9. Cardiopulmonary Support: Circulation

Cardiopulmonary resuscitation, often referred to as CPR, was developed to resuscitate patients who have no respiration or pulse but have not been pronounced legally dead.

In a cryonics case where death has been pronounced, we do not wish to promote resuscitation. We have the more limited objective of minimizing cerebral injury by circulating oxygen, glucose, and anti-ischemic medications in the blood stream. We will refer here to this procedure as *cardio-pulmonary support*, or CPS, to differentiate it from CPR.

This section focuses on CPS that has the primary goal of promoting circulation of the blood by applying external chest compressions to reduce the volume of the chest cavity and squeeze the heart.

Section 10, which follows, will focus on CPS that has the primary goal of ventilating the lungs by forcing air or oxygen down the trachea after a patient has been intubated.

In modern cryonics practice, it is preferable to ventilate cryonics patients receiving CPS with air rather than oxygen due to studies showing that patients resuscitated after cardiac arrest in conventional medicine suffer less brain injury if ventilated with air during the post-resuscitation interval. Pure oxygen may worsen post-ischemic injury caused by free radicals. See Section 10 for additional details.

History

In 1874, the German surgeon Moritz Schiff is reported to have used open-chest cardiac massage on an animal model in the physiology laboratory at the Institute of Advanced Studies in Florence, Italy. Schiff had been comparing the effects of anesthetics, and showed that he could induce circulation by

massaging the heart after cardiac arrest had been caused by chloroform. As the anesthetic started to wear off, the heart resumed beating spontaneously.

During the early 1900s, this procedure was used intermittently on human patients, initially with mixed results. Today heart massage is still an option during surgery where the chest has already been opened, or for patients in a hospital who have a chest incision that can be reopened quickly. It is usually done in conjunction with medications and a defibrillator, and has the advantage of providing more cardiac output than external, closed-chest cardiac massage.

The concept of closed-chest massage was explored in Germany in the late 1800s, but, surprisingly, fell into disuse until being revived decades later by William Kouwenhoven, a retired electrical engineer who was investigating the use of electric current to defibrillate the heart at Johns Hopkins University. After Kouwenhoven noticed that merely placing a heavy weight on the chest of an anesthetized dog would elevate its blood pressure, he developed a method to apply chest compressions with a success rate of about 70 percent for resuscitation after cardiac arrest.

In 1960, when Kouwenhoven was 74, an account of his work was published describing how the heel of one hand should be placed on top of the sternum, the other hand should be placed on top of the first hand, and firm pressure should be applied downward approximately 60 times per minute. Today, the goal is to apply 100 to 120 compressions per minute, but the basic procedure remains the same.

The use of chest compressions was endorsed by the American Heart Association in 1963, and was popularized by Peter Safar, who is often referred to as the “father of CPR” even though the technique was developed collaboratively.

Safar insisted that doctors should not be the only people allowed to administer chest compressions, and his advocacy was successful despite strong opposition from medical professionals. A similar situation exists in cryonics today where volunteers may be encouraged to provide some kind of cryonics first response (chest compressions, cooling, and administration of anti-clotting medications) if a professional standby team cannot respond in a timely fashion.

CPR is now recognized in the United States and most other countries as an acceptable intervention that anyone with minimal training may administer, without fear of legal repercussions, in an effort to revive a victim of cardiac arrest. There is no statutory limit on the length of time for which CPR may be applied.

CPS Scenarios

Four scenarios (two of them ideal, and two of them non-ideal) may help to illustrate the role that chest compressions may fill in a cryonics case.

