of the instrument to tissue with which it comes in contact.

In accordance further with the present invention, liquefied gas coolant is delivered in the liquid phase to a nozzle, the diameter of which is chosen in conjunction with the pressure of the liquefied gas coolant source so as to atomize the coolant as it leaves the nozzle, the coolant therefrom partially vaporizing so that it neither splashes nor obscures the field of application by over vaporization. A further aspect of the invention is that by delivering liquid, rather than vapor, to the lesion, a much greater depth and area of freezing can be achieved, and a given amount of freezing takes less time while still maintaining precise control of the affected tissue.

The forgoing and other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of preferred embodiments thereof as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially sectioned, broken away side elevation view of one embodiment of the present invention adapted for unvented application of cryosurgical coolant;

FIG. 2 is a sectional view taken along the line 2—2 in FIG. 1;

FIG. 3 is a partially sectioned, broken away side elevation view of another embodiment of the present invention including venting of vapor from the coolant application area;

FIG. 4 is a top plan view of the embodiment OF FIG. 3;

FIG. 5 is a partially broken away end elevation view of the embodiment of FIGS. 3 and 4;

FIG. 6 is a partial sectioned elevation view of the detail of coaxial delivery and vent tubes in accordance with the present invention;

FIG. 7 is a pictorial illustration of the application of atomized coolant utilizing the embodiment of FIGS. 1 and 2;

FIG. 8 is a chart illustrating the ranges of pressures which will deliver liquid nitrogen coolant with neither spurting nor splashing for various sized nozzles;

FIG. 9 is a sectioned elevation view of an applicator tip known to the art;

and FIG. 10 is a side elevation illustrating coating of the delivery tube.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, one embodiment of a cryosurgical liquefied gas coolant delivery and application system in accordance with the present invention comprises a container 20 within which the liquefied gas coolant is placed. The container 20 is threaded (22) so as to releasably engage a cover assembly 24, which has matching threads. A delivery tube 26, fitted through a hole 27 in the cover assembly 24, has a bend 28 therein so as to provide an external, substantially horizontal portion 32. At the external end of the tube 26 there is a fitting 34, which may comprise any suitable compression or flared fitting known to the art, a number of which are commercially available. This fitting may have any suitable application means 36 attached thereto; in accordance with one aspect of the present invention, the application means 36 comprises a nozzle formed by drilling a suitable hole (as described with respect to FIGS. 7 and 8 hereinafter) in a blind cap or plug, to provide a controlled spray.

The cover assembly 24 has a pressure control vent hole 38 therein, which provides gaseous communication with a passage 40 in a handle assembly 42. The handle assembly 42 is affixed to the cover assembly 24 by any suitable means such as screws 44 (see also FIG. 2). The passage 40 joins and is axially aligned with a further passage of a larger diameter 46. Within the passage 46 is a passage closure means 48 which may comprise a cylindrical barrel portion 50 being conical at one end 52, and having a cap portion 54 at the other end. The closure means 48 may be resiliently urged to the left in FIG. 1 by any suitable means such as a spring 56, one end of which is inserted in a hole 58 within the closure means 48. The other end of the spring 56 may be fastened to the handle assembly 42 by a screw 60. With the closure withdrawn to the left (as seen in FIG. 1), the passage 46 is in communication with a passage 62 which passes any gas therein out of a port 64 to atmosphere.

In operation, the container 20 is filled with liquefied gas coolant, such as liquid nitrogen, to a suitable level. The container 20 may consist of metal or glass, or other suitable material capable of conducting heat from ambient atmosphere to the liquid therein. This causes some of the liquid to boil, resulting in the generation of gas. So long as the closure means 48 is left in its rest position (to the left, as shown in FIG. 1), the gas is vented to atmosphere through the passages 40, 46, 62. However, when delivery of coolant to tissue is desired, the nozzle 36 may be directed by the surgeon (holding the instrument by the main shank portion 65 of the handle assembly 42) toward the tissue, and the surgeon may push the closure means 48 (to the right in FIG. 1), thus causing the conical end 52 to sealably engage a chamfered surface 66 at the intersection of the passages 40, 46, 62. It has been found that relatively light force applied by the surgeon's thumb to the button end 54 of the closure means 48 will positively block the vent passages 40, 46, so that pressure will build up within the container 20. This pressure forces liquid coolant into the delivery tube 26 and through the nozzle 36.

