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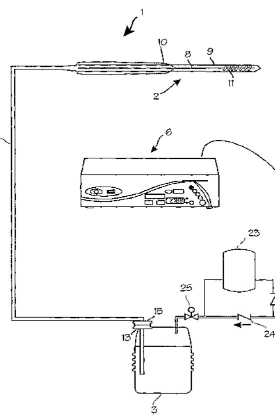
(54) Title: CRYOSURGICAL SYSTEM



(57) Abstract: A cryosurgical system using a low-pressure liquid nitrogen supply, which requires only .5 to 15 bar of pressure to provide adequate cooling power for treatment of typical breast lesions. The pressure may be provided by supplying lightly pressurized air into the dewar, by heating a small portion of the nitrogen in the dewar, or with a small low pressure pump.

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Cryosurgical System

Field of the Inventions

The inventions described below relate the field of cryosurgical systems.

Background of the Inventions

Cryosurgery refers to the freezing of body tissue in order to destroy diseased tissue. Minimally invasive cryosurgical systems generally include a long, slender cryoprobe adapted for insertion into the body so that the tip resides in the diseased tissue, and source of cryogenic fluid, and the necessary tubing to conduct the cryogenic fluid into and out of the probe. These cryosurgical systems also include heating systems, so that the probes can be warmed to enhance the destructive effect of the cryoablation and to provide for quick release of the cryoprobes when ablation is complete.

Our own Visica® cryoablation system has proven effective for the treatment of lesions within the breast of female patients. The system uses Joule-Thompson cryoprobes, and uses argon gas as the cryogenic fluid. The argon gas, supplied at room temperature but very high pressure, expands and cools within the tip of the cryoprobe to generate the cooling power needed to freeze body tissue to cryogenic temperatures. The Visica® cryoablation system uses high-pressure helium flow through the cryoprobe to heat the probe. The system requires large supplies of argon gas, but is otherwise quite convenient.

Present cryoprobes utilizing Joule-Thomson systems have inherent disadvantages such as inefficient heat transfer and excessive use of cryogen. As a result, these systems require large quantities of gasses under high pressure and high flow rates. Use of high-pressure gasses increases the material costs of surgical systems. This is due to the high cost of materials required for use with systems utilizing high-pressure gases, the high costs associated with obtaining high pressure gases and the large quantities of cryogen required for use with these systems.

Earlier cryoprobes proposed for other surgeries, such as prostrate cryosurgery, used liquid nitrogen, which has the advantage that it is more readily available than argon, and the volume necessary for a given cryosurgical procedure is much smaller then argon. Cryoablation systems using liquid nitrogen, such as the Accuprobe™ cryoablation system, have been proposed and used, but these systems have been abandoned in favor of the Joule-Thompson systems. The literature and patent filings indicate that liquid nitrogen systems were plagued by various problems, such as vapor lock and excessive consumption of liquid nitrogen. Proposals to solve these problems, though never successfully implemented, include various schemes to prevent vapor lock and maximize efficiency of the heat exchange. See Rubinsky, et al., Cryosurgical System For Destroying Tumors By Freezing, U.S. Patent 5,334,181 (Aug. 2, 1994) and Rubinsky, et al., Cryosurgical Instrument And System And Method Of Cryosurgery, U.S. Patent 5,674,218 (Oct. 7, 1997), and Littrup, et al., Cryotherapy Probe and System, PCT Pub. WO 2004/064914 (Aug. 5, 2004). Systems like those disclosed in Rubinsky '181, Rubinsky '218 and Littrup are complicated and expensive to manufacture.

Rubinsky '181 and '218 are extremely complex systems. The Rubinsky system is directed towards a system that includes a vacuum chamber and means for drawing a vacuum on a reservoir of liquid nitrogen while sub-cooling the liquid nitrogen. Specifically, the system accomplishes the sub-cooling of liquid nitrogen by evaporative cooling induced by using an active vacuum on a reservoir of liquid nitrogen. The liquid nitrogen (LN_2) in Rubinsky flows through a heat exchanger disposed within a vacuum chamber prior to entering the probe through an inlet tube. The LN_2 is sub-cooled to temperatures far below -195.8° C (sub-cooling) in the vacuum chamber.

Rubinsky takes the drastic approach of sub-cooling the LN2 in an effort to overcome inefficiencies found in traditional cryoprobe systems. Most conventional cryosurgical probe instruments operate with liquid nitrogen or other liquefied gas as the cooling medium. The LN_2 is introduced into the freezing zone of the probe through an inlet tube (which is usually the innermost tube of three concentric tubes). The inlet tube extends into an expansion chamber at the closed probe tip end but terminates a distance from the tip. The LN2 immediately and rapidly vaporizes and undergoes over a one hundred-fold increase in volume. As the liquid vaporizes, it absorbs heat from the probe tip to lower its temperature, theoretically to the normal boiling point of LN2 (about -196° C.). However, in actual practice, as liquid nitrogen boils, a thin layer of nitrogen gas inevitably forms on the inner surface of the closed probe tip end. This gas layer has a high thermal resistance and acts to insulate the probe tip freezing zone such that the outside probe tip temperature does not usually fall below about -160° C. This effect is known as the Liedenfrost effect. Other inefficiencies found in traditional cryoprobe systems include vapor lock. Vapor lock occurs when the back pressures produced by the boiling LN_2 reduce the LN_2 flow into the freezing zone, thereby further reducing the efficiency of the probe tip to cool. Rubinsky sub-cools the LN_2 as a way to overcome these inefficiencies

In order to address inefficiencies found in traditional cryoprobe systems, Littrup takes a different approach than Rubinsky. Littrup pressurizes the liquid nitrogen to near critical pressures along the phase diagram to pressures of about 494 psi (nearly 33.5 atmospheres) to overcome the Liedenfrost effect and back pressure. The Littrup system uses a cryotherapy probe with a shaft having a closed distal end adapted to insertion into a body and having a hollow zone within the shaft. A thermally isolated inlet capillary is provided in fluid communication with the hollow zone for providing a flow of liquid towards the hollow zone. An outlet capillary is provided in fluid communication with the hollow zone for providing a flow of liquid away from the hollow zone. A vacuum jacket is adapted to provide thermal insulation of the inlet and outlet capillaries within the shaft. The Littrup device requires two tubes thermally isolated from one another disposed within the shaft of the probe. Working pressures in the Littrup device range from 420 psi to 508 psi (29 to 35 bars) of pressure. The high pressures required in Littrup necessitate the use of expensive materials and fittings to maintain the cryogen at these pressures and prevent system failure.

To date, the problems inherent in liquid nitrogen systems have led the art to avoid them in favor of gaseous argon systems.

Summary

The devices and methods described below provide for use of liquid nitrogen in cryoablation systems while preventing the vapor lock typically associated with those systems, and minimizing the amount of liquid nitrogen used in a given procedure. The system uses cryoprobes of coaxial structure, and is supplied with cryogen from a dewar of liquid nitrogen.

The system includes various enhancements to avoid heat transfer from the liquid nitrogen to the system components, and as a result permits use of very low-pressure nitrogen, and, vice-versa, the use of low pressure nitrogen permits use of the various enhancements (which could not be used in a high pressure system). The result is a system that provides sufficient cooling power to effectively ablate lesions, tumors and masses within the breast of female patients while using very little nitrogen and a compact and inexpensive system based on readily available and easy to handle liquid nitrogen.

The system includes a low-pressure liquid nitrogen supply, which preferably uses only about 22 to 50 psi (about 1.5 to 3.5 bar), and more preferably between about 22 to 30 psi (about 1.5 to 2 bar), of pressure to provide adequate cooling power for treatment of typical breast lesions. The pressure may be provided by supplying lightly pressurized air into the dewar, by heating a small portion of the nitrogen in the dewar or with a small low pressure pump. For example, our prototype utilizes a compressor commonly used in household aquariums to pressurize the dewar.

The use of low pressure liquid nitrogen permits use of polymers for several components, such as the supply hose, the cryoprobe inlet tube, and various hose connectors which are typically made of metal, so that the system is much more efficient and uses very little liquid nitrogen. Additionally, because the liquid nitrogen is lightly pressurized, the boiling point remains low, and the liquid temperature also remains low compared with higher pressure systems.