Cardiac Arrest Scenario with Favorable Outcome

A member of a cryonics organization suffers unexpected cardiac arrest at home in his kitchen. Half an hour passes before he is discovered by two relatives. One of them begins to administer chest compressions while the other calls the cryonics organization and a local team of paramedics. The relatives take turns doing vigorous chest compressions, with ventilation of the lungs, for the next hour. The patient shows no vital signs. When paramedics arrive, chest compressions are interrupted long enough to allow attempts to restart the heart with a defibrillator. These attempts are unsuccessful. A phone call to the patient's physician confirms a recent medical history of cardiovascular problems. An autopsy will not be necessary. Death is pronounced, and chest compressions are continued by family members while ice is placed around the head. Standby team members from a local group of cryonicists arrive and continue chest compressions while administering medications and moving the patient to a local mortuary, where stabilization is completed prior to transport. Chest compressions probably played an important role in this case.

Disease Scenario with Favorable Outcome

A patient who has made arrangements to be cryopreserved after death has checked into a hospice less than 10 miles from the cryonics organization. The patient is dying from problems associated with metastatic cancer. Standby personnel are present. Relatives are also present, but have been fully informed and are not hostile to the procedures. A hospice nurse has agreed to honor the

patient's wishes for cryopreservation. Eventually, cardiac arrest occurs. The hospice nurse has authority to pronounce legal death, and does so. Immediately, the team members apply chest compressions and start to administer medications while the patient is moved by a purpose-built transport vehicle to the cryonics facility, where the operating room has already been made ready for cryoprotective perfusion. Here again, chest compressions are an important part of the intervention.

Four Accidental Death Scenarios with Unfavorable Outcomes

A man suffers cardiac arrest in his home workshop. He languishes for an hour or more at room temperature, without any intervention, because:

He lives and works alone, or

People who find him don't know how to do CPR, or

They do chest compressions for 10 minutes and then give up, or

Other severe injuries have occurred (for example, massive bleeding) which encourage emergency personnel to feel that CPR is pointless.

Four Disease Scenarios with Unfavorable Outcomes

A person who is hospitalized suffers a stroke. The heart continues beating, but respiration does not return spontaneously. The patient is placed on a ventilator and remains in a coma. The stroke causes brain damage that is irreversible because:

Hospital protocol requires a time-consuming MRI before life support can be discontinued and cryopreservation personnel can intervene, or

Relatives refuse to allow removal of the ventilator, or

Standard hospital procedures suggest an autopsy, and no one objects to this, or

The patient has left no instructions for procedures under these circumstances.

The above examples are all based on various actual cryonics cases. While underlining the obvious conclusion that ideal scenarios are rare compared with non-ideal scenarios, they also indicate that difficult judgment calls may be necessary when deciding whether to apply CPS.

Advisability and Duration of CPS

The amount of warm ischemic time that has elapsed before pronouncement will determine whether we wish to apply minimal chest compressions (just enough to circulate an anticoaugulant) or prolonged, vigorous chest compressions, continuing throughout administration of a full range of meds, up to the point where blood washout begins. Explaining this scenario persuasively to medical personnel or relatives is important but can be challenging and may take valuable time.

Instructing Bystanders to Administer CPS

The difference between a good case and a suboptimal case may depend on next-of-kin who know how to administer chest compressions or can receive instructions over the phone from EMS (911 call) if medical resuscitation may still be possible and is desirable (no terminal illness), or from a well-informed employee at a cryonics organization if legal death has already been pronounced. A family member who has just discovered the lifeless patient may be too distraught to provide help unless telephone advice is calm, patient, compassionate, and precise.

In one Alcor case, the son of a member called for advice just minutes after he had found his father with no heartbeat and had called paramedics. The paramedics gave up trying to resuscitate the member while the son was on the phone with Alcor. The son stated that his father, who was a doctor, had a vial of heparin and had asked for it to be injected in case of death. After an autopsy waiver was obtained from the coroner's office, the son was advised how to do this in absence of blood pressure, and then administered sufficient chest compressions to circulate the medication. Patience and kindness were essential to maintain assistance from the son. The case later perfused successfully.

