

10: Cardiopulmonary Support: Ventilation

As discussed in Section 9, (mechanical) chest compressions can provide benefits, such as circulation of (neuroprotective) medications and enhanced cooling, without ventilating the patient. But the most fundamental objective of circulation is to oxygenate the blood to meet the metabolic demand of the human body. In theory, if compressions were adequate to meet the metabolic needs of the brain, there would be no need for other interventions to mitigate cerebral ischemia; but this situation rarely, if ever, occurs in cryonics.

Despite its obvious benefits, ventilation is among the most contested issues in human cryopreservation. To understand this controversy, picture the conditions under which cryonics patients are ventilated along a continuum. At one end is the ideal situation of cryonics as an elective medical procedure. The patient would be artificially ventilated while extracorporeal perfusion is used to lower body temperature until metabolic demands have diminished to a point where ventilation can be omitted without causing hypoxia. At the other end of the spectrum are cases where the patient has been in circulatory arrest for such a long time, starting ventilation would no longer confer any benefits.

What distinguishes these two polar opposite scenarios is that we do not require additional research to conclude that ventilation for a living patient is mandatory. If there is any research in this area to be done, it is to establish the optimal ventilation regime for such patients as they are cooled. Unfortunately, in patients who have suffered extensive periods of warm ischemia, there is no such obvious answer available. We cannot just argue that we should always ventilate because the patient will benefit if it works, and will not be worse off if it does not work. Under certain conditions, initiating ventilation can actually make things worse.

Reperfusion Injury

During the last fifty years there has been increasing recognition in biomedical literature and clinical practice that simply restoring circulation and ventilation to a patient suffering from an ischemic insult (i.e., cardiac arrest or stroke) can have adverse effects on the outcome of the patient. The evidence for this perspective is corroborated in ultrastructural studies where organelles (such as mitochondria) that were subjected to transient ischemia (ischemia plus restoration of circulation) look worse than organelles where the ischemic insult is permanent.

There is an extensive literature about the biochemical mechanisms and pathophysiology of reperfusion injury which reflects a growing consensus that such reperfusion injury is multi-factorial in nature. Reperfusion injury is of great interest to the practice of cryonics because it can interfere with two important objectives of cryonics procedures: securing viability of the brain during stabilization procedures, and eliminating ice formation during long-term care. Reperfusion injury can interfere with both of these objectives by producing additional injury to the brain during cardiopulmonary support (and blood substitution) and contributing to perfusion impairment during cryoprotective perfusion.

In the context of ventilation there are two (proposed) mechanisms of reperfusion injury that matter: oxidative damage and apoptosis. Apoptosis is an energy-dependent form of cell death that may not be of great concern in cryonics because lowering the temperature of the patient, which defines the practice of cryonics, will inhibit the completion of apoptotic cell death. Of more concern is the potential for generating oxidative damage upon restoring circulation and ventilation.

To illustrate the challenge of making an informed decision about whether to ventilate a patient, consult the simplified graph in Figure 10-1. When ischemia is at zero, the benefit of ventilation is maximized with no reperfusion injury (there is no *re*-perfusion). When ischemic time is maximal there are no benefits to ventilation and only reperfusion injury. As is clear, there is a point where these two lines intersect; the benefits of ventilation are completely offset by the adverse effects of reperfusion injury.