Brief Description of the Drawings

Figure 1 illustrates a cryosurgical system which uses liquid nitrogen as a cryogen.

Figure 1a illustrates a cryosurgical system which uses liquid nitrogen as a cryogen.

Figure 2 illustrates the cryoprobe and supply hose of Figure 1.

Figure 2a illustrates the cryoprobe and supply hose with a low-pressure fitting.

Figure 3 illustrates the cryosurgical system of Figure 1 modified by addition of an accumulator.

Figure 4 illustrates a supply hose modified to enhance operation of the system of Figure 1.

Figure 5 illustrates the dewar and compressor arrangement of the cryosurgical system of Figure 1, disposed within the housing of the control system.

Figure 6 illustrates the control system interface of the cryosurgical system.

Figure 7 illustrates a cryosurgical system which uses liquid nitrogen as a cryogen and a small heater in the cryogen source to pressurize the cryogen.

Figure 8 illustrates a cryosurgical system which uses liquid nitrogen as a cryogen and a pump for driving cryogen flow.

Figure 9 illustrates a cryosurgical system without control valve using a compressor to regulate cryogen flow.

Detailed Description of the Inventions

Figure 1 illustrates a cryosurgical system which uses liquid nitrogen as a cryogen. The cryosurgical system 1 comprises cryoprobe 2, a cryogen source 3, pressurization pump 4, and a control system 6 for controlling pump. The desired flow of cryogen from the cryogen source to the cryoprobe is induced in this embodiment by pressurizing the cryogen source with air delivered by the pressurization pump. The cryogen source is preferably a dewar or other reservoir of liquid nitrogen, though other liquid cryogens may be used. The cryosurgical system 1 may be adapted to accommodate multiple cryoprobes with the addition of appropriate manifolds, and the control system may be computer-based or otherwise operable to automatically control the pressure and flow rate and other system components to effect the cooling profiles for desired cryosurgeries.

The cryoprobe 2 comprises an inlet tube **8**, a closed-ended outer tube **9**, and a handle portion **10**. The inlet tube 8 comprises a small diameter tube, and the outer tube comprises a closed end tube, disposed coaxially about the inlet tube. The inlet tube is preferably a rigid tube with low thermal conductivity, such as polyetheretherketone (PEEK, which is well know for its temperature performance), fluorinated ethylene propylene (FEP) or polytetrafluoroethylene. The cryoprobe preferably includes the flow-directing coil **11** or baffle disposed coaxially between the inlet tube and the outer tube at the distal end of the cryoprobe. The coil serves to direct flow onto the inner surface of the outer tube, thereby enhancing heat transfer from the outer tube that the cryogen fluid stream. The cryoprobe is described in detail in our co-pending application, DeLonzor, et al., Cryoprobe For Low Pressure Systems, U.S. Patent Application Number 11/318,142 filed December 23, 2005, the entirety of which is hereby incorporated by *reference*. The cryoprobe is supplied with cryogen from the cryogen source or dewar 3 through a supply hose **12** and the supply hose fitting 15 and dewar outlet fitting **13**. The dip tube **14** extends from the supply hose fitting into the dewar, and is preferably a continuous extension of the inlet tube 8 or an intervening supply tube that extends from the cryoprobe handle to supply hose fitting **15** as illustrated in Figures 2 and 2a. If the cooling demands and available cryogen flow rates permit, the beneficial aspects of the other various features can be employed and combined with a control valve interposed between the cryogen source and the cryoprobe. As shown in Figure 1a, the cryosurgical system may be modified by the addition of cryogen flow control valve 5 and releasable couplings 41 between the cryoprobe and the supply hose and the dewar and the supply hose. The other aspects of the system, including the cryoprobe 2, a cryogen source 3, pressurization pump 4, and a control system 6 are provided, as described in relation to Figure 1. This valve may be operated as a cut-off valve or as a throttle valve to control the flow cryogen. If provided as a cut-off valve, the flow of cryogen may be varied by varying the pressure supplied by the pressurization pump, and if provided as a throttle valve, the flow of cryogen can be controlled by manipulation of the valve while maintaining a constant pressure on the cryogen source.

As shown in Figure 2 the fluid pathway of the cryoprobe 2, including the inlet tube 8, the inner tube **16** and the dip tube 14, may be manufactured from a single, continuous and uninterrupted tube devoid of intervening fittings. The handle portion 10 and supply hose 12 may be integrally formed. A single coupling 15 disposed about the proximal end of the supply hose 12 is used to couple the supply hose, inner tube and dip tube to the cryogen source. The reduction and elimination of fittings result in a more efficient system since fitting locations are prone to cryogen leaks and act as heat sinks. When used in the current system, with low-pressure liquid nitrogen, cryoprobes having an inlet tube of about 1 mm inner diameter and about 1.6 mm outer diameter, and an outer tube with about 2.4 mm inner diameter and about 2.7

mm outer diameter work well. The probes outer diameters may range from about 4 mm to about 1.5 mm.

Figure 2a illustrates a handle portion and supply hose joined to the outer tube with a low-pressure cross-over fitting **17**, which provides for transition from the coaxial flow of exhaust gas over the inlet tube to the eccentric and side-by-side flow of the exhaust and inlet conduits in the supply hose, while inducing very little heat introduction into the cryogen flow path. The inlet tube 8, which runs the length of the cryoprobe, is joined to the inner tube 16 via this low-pressure cross-over fitting. The inlet tube extends proximally through the low pressure fitting and terminates in channel **18** which terminates proximal in the a frustro-conical nozzle. The swaged (flared) distal end **19** of the inner tube 16 fits over the nozzle to readily form a liquid tight seal. The exhaust flow from the cryoprobe outer tube 9 empties into exhaust plenum **20**, and passes through nozzle **21** into the swaged distal end of an exhaust tube **22**, and is eventually exhausted to atmosphere through exhaust vent 22a in or near the supply hose fitting 15. (Though shown separated for clarity, the nozzles and swaged tubes are tightly fitted.) As in Figure 2, the inner tube 16 and the dip tube 14 are formed from the same tube, to avoid a coupling transition at the supply hose fitting 15. The preferred material for the inlet tube, inner tube and dip tube is PEEK. The low pressure fitting may comprise PEEK, FEP, nylon or other thermally resistant polymer with very low thermal mass, and may comprise a releasably attachable fitting to join the supply hose to the cryoprobe, or the outer tube to the handle, so that the supply hose can readily be attached and detached from the cryoprobe without use of special tools.

As shown in Figures 1, 2 and 2a, the fluid pathway of the cryogen, which includes the dip tube, the inner tube of the supply hose, the inlet tube in the cryoprobe and the exhaust pathway established by the outer tube and exhaust tube, is devoid of valves, high-pressure fittings or substantially metallic or other heat-conductive fittings. The cryogenic system of Figure 1, 2 and 2a is arranged without a control valve in fluid communication with the fluid pathway between the cryogen source (even the outlet of the cryogen source is regulated by any valve) and the cryoprobe or in the exhaust pathway. The necessary cryogen flow rate of the cryogen may be achieved by regulating the pressure in the cryogen source 3 using the pressurization pump 4. Preferably, the pressurization pump 4 is operated to achieve a substantially constant pressure in the dewar during steady state operation. If it is desired to vary the cryogen flow rate, the control system may be adapted to control the pressurization pump 4 to increase pressure in the cryogen source 3 when a higher flow rate (and lower temperature) is desired in the probe or decrease pressure in the cryogen source 3 when a lower flow rate (and higher temperature) is desired in the probe.

Figure 3 illustrates the cryosurgical system of Figure 1 modified by addition of an accumulator. In this Figure, an accumulator **23** is disposed in parallel between the pressurization pump 4 and the dewar 3. Check valves **24** prevent backflow from the accumulator to the pump, and pressure control **25** prevents flow from the accumulator into the dewar until desired. The control system 6 in this embodiment may be programmed to operate the pump to pressurize the accumulator prior to treating a patient or initiating cryogen flow to the cryoprobe, and open the control valve 25 (provided or operated as a stop valve in this embodiment) when the surgeon operating the system provides input to initiate flow. The stored pressurized air in the accumulator is then dumped into the dewar, immediately pressurizing the dewar and forcing cryogen to flow. This avoids any delay in building up pressure in the dewar using the pump alone.