In order to prevent the loss of pressure within the container 20, and to prevent vapor from escaping about the cap and handle assemblies 24, 42, suitable seals are provided. A gasket 68 (FIGS. 1 and 2) provides a seal between the container 20 and the cap assembly 24. The gasket 68 may be fitted tightly into the cap assembly 24 as is well known in the art. It may be of any suitable material, depending on the temperature of the liquid coolant chosen; cotton, cork and other natural products (except rubber) as well as silicon rubber and "Teflon" are suitable materials even at liquid nitrogen temperatures.

The delivery tube 26 is preferably welded to the hole 17 so as to seal the joint as well as to give structural support to the tube 26. However, other modes of attachment and sealing may be utilized.

To provide a seal at the joinder 70 of the handle assembly 42 with the cap assembly 24, some modicum of sealant is required. For instance, a thin sheet of "Teflon," coated on each side with silicon (vacuum) grease, works quite well. Other means may be used to suit any design criteria in accordance with the skill of the art.

The embodiment of the invention thus described with respect to FIGS. 1 and 2 comprises a completely self-contained, untethered cryosurgical instrument. It can be directed toward a field of application from many angles without requiring repositioning of the subject, or the rolling around the room of a console (as is true of prior devices). It can, by suitable choice of length of delivery tube 32, be used to reach into small cavities, or by bending the delivery tube 32 (which is not possible with prior devices), be used to reach around corners or traverse tortuous routes.

A second embodiment of the present invention is adapted for use where venting of coolant vapor from the point of application is required. As seen in FIGS. 3–5, this is identical to the

embodiment of FIGS. 1 and 2 except that a vent tube 100 is provided coaxially with and externally of the delivery tube portion 32. The vent tube 100 may be press-fit into a passage 102 in the handle assembly 42, with an extension 104 of the passage 102 venting the tube 100 to atmosphere through the main shank portion 65 of the handle assembly 42. Note that the vent passages 62 (FIGS. 1 and 2) and 104 (FIGS. 3–5) vent cold vapor away from the treatment area, and downwardly so as not to injure the patient, nor to injure nor obscure the vision of the surgeon.

The delivery tube 26 may be assembled to the vent tube 100 by slotting the vent tube 100 at the bottom thereof to the left of the delivery tube portion 30 (as seen in FIG. 3). The tube 100 may thereafter be welded shut, or may remain slotted, since the tube 26 and the handle assembly 42 are sealed with respect to the cap assembly 24, and no leakage will take place therebetween, as described hereinbefore with respect to FIGS. 1 and 2.

The apparatus of FIGS. 3–6 may have a fitting 110 thereon so as to permit connecting chambers of the type described and claimed in my prior copending application, Ser. No. 886,260, filed Dec. 18, 1969, entitled CRYOGENIC APPLICATION CHAMBERS AND METHODS, attached thereto, or regular applicator tips 112 known to the prior art, of the type illustrated briefly in FIG. 9 may be threaded thereon. On the other hand, the invention may also be practiced by fastening any suitable application means to either or both of the tubes 32, 100, in any suitable way, or by forming the end of tube 100 in a suitable fashion as an applicator. The pertinent fact is that the invention may use a non-vented spray, or vented application of various types.

As seen in FIG. 6, very small coaxial tubes may be spaced from one another, according to the invention, by a thin thread or filament 108 wound about the inner tube 32. The thread or filament may be stranded, or may be a monofilament. It may be of any suitable material such as cotton (or other natural fiber) or suitable plastic or fluorocarbon. A poor heat conductor is preferably selected. This allows very close tolerances while maintaining independent spacing of the two tubes.

Referring now to FIGS. 7 and 8, the spraying of atomized coolant directly on a lesion is illustrated. This is quite advantageous when a large area is to be treated due to the high rate of heat exchange and the mobility of the application. It is also quite advantageous in treating lesions of irregular shape. One problem with this type of application which is overcome by the present invention is that splashing of the coolant can result in freezing of tissue other than that which it is desired to treat. Even if tissue surrounding the lesion is protected with cloth or other covering, a severely cold coolant (such as liquid nitrogen) may penetrate the covering as a liquid, or heat transfer may take place through a non-permeable covering. Additionally, splashing results in a dense and opaque spray or vapor which interferes with the surgeon's vision of the field of application. On the other hand, if the coolant leaves the nozzle as a vapor, it does not have a high cooling capacity, since it is at a temperature higher than the liquid phase which may exist at temperatures as low as −196° C. Additionally, the vapor phase does not absorb the heat of transfer as does the liquid when being vaporized by the heat of the tissue. Therefore, a very significant degradation of freezing capacity results when the coolant is ejected primarily as a vapor. Moreover, if the spray falls between liquid and vapor, spurting of liquid between periods of vapor may result. This makes it difficult for the surgeon to judge the isotherm profile achieved during an application period, and is otherwise difficult and less comfortable to work with.