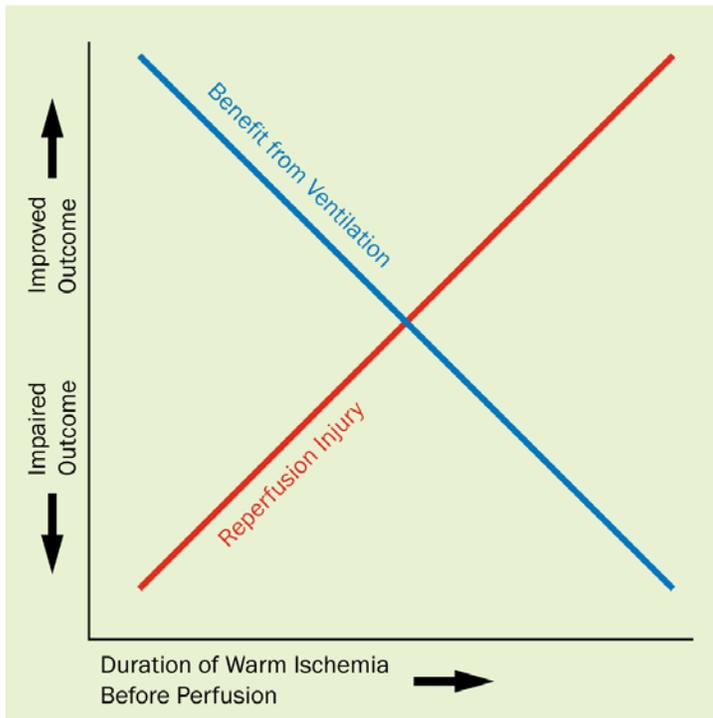


Figure 10-1. The benefits of ventilation must be balanced against the penalties of reperfusion injury, which will increase with prior warm ischemic time.

One of the simplifying assumptions in this figure is that it omits two of the defining elements of stabilization procedures: the administration of medications to mitigate reperfusion injury, and the induction of hypothermia. The existence of such interventions further complicates the question of when to omit ventilation during a cryonics case. In the absence of realistic cryonics research models that can capture these complexities, the existing biomedical literature is of little benefit in giving specific guidelines about ventilation in cryonics.

A Hard Criterion Against Ventilation

In absence of detailed understanding of when the negative consequences of ventilation exceed the benefits, it would be reasonable to posit that there are no benefits to ventilation when mitochondria in the brain are so injured that

biological respiration has been irreversibly damaged. At that point, all one would do is to supply oxygen to generate oxidative damage without meeting the metabolic needs of the tissues. Such knowledge would at least be capable of putting an evidence-based categorical prohibition on ventilation of certain categories of cryonics patients.

The search for such a firm criterion may be more complicated than imagined because mitochondrial dysfunction is, not unlike many other biochemical processes in the body, a matter of degree. Experimental research into the effects of cerebral ischemia on mitochondria indeed indicates a time-dependent loss of function. Recent investigations reveal that ATP production is still possible in mitochondria isolated from human brains for up to 8.5 hours postmortem. What reduces the usefulness of such studies for making determinations about ventilating cryonics patients is that mitochondrial viability should be expected to correlate strongly with temperature, and the conditions under which these samples have been obtained and stored can greatly vary.

A further complication is that the ability of mitochondria to generate ATP is a necessary but not a sufficient criterion to endorse ventilation. If the overall state of cells is of such a nature that degradation will not be halted, there is still no benefit to supplying tissues with supplemental oxygen. In light of all these uncertainties, we cannot document an existing body of knowledge about reperfusion injury and ventilation in cryonics that allows for unambiguous recommendations. Since the stabilization medications that Alcor uses have been effective in recovering dogs from at least 15 minutes of warm ischemia without neurological deficits, ventilation should not be withheld from cryonics patients with less than 15 minutes of warm ischemia. It can also be argued that if ventilation is attempted after longer periods of warm ischemia that it should always be accompanied by rapid induction of hypothermia and administration of cerebroprotective medications to ensure the benefits of oxygenation while mitigating the potential adverse effects of ventilation.

Although the brain should be given priority in assessing the need for ventilation, it is also important to recognize that red blood cells have metabolic needs. When red blood cells run out of ATP they will become more

rigid and liable to block small vessels. Under such circumstances, the absence of ventilation will contribute to perfusion impairment during cryoprotective perfusion.

A final complicating factor is the role of ventilation in removing carbon dioxide. If carbon dioxide is allowed to accumulate, aerobic and then anaerobic metabolism will exhaust pH buffering capacity of the body. The resulting respiratory acidosis (low pH) is itself damaging to tissue.