Unknown Outcome

Anyone can learn to do chest compressions in a brief, low-cost class provided by a county health department or fire department. However, chest compressions have little value unless they are administered very vigorously, as soon as possible after cardiac arrest, and without significant interruptions. Strength and stamina are essential if the compressions are done manually.

The outcome of chest compressions is unpredictable. Even when they are administered according to the usual guidelines, they cannot create normal blood flow and pressure. Consequently, manual CPS alone may fail to prevent brain damage, even under relatively ideal circumstances. For this reason, vigorous chest compressions should always be augmented by induction of rapid cooling and administration of neuroprotective medications.

Normal Mean Arterial Pressure (MAP) is between 70 and 110 mmHg. MAPs of ~ 50/ 60 and higher are associated with cerebral viability. Manual CPR is rarely higher than 40 mmHg. Conventional CPR typically generates around one-third to one-quarter of normal cardiac output. This is generally not sufficient to meet cerebral energy demands and should only be used as a bridge to defibrillation (in conventional medicine) or blood washout (in cryonics).

In cryonics patients, cardiac output may be further compromised because many patients are atherosclerotic and/or have gone through a prolonged period of shock or multiple organ failure prior to pronouncement of legal death. However, in ideal cases, securing cerebral viability may still be feasible if aggressive multimodal techniques are used. An example of such a scenario would be a case where the team is able to intervene immediately after pronouncement of legal death; circulation and ventilations are promptly restored using a mechanical device capable of active compression-decompression CPS; a respirarory impedance valve is attached to the airway to improve venous return to the heart; blood pressure is supported by vasopressin and/or epinephrine; and rapid administration of neuroprotective medications and induction of hypothermia are started to protect the brain until blood substitution or cryoprotection is possible.

Risk of Resuscitation

If chest compressions are administered very quickly after cardiac arrest, and the patient had a rare neurological adaptation to low cerebral blood flow as a consequence of chronic vascular disease, there is a theoretical risk of restoring consciousness. We are not aware of any cryonics case where this has actually occurred, bearing in mind that terminal patients typically lose consciousness or become semicomatose before the heart stops beating. Furthermore, general anesthesia is a side effect of the anesthetic administered to decrease cerebral metabolism for neuroprotection during cryonics stabilization procedures. Cardiac autoresuscitation during CPS is prevented by administration of sodium citrate for anticoagulation. Citrate causes cardioplegia by chelating calcium.

Conventional Application

The following steps for administering chest compressions incorporate standard guidelines from the American Heart Association.

1. First be sure that the heart has stopped beating. If you are not experienced in taking a pulse, ask someone who is. Respect the judgment of any professionally qualified nurse, doctor, EMT, or paramedic. A weak pulse may be easy to miss.

2. The patient should be on a low, flat, rigid surface.

3. Locate the xiphoid process, which is a tab of bone extending downward from the junction of the ribs at the front of the body. From this point, shift your hand toward the head of the patient by a short distance equal to the width of two fingers pressed together. This is the lower limit of the area where you need to apply pressure. In Figure 9-1, the xiphoid is shown in red while the safe area for chest compressions is shown in green. Do not press on the xiphoid process itself. If it breaks off, it can puncture or lacerate the diaphragm, or may damage the liver, causing a hemorrhage.