The accumulator can also be pressurized to a pressure well above that required for steady state flow, so that initial flow delivered to the cryoprobe is higher (more grams per second) than that to be provided by the pump alone. This helps cool down the cryoprobe quickly, while naturally leading to reduced steady state flow, without the use of throttle valve or the lag time associated with the pump pressurization. For example, if the control is programmed to operate the pressurization pump to achieve a steady state operating pressure of 30 psi (2 bar) the control system may be further programmed to charge the accumulator to 50 or 60 psi (about 3.5 to 4 bar) upon system startup (that is, when the surgeon energizes the system or otherwise indicates that the accumulator is to be charged in preparation for a procedure) and maintain that pressure awaiting an input indicating that cryogen flow is desired (that is, while the surgeon is preparing the patient and inserting the cryoprobe into the body). When the surgeon initiates flow by providing the appropriate input to the control system, the control system will open valve 25 to dump the pressurized air in the accumulator into the dewar. In this embodiment, accumulator is sized such that the amount of pressurized air in the accumulator is sufficient to charge the dewar to pressure of, for example, 40 psi (about 2.75 bar), which is above the steady state pressure required for steady state flow. This overpressure will cause high initial flow of cryogen, and, as it dissipates, cryogen flow will decrease to the steady state flow induced by the pressurization pump.

The accumulator can also be operated as the primary source of pressurization gas by placing the accumulator in series between the pressurization pump and the dewar (by closing or eliminating the flow path directly from the pressurization pump and the dewar), and providing a throttle valve (in place of, or in addition to, valve 25) between the accumulator and the dewar, and pressurizing the accumulator from the pressurization pump and thereafter throttling pressurized air form the accumulator to the dewar as necessary to drive cryogen flow. The control system in this embodiment would be programmed to operate the throttle valve as necessary to pressurize the dewar promptly on command and maintain a steady state or variable pressure on the dewar as required to meet the cryogen flow requirements.

The supply hose 12, illustrated in cross section in Figure 4, is particularly suited to use with the low-pressure liquid nitrogen system. The supply hose comprises an inner tube 16 of PEEK, FEP, nylon or other thermally resistant polymer with very low thermal mass (the ability to absorb heat) (polymers typically have a low coefficient of thermal conductivity, about .2 to .3 W/mK) which remains flexible at cryogenic temperatures of the liquid nitrogen. The inner tube extends proximally beyond the supply hose fitting 15 disposed on the proximal end of the supply hose and forms a dip tube 14. The inner tube 16 of the supply hose and the dip tube can be a single tube, or the inlet tube 8 of the cryoprobe, the inner tube 16 of the supply hose and the dip tube 14 can all manufactured from a single tube. Alternatively, the inlet tube 8 of the cryoprobe, the inner tube 16 of the supply hose and the dip tube may be provided as discrete tubes and bonded together without the use of high-pressure fittings. When the supply hose is coupled to the dewar, the dip tube extends into the dewar placing the dip tube in fluid communication with the cryogen. The outer tube or jacket 26 of the supply hose is manufactured from any suitable flexible material (ethylene vinyl acetate (EVA), low density polyethylene (LDPE), or nylon, for example) and may be corrugated transversely to promote omni-directional flexibility. The handle portion 10 and the outer jacket of the supply hose can be a single structure. The space between the inner tube and outer jacket is filled with aerogel beads or particles (indicated at item 27) or provided as a continuous tube of aerogel. (Aerogel refers to a synthetic amorphous silica gel foam, with a very low thermal conductivity (10^{-3} W/mK and below) with pores sizes in the range of about 5 to 100 nm.) The supply hose is preferably about 1.5 to 3 feet long (0.5 to 1 meter), which provides convenient working length (with a patient located in immediate proximity to the system) while minimizing cooling losses. The outer tube is preferably about 15 mm in outer diameter, while the inner tube is preferably about 1 mm in inner diameter and 1.5 mm outer diameter. The aerogel beads, if used, may be about 1mm diameter beads, and may be wetted lightly with silicone oil or similar clumping agent to prevent excessive dust dispersion in the case of rupture of the inner tube and/or outer jacket. Occasional spacers, in the form of washers 28 comprising materials such as polymethacrylimide closed-cell foam (PMI), may be placed along the inner tube to prevent collapse of the outer jacket and displacement of the aerogel beads. An aerogel tube may be formed by wrapping flexible aerogel blankets around the inner tube, or extruding and aerogel and binder mixture. The inner tube may also be wrapped with polyethylene foam sheets (typically used for packaging) which have proven quite effective given the thermal efficiencies provided by other features of the system. The annular space between the inner tube and outer jacket of the supply hose may also be filled with other low thermal mass materials such as perlite powder, cotton fiber, etc., though aerogel and polyethylene sheets have both proven particularly effective in limiting warming of the cryogen within the supply tube while providing a supply hose that is easy to manipulate during the course of a cryosurgical procedure. An insulating layer **29** may also be disposed about the dip tube 14 to reduce temperature loss of the cryogen when flowing through the dip tube 14. Coupling 15 is provided to releasably attach the supply hose to the dewar, so that the supply hose can readily be attached and detached from the dewar without use of special tools. The coupling in the system 1 may comprise any releasable fitting structure, such as Luer fittings, bayonet fittings, large threaded fitting that are operable by hand, quick-lock fittings and the like.

Figure 5 illustrates a detailed sectional view of the cryogen source and the compressor 4. The dewar comprises a liquid nitrogen vessel **31** containing liquid nitrogen surrounded by an outer housing **32**. The dewar outlet fitting 13 enables the dewar to be coupled with the supply hose when the supply house coupling 15 is disposed about the fitting. The space between the vessel and outer housing is filled with low thermal mass materials such as aerogel beads, particles or a continuous tube of aerogel. The annular space between the inner vessel and outer housing of the dewar may also be filled with other low thermal mass materials such as perlite powder, cotton fiber, etc., though aerogel has proven particularly effective in limiting warming of the cryogen within the dewar during the course of a cryosurgical procedure. The compressor is placed in fluid communication with the dewar at the outlet of the dewar, through a low pressure supply tube **33** in fluid communication with the supply hose coupling 15 and the low pressure supply tube coupling **34**. The compressor is operable by the control system to provide air pressure between about 0.5 to 15 bar of pressure to the cryoprobe. The system typically pressurizes the liquid cryogen between about 22 to 50 psi (about 1.5 to 3.5 bar), and more preferably between about 22 to 30 psi (about 1.5 to 2 bar). The dip tube 14 extends proximally beyond the proximal end of the jacket of the supply hose 12 and the supply hose coupling 15 and is disposed within the cryogen source 3 while being placed in fluid communication with the liquid in the source 3. A peristaltic valve or pinch valve may be used to regulate flow of cryogen through the dip tube. The peristaltic valve 35 is disposed within the dewar and operably connected to the dip tube 14. The valve may be operably connected to a control system and flow rate may be controlled by the system.

The control system interface **36** is illustrated in Figure 6. The interface comprises a digital display or other suitable means for displaying information such as an LCD or OLED. The display contains a probe temperature indicator 37 for displaying the temperature of the probe as well as a time remaining indicator **38** for displaying the amount of freezing time available in the system. The interface further comprises cycle indicator lights **39** to indicate to the operator that the system is testing itself, performing a Hi-freeze procedure, performing a low freeze procedure, thawing the target tissue or warming the cryogen. The cycle indicators lights are operable by the control system to indicate the current status of the system. Membrane switches, or any other form of input device may be used as input buttons for the control system. The indicator lights may be replaced with any form of visual, audible, or tactile indicator capable of providing several distinct signals to the user.

In use, the cryoprobe is inserted into the body, with its distal tip within a lesion or other diseased tissue that is to be ablated, the surgeon will operate the systems through controls on the control system. The dewar may be pressurized to between about 0.5 to 15 bar (about 7.25 to 220.5 psi). Preferably, the dewar is pressurized to about 22.5 to 29.4 psi. The dewar is pressurized to provide flow to the cryoprobe at about 0.5 to 2 grams per second to effect cryoablation of the lesion. The flow of cryogen is continued as necessary to freeze the lesion to cryogenic temperatures. Preferably the operation of the system is controlled automatically via the control system, though it may be implemented manually by a surgeon, including manual operation of the pressurizing means of the dewar. When used to treat lesions in the breast, the system may be operated according to the parameters described in our U.S. Patent 6,789,545.