Contra-Indications for Ventilation

Despite our poor understanding of reperfusion injury in cryonics, there are a number of circumstances that constitute contra-indications for ventilation:

1. In the absence of qualified personnel, ventilation is contra-indicated because of the risk of poor placement of airways.
2. In the absence of a sufficient number of personnel and mechanical chest compression equipment, a standby team may be forced to alternate between chest compressions and ventilations. In such circumstances the patient will benefit more from uninterrupted vigorous chest compressions; such a protocol will still permit some degree of ventilation and will prevent cardiac output to decline over the course of CPS.
3. The presence of pulmonary edema. Pulmonary edema interferes with effective gas exchange and absent specific measurements to overcome the cause and/or symptoms of pulmonary edema, ventilation is contra-indicated.
4. A determination is made that the adverse effects of ventilation outweigh the benefits of ventilation. This is generally the case when Alcor expects ventilation to mainly contribute to oxygen-mediated vessel damage instead of meeting metabolic needs. There is at present no consensus about when this time is, except that it is likely measured in hours rather than minutes.

Anoxic CPS

Because circulation expedites cooling and is necessary to circulate medications, there can be circumstances where it is preferable to restore circulation without exposing the patient to air or oxygen. Conducting anoxic CPS is not the same as eliminating ventilation because vigorous chest compressions are still effective in generating some degree of ventilation.

A further complication is added by the fact that, for most patients upon circulatory arrest, there is still a significant amount of oxygen in the large vessels. Upon restoration of circulation without ventilation such residual amounts of unutilized oxygen can still contribute to free radical damage. During reperfusion, high amounts of superoxide convert available nitric oxide to peroxynitrite—a highly damaging oxidant to (cerebral) vessels.

For rigorous anoxic CPS it may therefore not be sufficient to omit ventilation and other measures would have to be initiated such as occlusion of the airway or initial measures to desaturate residual oxygen in the vessels such as ventilation with an inert gas like nitrogen. Anoxic CPS may also require complimentary pharmacological interventions to mitigate the effects of anoxia such as metabolic imbalances and red cell aggregation and inflammatory vascular damage.

Airway Access Options

After the patient has stopped breathing and is pronounced legally dead, stabilization procedures require prompt restoration of breathing using positive-pressure ventilation. There are a number of manual and mechanical techniques to accomplish this objective:

Mouth-to-Mouth Breathing

Mouth-to-mouth (or mouth-to-nose) breathing is a common emergency ventilation technique for cases of sudden cardiac arrest or respiratory failure. This technique is not efficient and because of its associated fatigue and risk for transferring disease by direct contact with the patient's mucous membranes, this is not recommended for cryonics stabilization procedures. A

related technique is mouth-to-mask ventilation. Unlike mouth-to-mouth ventilation, this mode of manual ventilation does not require direct physical contact between the stabilization team member and the patient. Like mouth-to-mouth breathing, the use of this technique is not likely in cryonics because it is hard to perform on a moving patient during transport and if a team has access to a facemask it usually has access to a bag-valve-mask.

Bag-valve-mask

The bag-valve-mask (BVM, also known as an “Ambu bag”) is the most common basic aid to perform positive-pressure ventilation in emergency medicine. The design of bag-valve-masks can vary. Some have a port for mechanical oxygen administration, but the most basic versions consist of a face mask that is pressed against the patient’s mouth to create a seal in conjunction with manual squeezing of the bag to ventilate the lungs, as shown in Figure 10-2. The bag and valve can also be used in combination with an airway such as an endotracheal tube or the Combitube.

In cryonics stabilization procedures, the BVM can be used to restore ventilation while the patient is prepared for lifting into the ice bath. It may also be a permanent means of ventilation when no equipment or expertise for mechanical/automated ventilation is present. Because the use of a bag and mask in absence of an airway can lead to gastric inflation (and associated vomiting and aspiration), the recommended protocol in cryonics is to place a (basic) airway. Placement of an airway also prevents breaking of the seal during ventilation, fatigue, and interruptions associated with transport-induced movement of the patient. It may also allow more ice to be placed around the patient’s head and face.



Figure 10-2. A typical adult-size bag valve mask, by Lightning X EMS

Endotracheal Tube

Ventilation through a properly placed endotracheal tube, often referred to as an ET tube, is the “gold standard” for paramedics and anesthesiologists. Endotracheal intubation has been in common practice in cryonics and was the preferred method for facilitating ventilation in cryonics until the introduction of easier devices such as the Combitube and the King airway (see below). In emergency medicine, endotracheal intubation is classified as an advanced skill for paramedics, usually not permitted for EMTs. A basic ET tube is shown in Figure 10-3.