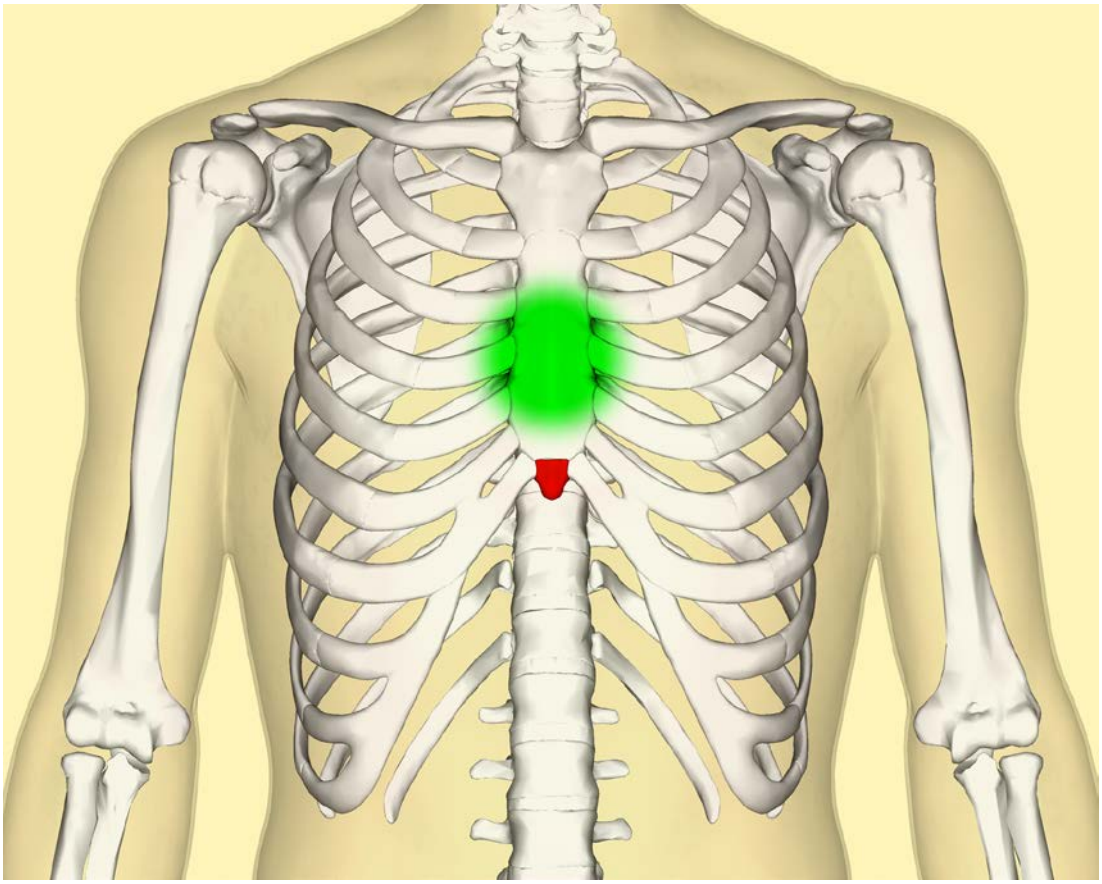

Figure 9-1. Chest compressions can be administered in the green area, while avoiding the xiphoid process, colored red.

4. While kneeling or standing over the patient, extend both arms with elbows completely straight.

5. Bend one hand up toward you and press the heel of this hand in the safe area you have located above the xiphoid process. Interlock the fingers of your second hand with the first, so that the second hand presses down on the back of the first hand. The correct position is shown in Figure 9-2.