Figure 7 illustrates a liquid nitrogen cryosurgical system which uses a heater to generate the desired pressure to drive the system. This system includes the cryoprobe 2, cryogen source 3 and control system 6 of Figure 1. A heater 7 is provided in the dewar, and is operable to heat a small volume of the nitrogen in the dewar and thereby increase the pressure in the dewar to the desired level of .5 to 15 bar (7.25 to 220.5 psi) above ambient pressure. The control system can automatically control the heater with feedback from pressure sensors in the dewar. The heater 7 may be submersed in the liquid nitrogen or placed within the gas above the liquid. It may be disposed on the inside wall of the dewar or suspended within the dewar. The heater 7 may also be disposed on the dip tube. In another embodiment of the system, a heater 7 may be placed in thermal communication with the dewar by disposing a heater outside the vessel 31 (shown in Figure 5).

As shown in Figure 7, the necessary cryogen flow rate may be adjusted by regulating the pressure in the dewar using the heater. The pressure in the cryogen source 3 or dewar is generated through use of the heater. The control system 6 operably controls the heater to heat the cryogen and increase pressure in the cryogen source 3 when a higher flow rate and lower temperature is desired in the probe. When a lower probe temperature is desired by the user, the heating of the cryogen is reduced or stopped by the control system 6 causing reduced pressure in the dewar and reduced cryogen flow to the probe 2.

As shown in Figure 8, the necessary pressure may also be provided with a cryogenic pump 45. In Figure 8, a cryogenic pump is placed at the outlet of the dewar, in line with the supply hose 12, and is operable by the control system to provide liquid nitrogen at about .5 to 15 bar of pressure to the cryoprobe. The necessary cryogen flow rate may be adjusted by regulating pump. The control system 6 operably controls the pump increase flow rate when a higher flow rate and lower temperature is desired in the probe. When a lower probe temperature is desired by the user, flow rate by the pump is reduced or stopped by the control system 6 causing reduced cryogen flow to the probe 2.

A cryogenic system can be implemented with various combinations of pressurizing means. As shown in Figure 9, the necessary cryogen flow rate may be adjusted by regulating the pressure in the cryogen source 3 using a compressor 4 or the heater 7 or both in combination. The control system 6 operably controls the compressor 4 and/or the heater to increase pressure in the cryogen source 3 when a higher flow rate and lower temperature is desired in the probe. When a higher probe temperature is desired by the user, the compressor 4 may be slowed or stopped by the control system, causing reduced pressure in the cryogen source 3 and reduced cryogen flow to the probe. Likewise, the heater may be energized at varying levels to increase or decrease pressure in the cryogen source. The control system in this embodiment may be programmed to operate the heater to pressurize the dewar quickly when cryogen flow to the cryoprobe is desired, and at the same time start the pump to provide steady state pressurization. The pressurized gaseous cryogen created by the heater immediately pressurizes the dewar and forces cryogen to flow. This avoids any delay in building up pressure in the dewar using the pump. The accumulator can also be pressurized to a pressure well above that required for steady state flow, so that initial flow delivered to the cryoprobe is higher (more grams per second) than that to be provided by the pump alone. As discussed in relation to Figure 3, this method of operation can be used to cool down the cryoprobe quickly, while relying on the pressurization pump to provide the pressure needed for steady state flow, without the use of throttle valve or the lag time associated with the pump pressurization.

The systems described above may be employed with various liquid cryogens, though liquid nitrogen is favored for is universal availability and ease of use. Also, though system has been developed for use in treatment of breast disease, it may be employed to treat lesions elsewhere in the body. Thus, while the preferred *embodiments of the* devices and methods have been described in reference to the environment in which they were developed, they are merely illustrative of the principles of the inventions. Other embodiments and configurations may be devised without departing from the spirit of the inventions and the scope of the appended claims.

We claim:

1. A cryosurgical system comprising:

a cryoprobe comprising a handle portion, a closed-ended outer tube disposed within the handle portion and an inlet tube disposed within the outer tube, said cryoprobe having a distal end corresponding to the closed end of the outer tube which is adapted for insertion into the body of a patient and a proximal end adapted for connection to a source of cryogenic liquid;

a cryogen source comprising a reservoir of cryogenic liquid;

a supply tube connecting the proximal inlet tube to a source of cryogenic liquid, said supply tube establishing a liquid flow path from the source of cryogenic liquid to the inlet tube of the cryoprobe, said liquid flow path devoid of intervening valves and thermally conductive couplings;

a pressurizing means for pressurizing the source of cryogenic liquid; and

a control system operable to control the pressurizing means to provide cryogenic liquid to the cryoprobe and to pressurize the cryogenic source in the range of about .5 to 15 bar.

2. The cryosurgical system of claim 1 further comprising:

a supply hose disposed about the supply tube;

a proximal supply hose coupling fixed to the proximal end of the supply hose, said supply hose fitting adapted to couple the supply hose and supply tube therein to the reservoir; and

a dip tube adapted for insertion into reservoir of liquid, said dip tube being in fluid communication with the supply tube, said dip tube depending from the proximal supply hose fitting into the reservoir said dip tube comprising the proximal extension of the supply tube.

3. The cryosurgical system of claim 2 further wherein:

the supply tube and the dip tube are formed from a single uninterrupted length of tubing.

4. The cryosurgical system of claim 2 further wherein:

the inlet tube, the supply tube and the dip tube are formed from a single uninterrupted length of tubing.

5. The cryosurgical system of claim 1 wherein:

the inlet tube and the supply tube are formed from a single uninterrupted length of tubing.

6. The cryosurgical system of claim 2 wherein:

the supply tube and the dip tube are formed from a single uninterrupted length of PEEK tubing.

7. The cryosurgical system of claim 2 wherein:

the inlet tube, the supply tube and the dip tube are formed from a single uninterrupted length of PEEK tubing.

8. The cryosurgical system of claim 1 wherein:

the inlet tube and the supply tube are formed from a single uninterrupted length of PEEK tubing.

9. The cryosurgical system of claim 2 wherein:

the supply tube and the dip tube are formed from a single uninterrupted length of low thermal conductivity tubing.

10. The cryosurgical system of claim 2 wherein:

the inlet tube, the supply tube and the dip tube are formed from a single uninterrupted length of low thermal conductivity tubing.

11. The cryosurgical system of claim 1 wherein:

the inlet tube and the supply tube are formed from a single uninterrupted length of low thermal conductivity tubing.

12. The cryosurgical system of claim 1 wherein the supply hose disposed about the supply tube and the handle portion are integrally formed.

13. The cryosurgical system of claim 1 wherein the supply tube is joined to the cryoprobe inlet tube with a cross-over fitting comprising:

a plenum communicating with the exhaust channel established by the outer tube, said plenum disposed about a portion of the inlet tube;

a first channel for receiving the proximal end of the inlet tube and communicating with the distal end of the supply tube, wherein the proximal end of the inlet tube is passes through the plenum and is secured to the first channel; and

a second channel communicating from the plenum to the exterior of the fitting.

14. The cryosurgical system of claim 1 further comprising:

a exhaust tube in fluid communication with the outer tube, extending proximally away from the cryoprobe and opening to atmosphere, said exhaust tube, together with the supply tube, inlet tube, and outer tube, establishing a liquid flow path from the source of cryogenic liquid to the exhaust port which is devoid of intervening valves and thermally conductive couplings.

15. The cryosurgical system of claim 2 further comprising:

a exhaust tube in fluid communication with the outer tube, extending proximally away from the cryoprobe and opening to atmosphere, said exhaust tube, together with the dip tube, supply tube, inlet tube, and outer tube, establishing a liquid flow path from the source of cryogenic liquid to the exhaust port which is devoid of intervening valves and thermally conductive couplings.

16. A cryosurgical system of claim 1 wherein the inner tube has an inner diameter of about 1 mm and said outer jacket has a diameter of about 15 mm, and the space between the inner tube and the outer tube is filled with aerogel.

17. A cryosurgical system of claim 1 wherein the inner tube has an inner diameter of about 1 mm and said outer jacket has a diameter of about 15 mm, and the space between the inner tube and the outer tube is filled with polyethylene foam.