Figure 10-3. A typical endotracheal tube.

Endotracheal intubation presents a formidable challenge for non-skilled persons because it requires the placement of a tube directly into the trachea of a patient. Since the natural angle for placing a tube in the mouth of a supine patient is to place it in the esophagus (a feature that is exploited by easier equipment such as the Combitube) a laryngoscope is necessary to ensure that the tube is inserted through the vocal cords. Reportedly, in cryonics cases where there is a (lengthy) delay between cardiac arrest and placement of the endotracheal tube, the difficulty of this procedure increases.

If there are qualified medical professionals on the case, endotracheal intubation remains a valid means of establishing an airway for ventilation of the patient, although the availability of easier devices have made some cryonics organizations decide to stock standby kits without endotracheal intubation kits.

Tracheotomy

A tracheotomy is an invasive surgical procedure in which an incision is made in the neck of a patient to insert an airway directly into the trachea. There are a number of variants of this procedure but due to its invasive nature it is uncommon in cryonics. At the time of writing, cryonics organizations no longer equip themselves to perform this procedure.

Combitube

In the absence of exceptional emergency medicine skills for “blind” intubation, the natural angle is to place a tube in the esophagus. The Combitube is a device that takes advantage of this fact by utilizing esophageal placement to ventilate the patient. This feat is achieved by closing the distal end of the tube to re-direct room air or oxygen to the trachea and lungs of the patient. Distal and proximal balloons secure the tube in place. The dual-lumen tubing that defines the Combitube permits conventional ventilation in the rare case where the tube is placed in the trachea after all. A Combitube is shown in Figure 10-4.

Aside from its ease of use, one interesting feature of the Combitube is that it allows administration of fluids that into the stomach of the patient, such as Maalox, through the distal end of the tube. If this option is utilized, it is of the essence that placement of the tube in the trachea is ruled out to prevent introducing fluid into the lungs.