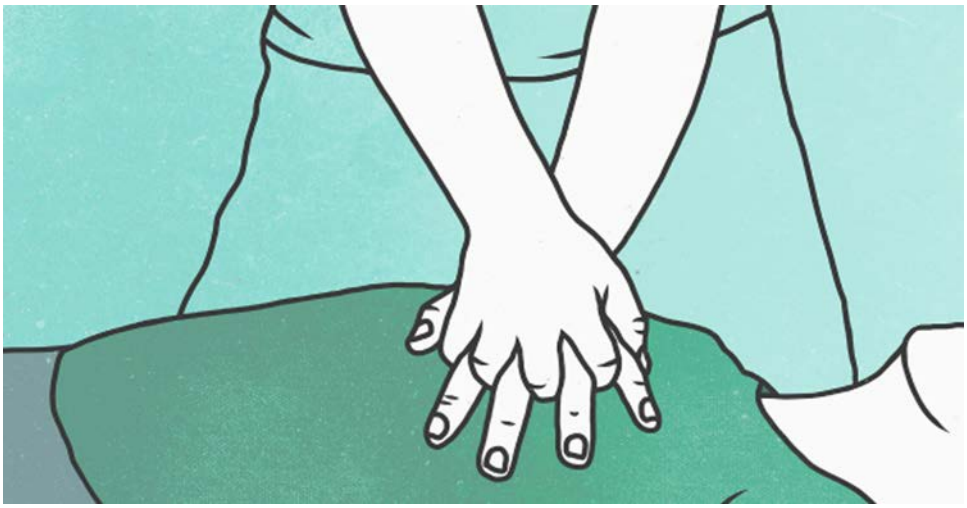

Figure 9-2. Correct use of the hands to administer chest compressions.

6. Press down sharply, with all your strength, with both hands, approximately 100 times per minute, while keeping your arms straight and rigid to transmit the momentum of your body to the patient.

Mechanically Administered Chest Compressions

Under ideal circumstances, immediately following pronouncement of legal death, CPS may be administered by cryonics personnel for up to 90 minutes to maintain blood circulation that will metabolically support the brain and speed patient cooling in an ice bath. This period is much longer than is common when CPR is used in conventional medicine.

Administering vigorous compressions manually for such a long time will be physically impossible for most people, and is a challenge even when two or more people take turns. This was recognized in the early days of cryonics when machines such as the Westinghouse Iron Heart or Brunswick Heart Lung Resuscitator were employed to automate the process of administering chest compressions and ventilations.

The Alcor Life Extension Foundation was a relatively early adopter of the Michigan Instruments Thumper, powered by compressed gas. Subsequently Michael Darwin introduced a specially modified version of the

Thumper that would apply suction to the chest on the up stroke as well as positive pressure on the down stroke.

Suspended Animation Inc. developed its own variant of the Thumper, and resold one to the Cryonics Institute together with an ice bath (see Section 11, Induction of Hypothermia). Alcor and Suspended Animation subsequently acquired electrically powered devices for chest compressions. Details are provided below.

Termination of CPS

Alcor's current protocol is to continue CPS until a temperature of 20 degrees Celsius is reached or when it is determined that the pace of cooling is becoming so slow that performing surgery for washout is the preferred approach. The rationale to continue chest compressions until this temperature is reached is that deep hypothermia allows for surgery to proceed without causing additional brain damage. If there is no washout or cryoprotection, in principle CPS can be continued until the patient reaches the temperature of water ice. There are few cases where such a practice has been documented.

Prolonged Mechanical CPS and Pulmonary Edema

As the duration of (mechanical) CPS increases, its efficacy decreases. Prolonged CPS in cryonics is also associated with a pink frothy foam coming from the patient's mouth or the endotracheal tube. Explanations for this phenomenon include the type of chest compressions (normal vs active compression-decompression CPS), ischemia-induced swelling and damage to the lungs, anti-coagulation, and the administration of fibrinolytics. To address these concerns and incorporate recent research, Alcor has deleted streptokinase from its initial stabilization medications list and added it to the washout or first cryoprotectant perfusion flush instead.

Michigan Instruments Devices

Figure 9-3 shows two early prototypes of chest-compression devices installed in a hospital setting, both using pneumatically powered pistons. Michigan Instruments founder Clare Barkalow tested similar equipment before marketing model 1001 of his own device in 1964. Model 1002 was added as an adjunct system providing ventilation, while model 1003 was marketed in 1969 as the M. I. L. Life Aid, combining chest compressions and ventilation in one unit. In 1972, model 1004 was the first to be named a “Thumper” and added an adjustment for compression depth.