18. A cryosurgical system of claim 3 further comprising:

means for releasably attaching the supply hose proximal end to the source of liquid cryogen, said means comprising low thermal mass polymeric fittings.

19. A cryosurgical system of claim 1 wherein the pressurizing means comprises:

a compressor operably connected to the source to pump air into the source and thereby pressurize the source to about .5 to 15 bar of pressure.

20. A cryosurgical system of claim 1 wherein the pressurizing means comprises:

a heater in thermal communication with the cryogenic liquid in the source, said heater being operable to heat a small volume of the cryogenic liquid and thereby pressurize the source to about .5 to 15 bar of pressure.

21. A cryosurgical system of claim 20 further comprising a cryogen heater disposed on the dip tube.

22. A cryosurgical system of claim 1 wherein the pressurizing means comprises:

a pump operably connected to the source to pump cryogenic liquid from the source to the cryoprobe at a pressure of about .5 to 15 bar of pressure.

23. A cryosurgical system of claim 1 wherein the pressurizing means comprises:

a compressor operably connected to the cryogen source to pump air into the source and thereby pressurize the source to about .5 to 15 bar of pressure;

an accumulator disposed in parallel between the compressor and the cryogen source; and

a control valve disposed between the accumulator and the cryogen source;

wherein the control system is operable to control the pressurization pump to charge the accumulator on command from an operator, and thereafter operate the control valve to pressurize the dewar from the accumulator and also control the pressurization pump to pressurize the dewar.

24. A cryosurgical system of claim 23 wherein the control system is further programmed to operate the pressurization pump to pressurize the dewar to a dewar to a first, steady state pressure chosen to provide a desired steady state cryogen flow through the cryoprobe, and operate the pressurization pump, prior to initiation of flow, to charge the accumulator to a second pressure substantially higher than the first pressure, and, upon command to initiate flow, to operate the control valve to pressurize the cryogen source from the accumulator promptly to the first steady state pressure.

25. A cryosurgical system of claim 23 wherein the control system is further programmed to operate the pressurization pump to pressurize the dewar to a dewar to a first, steady state pressure chosen to provide a desired steady state cryogen flow rate through the cryoprobe, and operate the pressurization pump, prior to initiation of flow, to charge the accumulator to a second pressure substantially higher than the first pressure, and, upon command to initiate flow, to operate the control valve to pressurize the cryogen source from the accumulator promptly to the third pressure which is higher than the steady state pressure, thereby initiating

cryogen flow at a rate higher than the steady state cryogen flow rate..

26. A method of cryoablating diseased body tissue in a patient, said method comprising:

providing a cryosurgical system comprising:

a cryoprobe comprising a closed-ended outer tube and an inner tube disposed within the outer tube, said cryoprobe having a distal end corresponding to the closed end of the outer tube which is adapted for insertion into the body of a patient and a proximal end adapted for connection to a source of cryogenic liquid;

a source of cryogenic liquid and pressurizing means for pressuring the cryogenic liquid;

a supply hose connecting the valve to the proximal end of the cryoprobe and establishing a liquid flow path from the valve to the inlet tube of the cryoprobe;

a control system operable to control the pressurizing means and valve to provide cryogenic liquid to the cryoprobe, said control system being programmed to control the pressurizing means to pressurized the source in the range of about .5 to 1 bar, and control the valve to provide cryogenic fluid flow to the cryoprobe;

operating the control system to pressurizing the source to about .5 to 1 bar of pressure and operating the control valve to provide cryogenic liquid flow to the cryoprobe, thereby providing about .5 to 2 grams per second of cryogenic liquid to the cryoprobe; and continuing the flow of cryogen as necessary to freeze the diseased tissue to cryogenic temperatures.