These difficulties are overcome by maintaining substantially a liquid coolant at the nozzle, and by a proper relationship between the size of the nozzle and the pressure of the coolant. Of course, unless ideal insulation is used along the delivery tube, some heat will be absorbed by the coolant as it traverses the tube, and therefore some of the coolant will vaporize before it reaches the nozzle. However, by choice of delivery systems, the coolant delivered to a nozzle can be substantially in the liquid phase (90 percent liquid, for instance).

Referring to FIG. 8, for liquid nitrogen, it has been found that coolant pressures between 3 pounds and about 15 pounds are preferred. With coolant pressures in this range, nozzles between about 15 mils (0.015 inches) and 40 mils give best results in the relationship set forth in the horizontally hatched (doubly hatched) area of FIG. 8. For instance, with a 30 mil nozzle, the pressure should preferably be between slightly over 5 psi and 10 psi (above atmosphere). If a 9 psi system is being used, then a nozzle size between about 17 mils and 35 mils should preferably be chosen. However, the invention may also be practiced to advantage, under some conditions, utilizing a combination of nozzle size and pressure which may fall slightly outside of the horizontally hatched area in FIG. 8. In other words, combinations of pressure and nozzle size which fall within the vertically hatched area of FIG. 8 may be advantageous. This depends, at least in part, on the particular delivery system being utilized. Nonetheless, the pressures and ranges set forth in the double hatched area (horizontally hatched area) of FIG. 8 are preferred since these will provide a proper spray without spurting or splashing. Choice of too high a pressure for a given size nozzle results in splashing; too low a pressure results in eratic spurting of coolant. Similarly, too large a nozzle for a given pressure results in splashing and too small a nozzle results in spurting. Proper choice of pressure and nozzle gives a really wet spray which is soft (it will not splash) and which is uniform and steady (without spurting). It should be understood that practice of this aspect of the invention is predicated on there being a flow of significant liquid, rather than vapor, through the selected nozzle.

As before described, if the coolant is delivered to the nozzle in a highly vaporized fashion, then the pressure/nozzle characteristics described hereinbefore and shown in FIG. 8 do not apply. Additionally, since there is a higher vaporization of the coolant when a system is first turned on and the walls of the delivery tube are relatively warm, the optimum adjustment for any given application will vary somewhat between the time that the system is started and the time that it establishes a relatively uniform rate of vaporization of liquid being passed through the delivery tube to the application area. In other words, when the system is first started up, more pressure for a given size nozzle or a larger nozzle for a given pressure may be most advantageous. As the system cools down, however, so that a very high percentage of liquid is being delivered to the nozzle, then smaller diameter nozzle and/or a lower pressure may be utilized. In fact, best results are achieved by running the system for a short period of time prior to commencing the application of coolant to tissue, so that the preferred conditions of the present invention may obtain during the application of coolant to the tissue as a result of having a relatively uniform flow of substantially liquid coolant to the nozzle, with the nozzle and pressure chosen in accordance with the relationship herein so as to provide a suitable spray in accordance with the present invention.

A spray obtained by matching of a nozzle to a suitable pressure in accordance with the present invention permits uniform application of large amounts of liquid directly to the tissue. This in turn avoids problems of matching the contour of the tissue being frozen, and allows freezing of deep and/or wide areas.

The preferred relationship between the pressure of coolant and the size of the nozzle, for liquid nitrogen, can be expressed mathematically.

Taking:

d = the diameter of the nozzle in mils;

p = the pressure in the coolant delivery system in psi above atmospheric;

and P = a constant, such that $3 \leq P \leq 8$;

then:

$$d = 40 \times 10^{-.06(p-P)}$$

or

$$p = P - 17.6(\text{Log}_{10} d - 1.6)$$

Thus, given either a diameter or a pressure, one may mathematically determine a preferred pressure or diameter, respectively, by selecting a value of P between 3 and 8 and obtaining a result in accordance with the appropriate relationship expressed above. To find a range of values, the relationship may be calculated twice, once for the value of $P = 3$ and once for the value of $P = 8$ in the above expressions. It should be noted that selecting a value of 3 defines the lower left curved portion of the single-hatched, preferred area of FIG. 8, whereas selecting a value of 8 in either equation will define the upper right curved portion of the single-hatched, preferred area of FIG. 8.