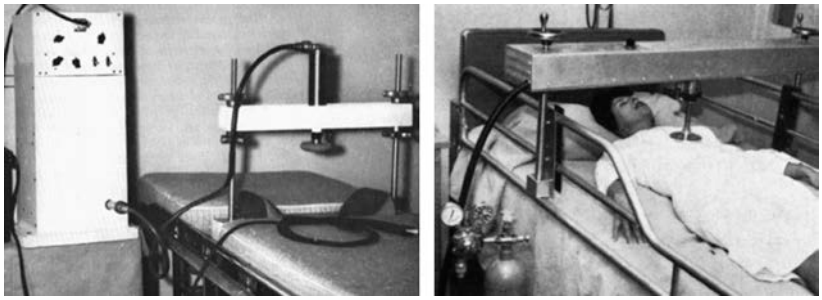

Figure 9-3. Early experimental devices to apply chest compressions.

Minor modifications were incorporated in model 1005, marketed in 1985. This model was purchased by Alcor and used in cryonics cases. Figure 9-4 shows it in low-resolution photographs taken for a transport manual.

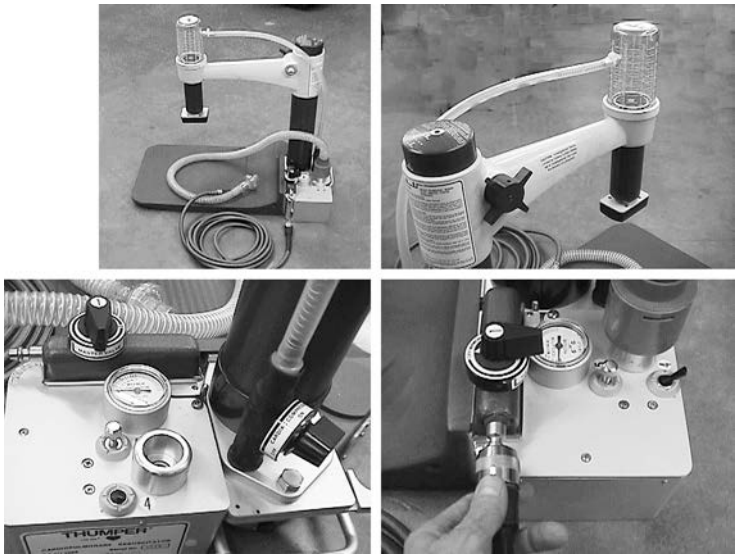

Figure 9-4. Photographs from an Alcor transport manual showing a Thumper used in cryonics cases.

In 1998, model 1007 of the Thumper was introduced, shifting the control knobs from the base plate to a small panel at the end of the movable arm that carries the piston assembly. Initially model 1007 was offered in two variants, 1007CC and 1007CCV. However, the 1007CCV has been replaced by the model 1008, which has dropped the Thumper name and is marketed as the Life-Stat. Unlike its predecessors, which were entirely mechanical, the Life-Stat includes some simple timing electronics. These are powered by a pair of 9V batteries.

The Thumper 1007CC is a simplified product that runs at a fixed rate of 100 chest compressions per minute. Unlike all previous models from Michigan Instruments, it does not ventilate the patient. Figure 9-5 shows the 1007-CC with its parts identified by the manufacturer, and Figure 9-6 shows the very simple control panel.