Fig. 1

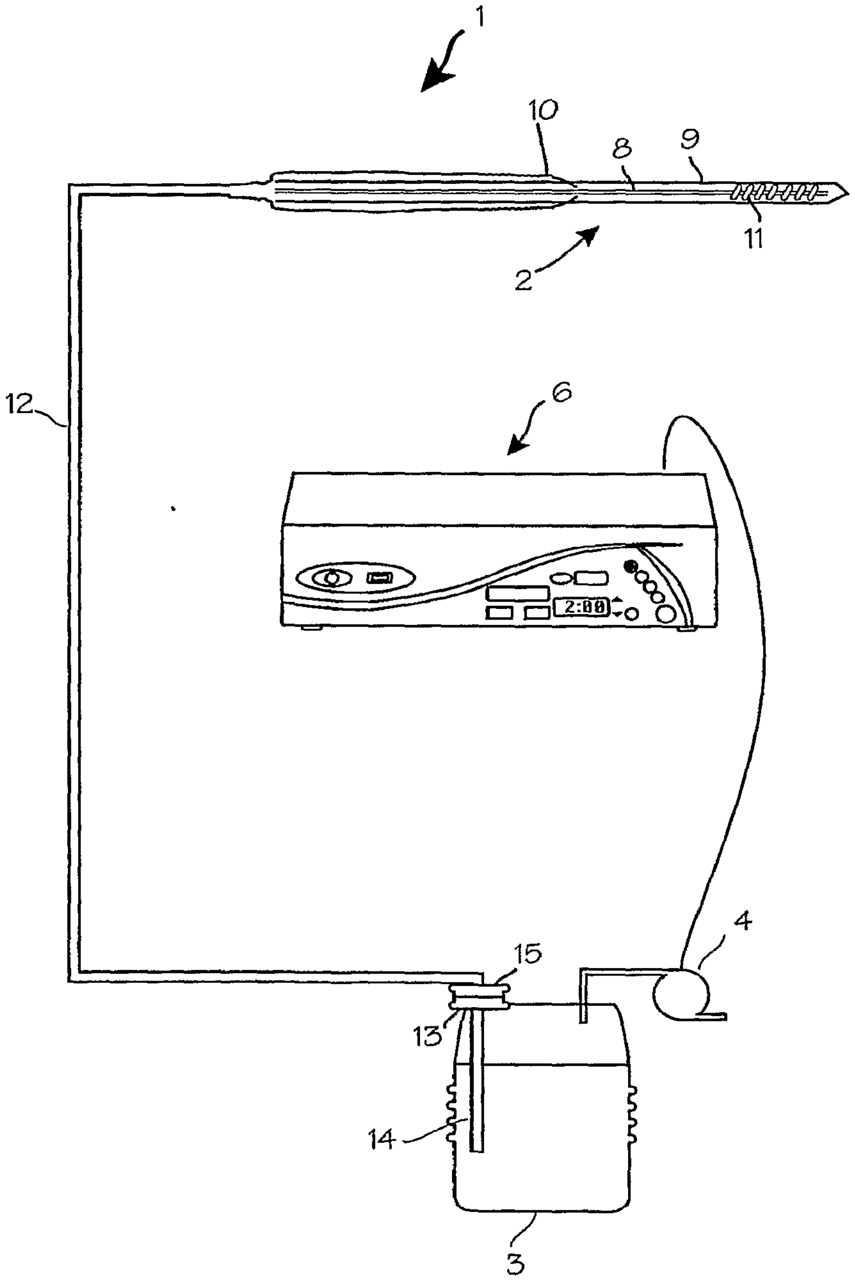


Fig. 1a

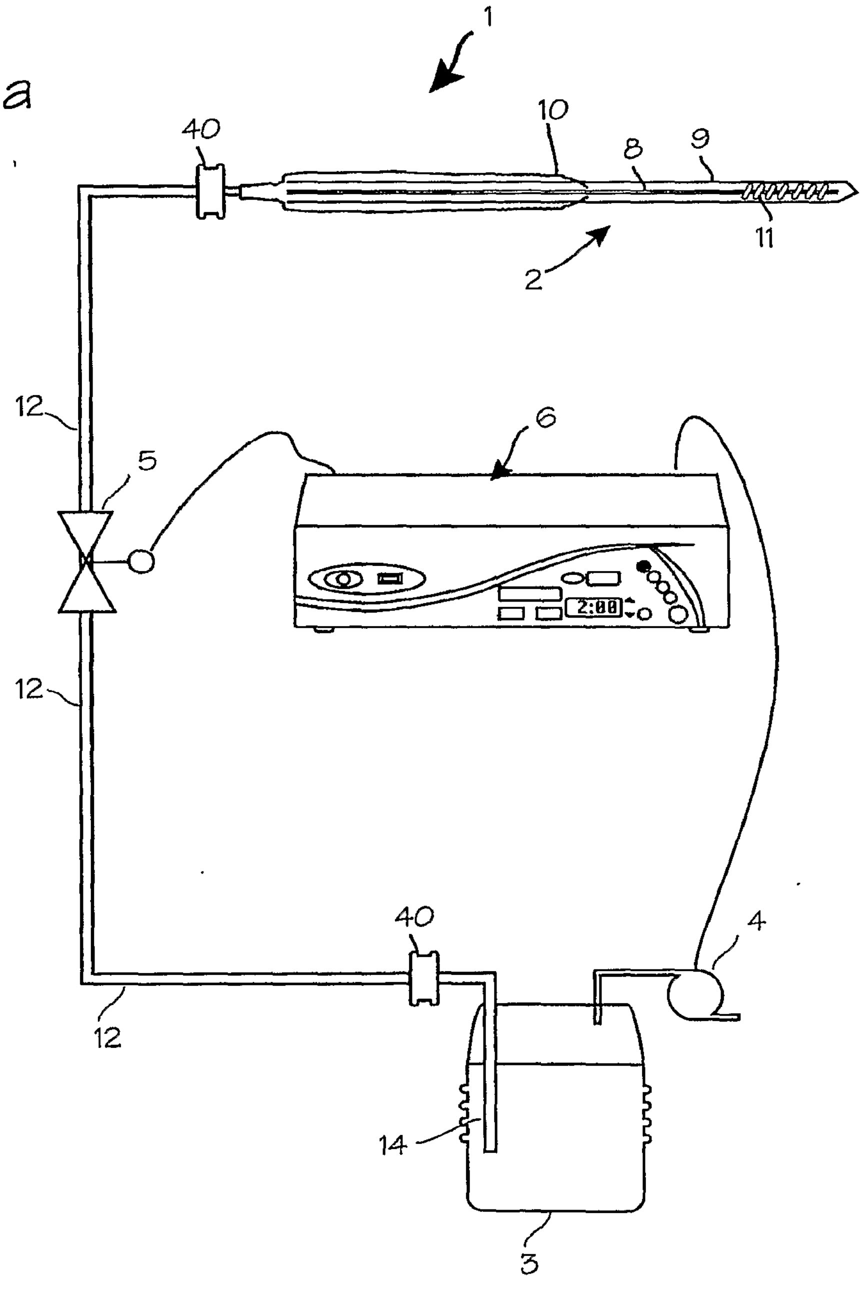


Fig. 2

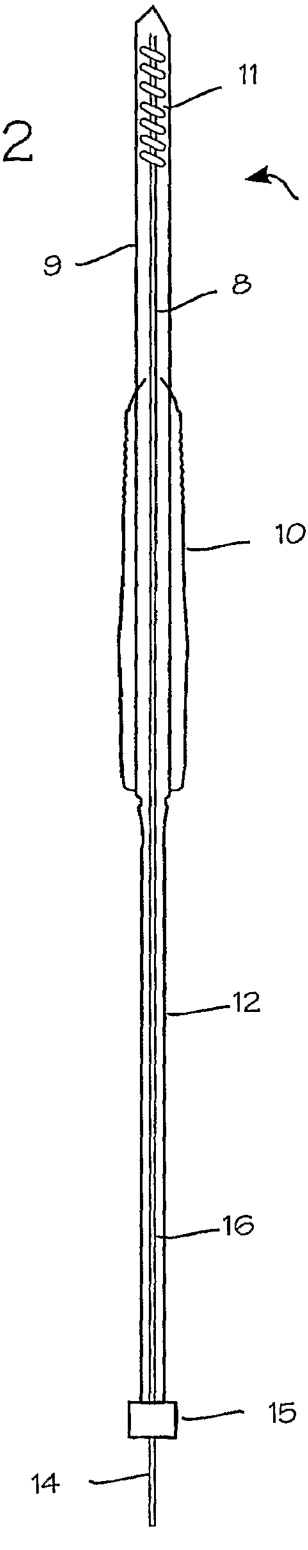


Fig. 2a

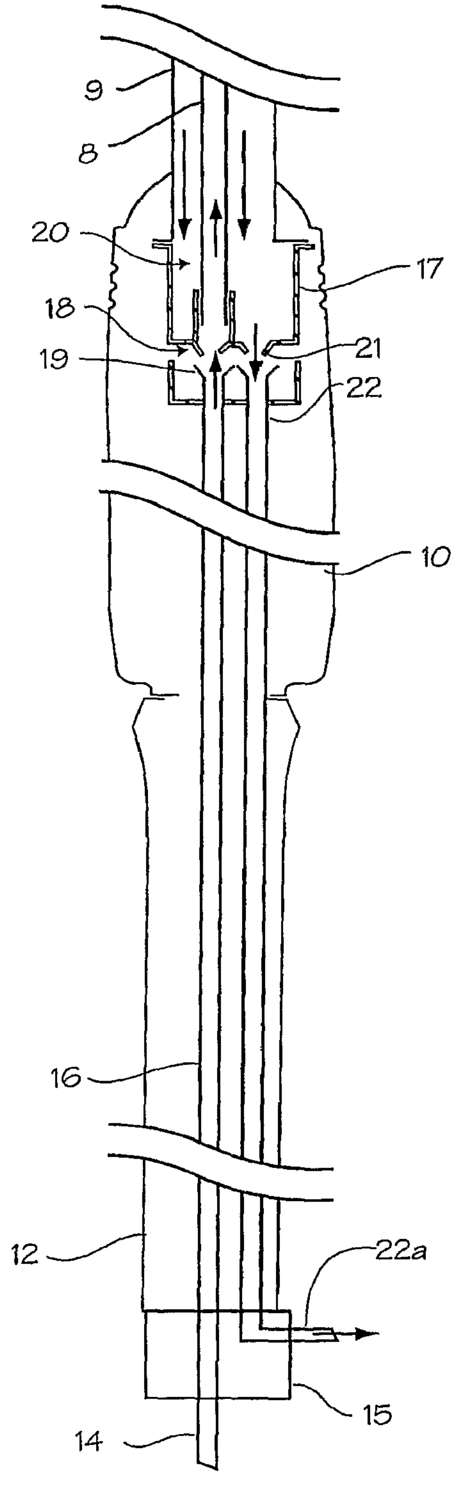