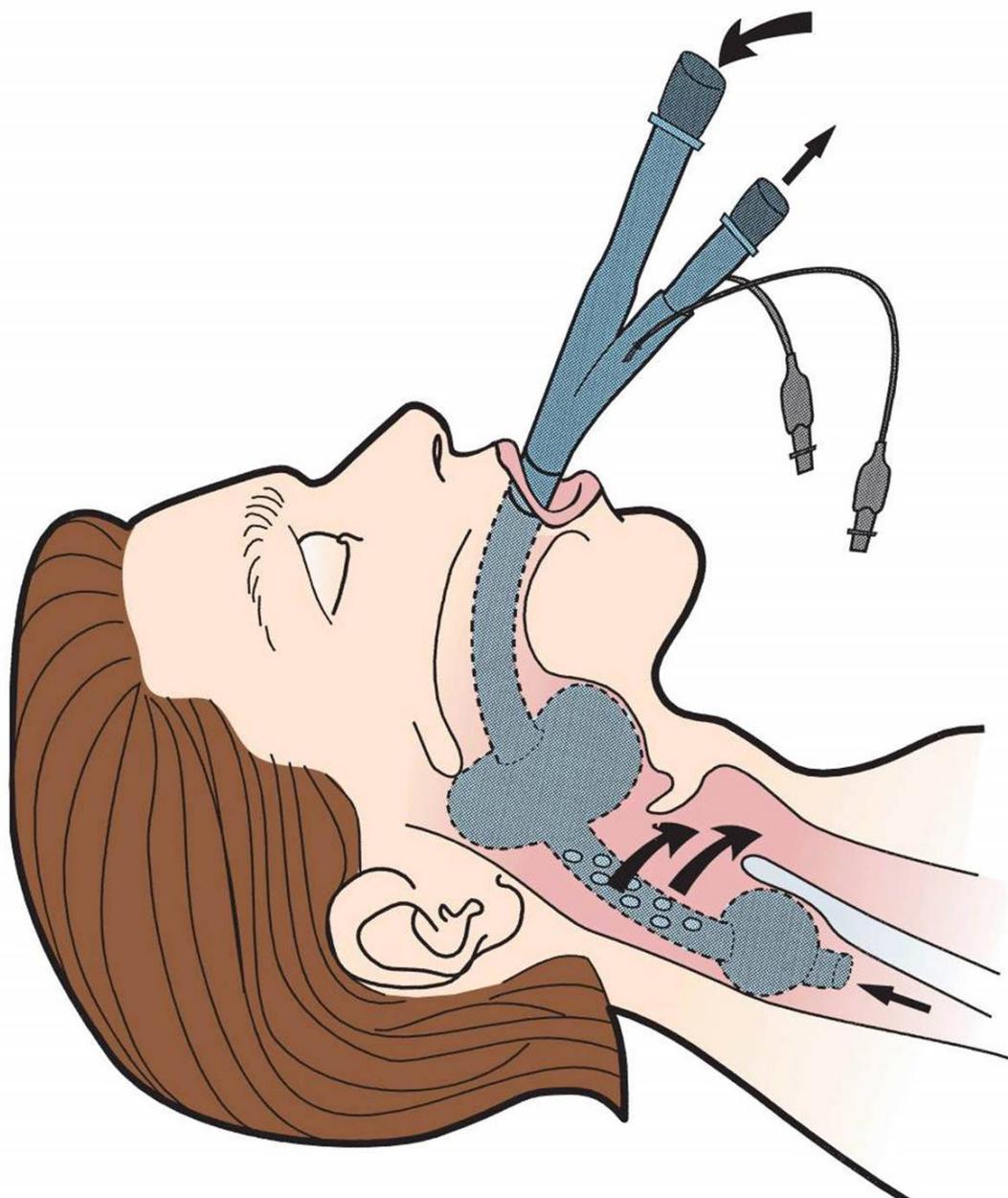


Figure 10-4. Placement of the dual-lumen Combitube. Note the perforations through which ventilation takes place while the tube is anchored in the esophagus. From *Trauma, seventh edition*, by Toschlog, Sagraves, and Rotondo.

The Combitube can be used for manual ventilation or mechanical ventilation. Its relative ease of use has led to its progressive replacement of the

endotracheal tube (or related airways) in cryonics since the mid-2000s. Prior to the introduction of the Combitube, the Esophageal Gastric Tube Airway (EGTA) had been included in standby kits and its placement was taught in cryonics transport courses. Like the Combitube, the EGTA prevents stomach contents from entering the trachea and the placement of the tube in the esophagus eliminates the need to visualize the vocal cords. The EGTA can also be used for administration of medications (such as Maalox) to the stomach. Unlike the Combitube and KING airway, the EGTA comes with a face mask with two ports for ventilation and stomach suctioning tubes. In contemporary emergency medicine, devices such as the Combitube have all but replaced the EGTA.

The King Airway

This is another supraglottic airway device that delivers air/oxygen to the patient above the level of the vocal cords. Unlike the Combitube, the King airway is a single lumen device with a single inflation port that eliminates the learning curve associated with the dual-lumen method of the Combitube. The King airway comes in a number of versions, the preferred version for cryonics being model LTS-D which allows passing of a gastric tube through a second channel of the airway to administer Maalox. The King airway is available in a number of color-coded sizes for infant, child, and adult use.



Figure 10-5. The King LTS-D Disposable Laryngeal Tube.

Liquid Ventilation

In liquid ventilation the lungs are directly oxygenated by cyclic introduction and withdrawal of an oxygen-carrier liquid, typically a perfluorocarbon. Liquid ventilation can be used to provide oxygen in situations where routine or emergency ventilation are not feasible or desirable, such as in cases of cardiac or lung trauma. In cryonics, liquid ventilation is envisioned as a means to rapidly cool the patient through the lungs without the necessity of surgical access. This concept is explored in Section 12.

Liquid ventilation (or cyclic lung lavage) can be achieved via a standard endotracheal tube.