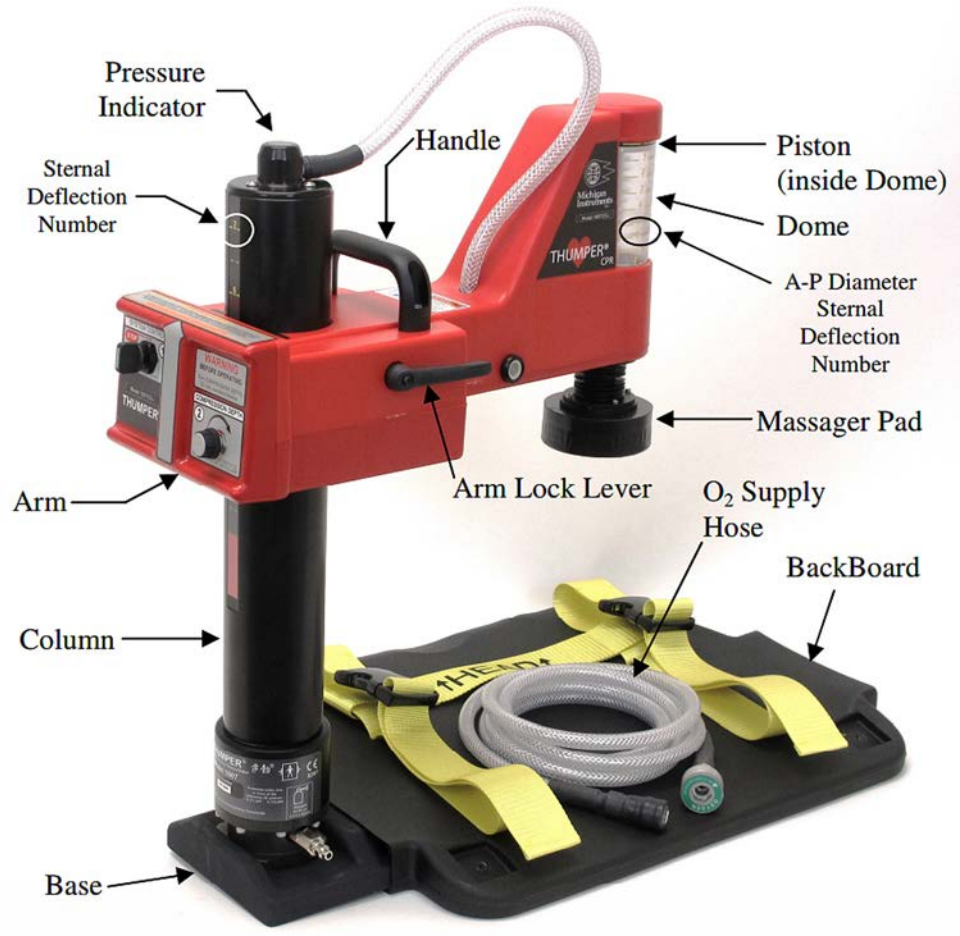

Figure 9-5. The Michigan Instruments Thumper model 1007-CC, which does not administer ventilation cycles.

Figure 9-6. Control panel for the Thumper model 1007-CC.

If the Life-Stat is used, and the patient has been intubated, ventilation can be supplied automatically on either a 30:2 basis (30 chest compressions, pausing to provide 2 cycles of ventilation) or a "CCV" basis (continuous chest compressions while delivering 8 to 9 ventilation cycles at the same time). The unit can be set up by the manufacturer to provide either 100 or 120 compressions per minute. The buyer must make this choice at the time of purchase, as it cannot be adjusted later. Figure 9-7 shows the Life-Stat with its parts identified by the manufacturer, and Figure 9-8 shows the control panel.

Figure 9-7. The Michigan Instruments Life-Stat, model 1008.

Figure 9-8. Control panel for the Life-Stat.

Chest compressions on both of these models and their predecessors from Michigan Instruments are administered with a gas-driven piston mounted on an arm that extends over the patient's chest. A shaft from the piston extends downward to a "chest massager" pad that must be located immediately above the xyphoid process. The arm of the device is lowered until the "massager" touches the chest. The operator then locks the arm in place by turning a lever to clamp the arm to a supporting column.

Before starting the device, it is essential that a dial controlling compression depth must be set to zero. After chest compressions are initiated, the dial is turned up until compressions reach the desired depth, shown by a pointer on a scale

Michigan Instruments products offer some advantages:

- **Simplicity.** The component parts of a Thumper are easy to understand
- **Manually adjustable.** Compression depth can be set by the operator.
- **High impulse.** Compressed gas enables a strong downward force.
- **Ventilation.** The same gas that drives the Thumper can ventilate the lungs (in all models except 1007CC).