Fig. 3

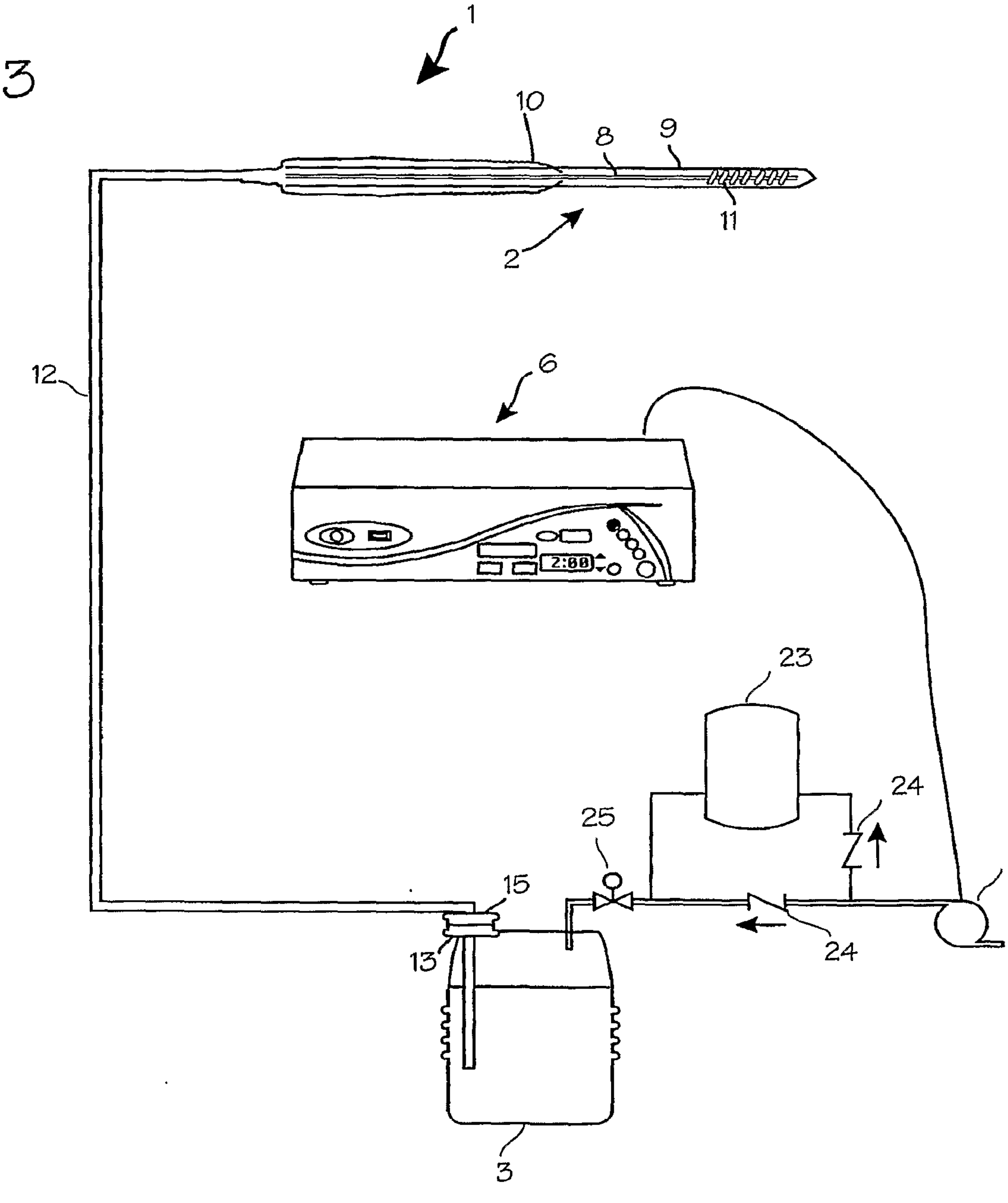
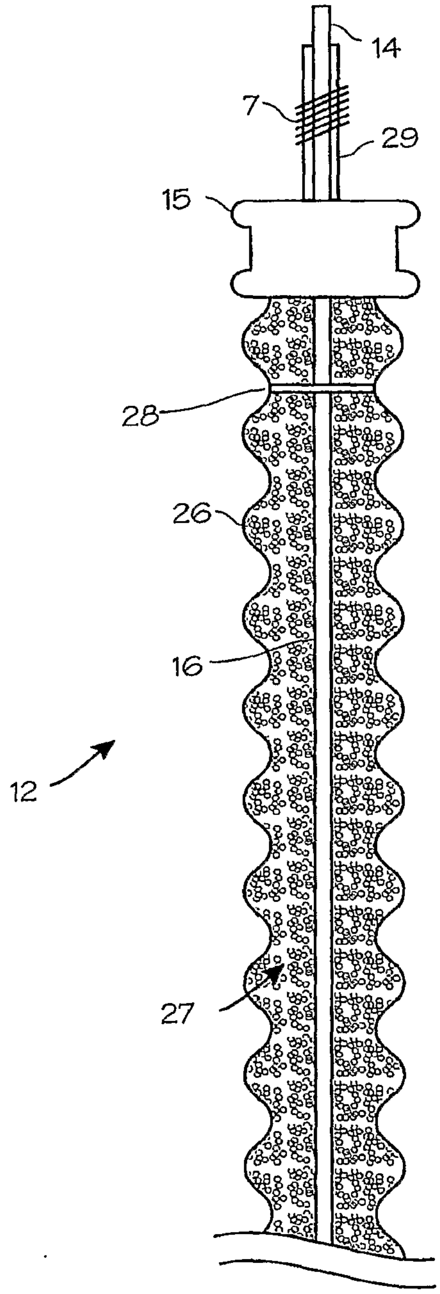


Fig. 4



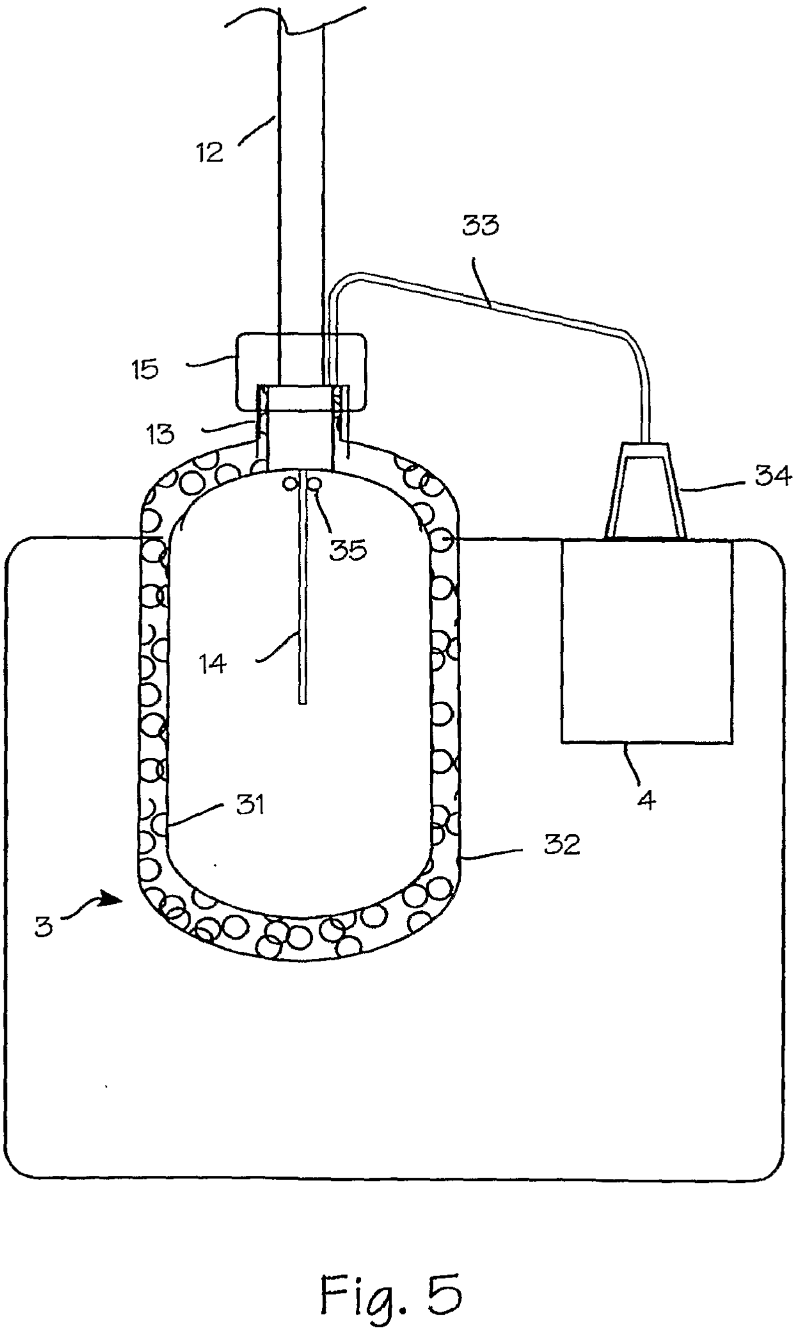
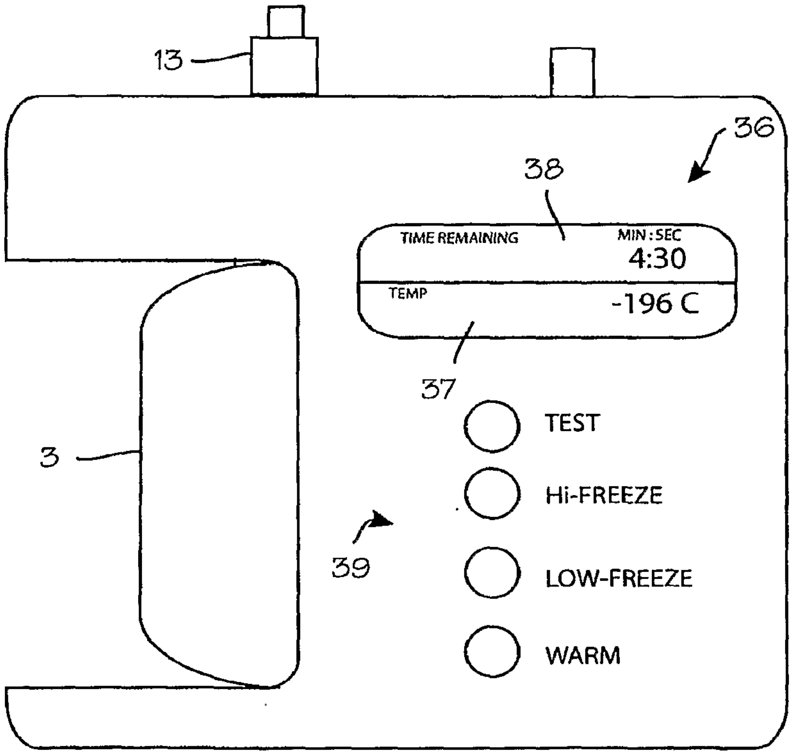