Cardiopulmonary Bypass

Emergency cardiopulmonary bypass can be used either during the initial stages of stabilization to restore circulation and oxygen or at a later stage of stabilization as means to internally cool the patient. Since putting a patient on cardiopulmonary bypass requires invasive surgery and cannulation (such as femoral-femoral cannulation), it cannot be considered a substitute for other means of restoring oxygen. Even if rapid emergency surgery is performed to

put the patient on bypass within minutes it is still necessary to ensure adequate circulation and ventilation before the procedure can be started.

Since cardiopulmonary bypass is mainly used as means to substitute an organ preservation solution for the blood, and to expedite cooling, it has been invariable practiced as strategy for blood washout and inducing hypothermia prior to shipping. As a matter of fact, with the exception of a small number of cryonics cases (brief review below) that involved the participation of cardiothoracic surgeon Jerry Leaf and cryonics researcher Michael Darwin, oxygenation during cardiopulmonary bypass in cryonics has been all but abandoned.

In ideal cases, it could be beneficial to continue oxygenation during cryoprotective perfusion, but cryonics cases in which this approach was pursued are even rarer than cases with cardiopulmonary bypass where oxygen was introduced during the procedure.

Cardiopulmonary bypass as a means of meeting oxygen demand stands apart from all other means of ventilation (including liquid breathing technologies) in that it does not require access to the patient's airway (although it could be combined with conventional ventilation). Oxygenation during cardiopulmonary bypass does not tie a cryonics team to a specific surgical protocol provided that the site chosen for cannulation allows for meeting the oxygen demands of the body. In practice, cryonics organizations prefer not to use the aorta (median sternotomy) in the field because it requires more skill than alternatives such as femoral-femoral bypass and it ensures that the heart and associated vessels are not damaged prior to cryoprotective perfusion.

Methods of Ventilation

In cryonics there are four distinct modes of providing oxygen or air to the patient: manually, mechanically (automated), cardiopulmonary bypass, and through oxygen-carrying solutions (which can be conducted in a manual or automated fashion). One of the great challenges of ventilation is to determine the right volume, frequencies, and pressures in the absence of physiological breathing. In ideal circumstances, blood gases and expired air would be

continuously monitored to match oxygen demand and oxygen needs. In a typical cryonics case, team members usually have to rely on emergency ventilation conventions and occasional feedback such as oxygen saturation and end-tidal CO₂ measurements.

The most common method of ventilating the cryonics patient in recent years involved the use of a bag-valve mask, either through securing the mask or through connecting the bag to an airway like the endotracheal tube or Combitube. The typical bag has a volume of approximately 1600 ml of air. Two hands should be used to completely squeeze the bag – observe chest rise and repeat after 5 seconds.

Some mechanical cardiopulmonary support devices support automated ventilation, as described in Section 9. Unlike manual bag-valve ventilation in which the patient is ventilated by room air, such devices can introduce 100% oxygen, if that is being used to power the piston of the device. Of the three major mechanical CPS devices that are used in cryonics—the Michigan Instruments Thumper, the LUCAS, and the AutoPulse—only the Thumper has a built-in ventilator.

With the rise in popularity of mechanical CPR devices without an integrated ventilator there has been an increased need in cryonics to identify affordable stand-alone mechanical ventilators. This need has not been met in many cases, but there have been a number of exceptions in recent years.

The Surevent SV2 is a unique device which does not require electrical power but does use a source of pressurized oxygen. It consists of a pressure regulator which delivers cycles of oxygen from a source of up to 50psi. It is light and easy to set up, is only a fraction of the cost of hospital mechanical ventilators, and ventilates until a specific pressure is reached, the peak inspiratory value being 20cm H₂O (although this can be adjusted). Flow rates range from 10 to 40 liters per minute. The ventilation rate can be set based on chest rise or ETCO₂ readings. One interesting feature is that the surevent allows for integrated PEEP. A battery-powered manometer is included in the SV2+. See Figure 10-6.