I have found that cryosurgical instrumentation frequently sticks to adjacent tissue with which it comes in contact during an operation. To overcome this, the various parts which are likely to come into contact with the body of a patient may be covered or coated with a non-sticking fluorocarbon, such as "-Teflon." As seen in FIGS. 9 and 10, this may comprise a sheath 120 slipped over a portion of the instrument (such as tube portion 32), or it may comprise a coating 113 applied by any suitable one of a number of techniques known to the prior art to a portion of the instrument (such as an applicator 112). By this feature of the invention, wet tissue may freeze, but it will not stick to the fluorocarbon.

Although the invention has been shown and described with respect to preferred embodiments thereof, it should be understood by those skilled in the art that the foregoing and other changes and omissions in the form and detail thereof may be made therein without departing from the spirit and scope of the invention.

Having thus described typical embodiments of the invention, that which I claim as new and desire to secure by Letters Patent of the United States is:

1. A cryosurgical instrument adapted for use in the freezing of tissue, comprising:
a nozzle; and
a source of pressurized liquified cryogenic gas coolant having a boiling point of less than −100° C. including means for delivering said coolant in substantially liquid phase to said nozzle at a pressure relating inversely to the internal diameter of said nozzle to provide a spray of the coolant emerging from said nozzle in substantially the form of atomized liquid.

2. A cryosurgical instrument according to claim 1 wherein:
said coolant comprises nitrogen; and
the pressure (p) of said source is related to the diameter (d) of said nozzle, in mils, by $p = P - 17.6\ (\mathrm{Log}_{10}d - 1.6)$ for values of P between 1 psi and 9 psi above atmospheric pressure.

3. A cryosurgical instrument according to claim 1 wherein:
said coolant comprises nitrogen; and
the pressure of said source bears a relationship to the diameter of said nozzle included in the range of relationships substantially within the vertically hatched portion of FIG. 8.

4. A cryosurgical instrument according to claim 1 wherein:
said coolant comprises nitrogen; and
the pressure of said source bears a relationship to the diameter of said nozzle included in the range of relationships substantially within the horizontally hatched portion of FIG. 8.

5. A cryosurgical instrument adapted for use with liquid nitrogen and capable of delivering nitrogen in substantially the form of atomized liquid, comprising: a nozzle; and means for delivering nitrogen in substantially liquid form to said nozzle, said means delivering nitrogen to said nozzle at a pressure related to the internal diameter of said nozzle to provide a spray of nitrogen emerging from said nozzle in substantially the form of atomized liquid.

6. A cryosurgical instrument according to claim 5 wherein:
the internal diameter of said nozzle is between 50 mils and 8 mils; and
said means is adapted to deliver nitrogen to said nozzle at a pressure of from 1 psi to 30 psi above atmospheric.

7. A cryosurgical instrument according to claim 6 wherein:
said means delivers nitrogen to said nozzle at a pressure related to said diameter to provide a spray of nitrogen emerging from said nozzle in substantially the form of atomized liquid.

8. A cryosurgical instrument according to claim 5 wherein:
said means is adapted to deliver nitrogen at a pressure (p), in psi above atmospheric pressure, related to the diameter (d), in mils, of said nozzle by $p = P - 17.6\ (\mathrm{Log}_{10}d - 1.6)$ for values of P between one psi and nine psi above atmospheric pressure.

9. A cryosurgical instrument according to claim 5 wherein:
said means is adapted to deliver nitrogen to said nozzle at a pressure (p) of from 1 psi to 30 psi above atmospheric; and
the internal diameter (d) of said nozzle, in mils, is given by $d = 40 \times 10^{-0.06}\ (p - P)$ for value of P between 1 psi and 9 psi.

10. A cryosurgical instrument according to claim 5 wherein:
said means is adapted to deliver nitrogen to said nozzle at a pressure which bears a relationship to the internal diameter of said nozzle included in the range of relationships substantially within the vertically hatched portion of FIG. 8.

11. A cryosurgical instrument according to claim 5 wherein:
said means is adapted to deliver nitrogen to said nozzle at a pressure which bears a relationship to the internal diameter of said nozzle included in the range of relationships substantially within the horizontally hatched portion of FIG. 8.

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