Fig. 5


13
36
38
TIME REMAINING
MIN : SEC
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TEMP
-196 C
37
3
TEST
Hi-FREEZE
39
LOW-FREEZE
WARM

Fig. 6

Fig. 7

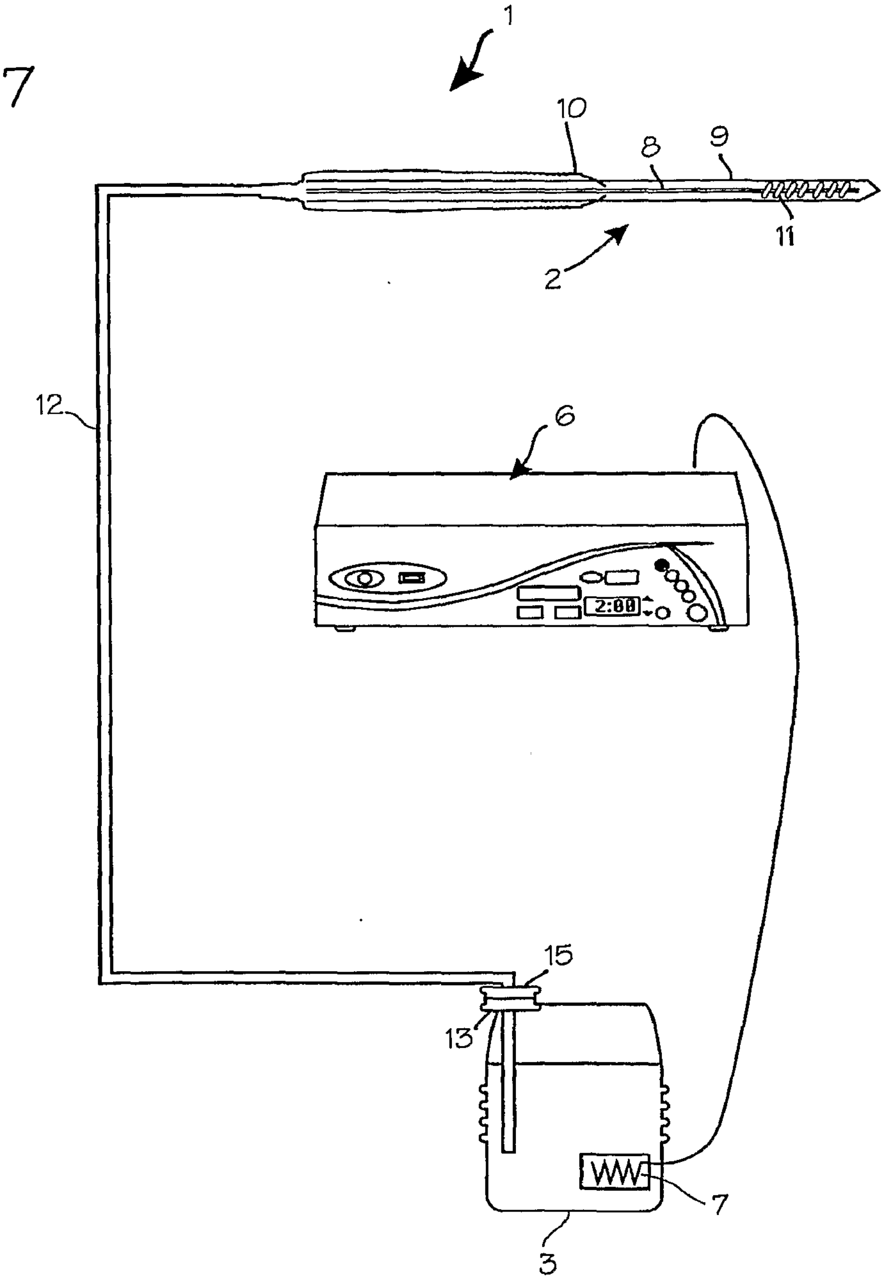

Fig. 8

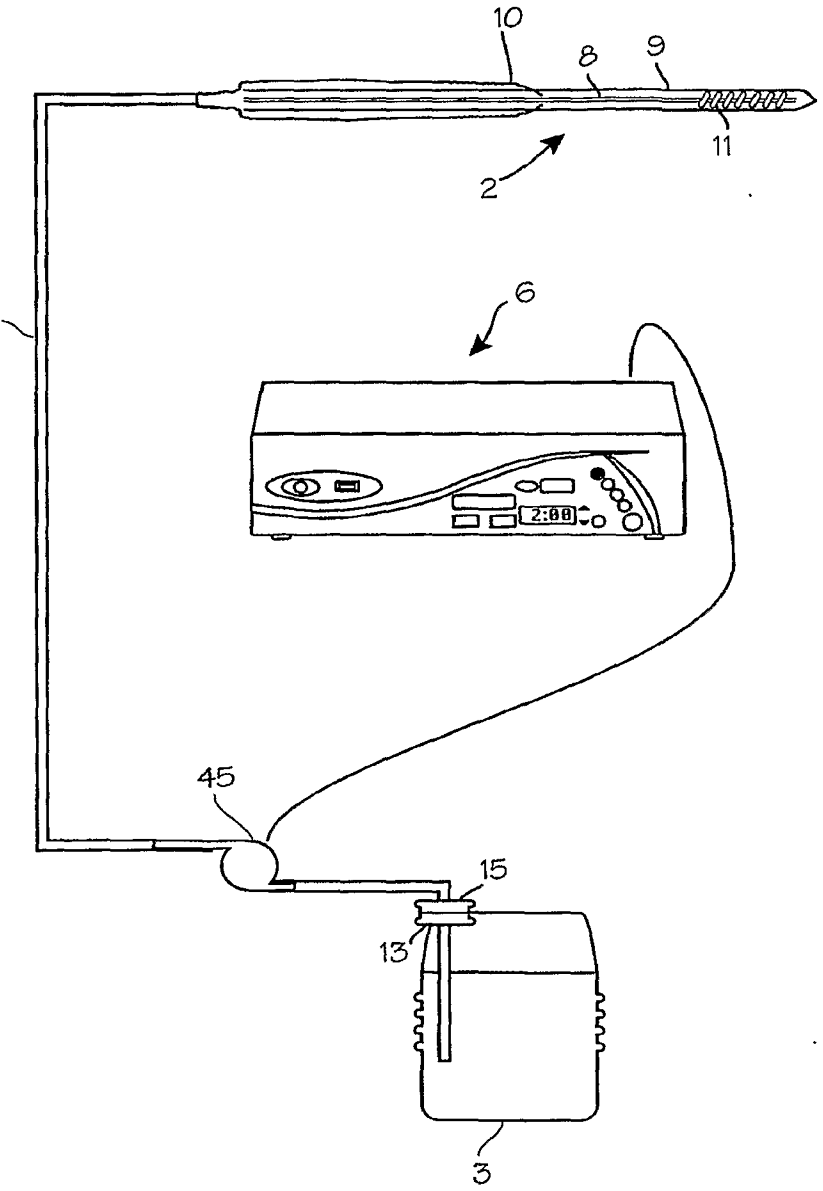

Fig. 9