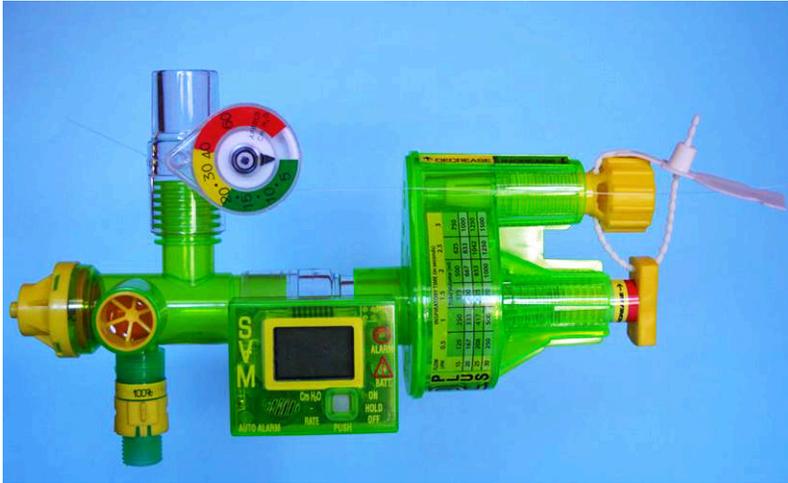


Figure 10-6. The Surevent SV2 attaches to an oxygen source and delivers metered inspirations to the patient. The SV2+ includes a battery-powered manometer, shown in this photograph.

Pulmonary Edema

One of the most notable problems in cryonics is the presence of pulmonary edema. This can be present prior to pronouncement of legal death as a consequence of terminal illness or acute insult, but is also a typical consequence from prolonged (mechanical) chest compressions. Pulmonary edema is also often associated with blood washout and cryoprotective perfusion, in particular under conditions of prolonged circulatory or respiratory arrest.

The most basic treatment for pulmonary edema is to supply oxygen. Other conventional treatments include PEEP, medications to reduce preload and afterload, suctioning, and diuretics that remove fluid from the circulatory system.

The most practical treatment in cryonics is negative pressure drainage of fluid from the lungs. Although Alcor standby kits have usually included inexpensive manual suction devices, the consensus among experienced cryonics practitioners has been to recommend more powerful portable machines such as the one displayed in Figure 10-7.



Figure 10-7. A Laerdal suction unit. It allows the option of battery power.

Another powerful treatment for pulmonary edema is liquid ventilation. Although the concept was not developed in cryonics with the intention of treating pulmonary disorders, it can remove fluids from the lungs by exploiting the fact that perfluorocarbons are heavier than water. As the perfluorocarbon liquid descends to the bottom of the lungs, water-based fluid rises above it and can be suctioned out.

Hypothermia and Oxygen Requirements

As the brain temperature of the patient decreases, so will oxygen demand. As a rule of thumb, a decrease of 10 degrees C in temperature will reduce cerebral

oxygen demand by 50%. A further drop of 10 degrees will reduce oxygen demand by a further 50%, and so on. This rule allows a cryonics stabilization team to interrupt chest compressions and ventilations at a temperature of approximately 20 degrees C to perform surgery and prepare the patient for remote blood washout or cryoprotective perfusion procedures.

In theory, as the temperature decreases, ventilation frequency should also decrease proportionately with decreased oxygen demand. In practice, such a linear protocol is hard to achieve using manual ventilation or the ventilation function on the Thumper. A more practical protocol would be to reduce ventilations by 50% when a temperature of 27 degrees C is reached. Oxygen saturation measurements and end-tidal CO₂ measurements can be used to time and review changes in ventilation.

Ventilation Adjuncts

There are a number of ventilation adjuncts to improve emergency ventilation or to deal with specific pathophysiological circumstances. In this chapter I will briefly review the use of the ResQPOD and PEEP.

The ResQPOD is an Inspiratory Impedance Threshold Device that is used in conjunction with chest compressions to improve cardiac output. While the aim of this adjunct is to improve blood flow its mechanism of action is to prevent positive-pressure ventilation during the decompression phase of chest compressions.

PEEP stands for positive end-expiratory pressure. This is the pressure in the lungs above atmospheric pressure that exists at the end of expiration. PEEP can be used to keep the lungs inflated and decrease intra-alveolar water accumulation (edema) during CPS. Although PEEP valves and bag-valve masks with PEEP have been included in cryonics standby kits, there is no documented history of deliberate use of PEEP in cryonics.

Monitoring Ventilation

A detailed review of monitoring options is provided in Section 14, but a brief review is included below.

Observation: Signs of good ventilation include breathing sounds, consistent chest expansion, and change of skin color (in the case of prior hypoxia, skin color should change from blue to pink).

Pulse Oximetry: Pulse oximeters can be attached to a finger (or ear lobe) to monitor pulse rate and oxygen saturation levels and are usually included in the standby kits of cryonics organizations for monitoring the patient prior to pronouncement. Its use during CPR is controversial because of the lack of a good signal and erratic readings. This situation may be aggravated in cryonics as a result of aggressive vasopressor use, hypothermia, and splashing of water. But bearing in mind the ease of taking pulse oximetry readings, pulse oximetry may be worthwhile when looking for trends.

End-Tidal CO₂: A good, and non-invasive indicator of cardiac output and oxygenation during CPS is end-tidal CO₂. This is the partial pressure of carbon dioxide (CO₂) at the end of an exhaled breath. In emergency medicine, disposable colorimetric ETCO₂ detectors are often used. More recently, compact numeric field capnometers have become available such as the Capnocheck. Normal ETCO₂ levels are between 35 and 45 mmHg. End-tidal CO₂ readings can also be used to validate proper endotracheal intubation. In the case of poor placement (in the esophagus), readings will be low or negligible.

Case Report Examples

Although ventilation and oxygenation of patients has been a standard procedure in the history of cryonics, cases in which ventilation procedures were described in detail and analyzed have been relatively rare. The following table identifies cryonics cases where ventilation and oxygenation were carried out in other procedures than CPS (as documented in the report) and where other ventilation/oxygenation challenges are described in some detail.

A-1068 (1985)	CPB oxygenation, CPA oxygenation, and blood gas analysis
A-1133 (1987)	Pulmonary edema, suctioning, CPB oxygenation, CPA oxygenation, and blood gas analysis
A-1165 (1988)	CPB oxygenation

A-1036 (1988)	CPB oxygenation
A-1169 (1998)	Blood gas analysis
A-1049 (1990)	ETCO2 monitoring, CPB oxygenation, <i>Nitrogen</i> CPA perfusion, and blood gas analysis
A-1312 (1991)	ETCO2 monitoring
A-1260 (1992)	ETCO2 monitoring, discussion of airways and suctioning, and (low flow) CPB oxygenation
A-1184 (1992)	Pulmonary edema
A-1871 (1995)	Pulse oximetry, ETCO2 monitoring, CPA oxygenation, and blood gas analysis
A-1110 (1997)	Blood gas analysis
A-1876 (2002)	Pulmonary edema, ETCO2 monitoring, perfluorocarbon cooling
A-2020 (2003)	Pulse oximetry
A-2024 (2005)	ETCO2 monitoring, administration of medications through endotracheal tube
A-2071 (2005)	CO2SMO (Capnograph/Pulse Oximeter)
	CO2SMO and SUREVENT Emergency Transport Ventilator
A-2420 (2009)	Mechanical ventilator, ETCO2 monitoring, and blood gas analysis
A-1556 (2010)	CO2SMO for patient assessment

As can be seen from this table, the practice of CPB oxygenation and CPA perfusion oxygenation have been abandoned since the early 1990s with only one case of CPB oxygenation in 1995, executed by BioPreservation, Inc. under contract with CryoCare Foundation. As a general rule, oxygenation of the patient since that period has been confined to ventilation during cardiopulmonary support.

Blood gas analysis has also been all but abandoned with only a recent exception in a recent (2009) case performed by Suspended Animation under contract with Alcor.

The 2000s continued to see occasional cases with end-tidal CO₂ monitoring and the use of more sophisticated capnography equipment such as the CO₂SMO. Since mechanical CPR devices such as the Lucas and the Autopulse do not support ventilation, a number of cases have seen the use of automated emergency ventilators. One Alcor case, A-1049 in 1990, shows the addition of nitrogen to the perfusion circuit during cryoprotectant perfusion to

protect the patient against oxygen-induced reperfusion injury. To our knowledge, such a protocol has never been repeated in cryonics.