However, there are significant disadvantages.

- **Limited duration.** A pair of E-size oxygen cylinders, which can be carried in a custom-designed backpack (shown in Figure 9-9), may last for less than 10 minutes. An H-sized cylinder of oxygen may last between 20 and 30 minutes.
- **Limited portability.** An H-size cylinder is usually available on an ambulance, but it cannot be moved easily from the vehicle as it weighs too much for one person to lift and must be handled with care.
- **Accidents with compressed gas.** If the valve at the end of a gas cylinder is broken off, the cylinder will behave literally like a rocket.
- **Dangerous oxygen accumulation.** If used in a confined space, such as the interior of an ambulance, without adequate ventilation, the large volume of oxygen released from a Thumper creates some risk of an oxygen-fuelled fire. For biological reasons, modern preference is to use compressed air instead of oxygen, which as a side benefit does not have this risk.
- **Vulnerable to error.** An operator must remember to turn the compression-depth dial to zero before starting the equipment. Injury may result if this step is omitted.
- **Noise.** The Thumper, as its name implies, cannot be used discreetly. The release of compressed gas while valves open and close creates a series of hissing, clicking, and hammering noises.

Figure 9-9. A backpack for carrying small oxygen cylinders.

Use of the Thumper in Cryonics Cases

The Thumper design was not entirely compatible with a portable ice bath, because the high sides of the bath prevented the base plate from being pushed under the patient from the side. As a compromise solution, the frame of an ice bath from the 1980s typically included a low section to allow Thumper access. (See Section 11 for a detailed pictorial history of ice baths.)

In a remote location, obtaining oxygen or compressed air to power the Thumper could be a challenge. Bearing in mind that medical gas requires a doctor's prescription, welding gas was sometimes purchased as a substitute, from a local industrial supplier if one was available (they were usually closed on evenings and weekends). A transport manual written by Michael Darwin suggested tapping into oxygen supply outlets in hospital rooms, and included pictures of adapters for this purpose. We have no information on how often this was actually done.

The MARC cart designed by Hugh Hixon at Alcor included two mid-sized oxygen cylinders to power a Thumper. Although they were made of aluminum, they increased the weight of the cart to the point where lifting it over a curb to get it onto a sidewalk was problematic. (The MARC is discussed in Section 11.)

Overall, gas supply has been the biggest problem for Thumper models.

Ambu CardioPump and ACDC Thumper

The CardioPump, shown in Figure 9-10, is a small, simple, unpowered device that is held between two hands while the user presses down to administer chest compressions via a suction cup. If the operator pulls up on the CardioPump after each down stroke, some suction can be induced inside the chest cavity, potentially enhancing blood circulation.

The CardioPump has some advantages:

- Some people prefer its use over unassisted manual CPR over long periods.
- A simple gauge shows the pressure exerted with each stroke.

- The suction cup improves cardiac output.

But, there have been some disadvantages.

- Because there is no power assistance, users still get tired.
- Some people feel that the CardioPump is actually more tiring than simple manual chest compressions administered directly with the hands.

The CardioPump was not FDA-approved when it was first introduced, and had to be imported from Canada.

Figure 9-10. The Ambu CardioPump.

In 1996, Michael Darwin commissioned Michigan Instruments to build a customized version of the Thumper that would have a piston shaft terminating in a suction cup instead of a massager. The company declined to assemble this configuration, because the suction cup was not FDA-approved. Therefore the Thumper was delivered with a bare piston shaft with a groove at the end, enabling Alcor to push-fit the suction cup on its own initiative. Together with other features, this created what Darwin referred to as the "ACDC Thumper," referring to its ability to administer Active Compression and Decompression. In Figure 9-11, Darwin is shown setting up the ACDC Thumper, probably during his time as president of Biopreservation, Inc, a service provider that contracted with CryoCare Foundation.

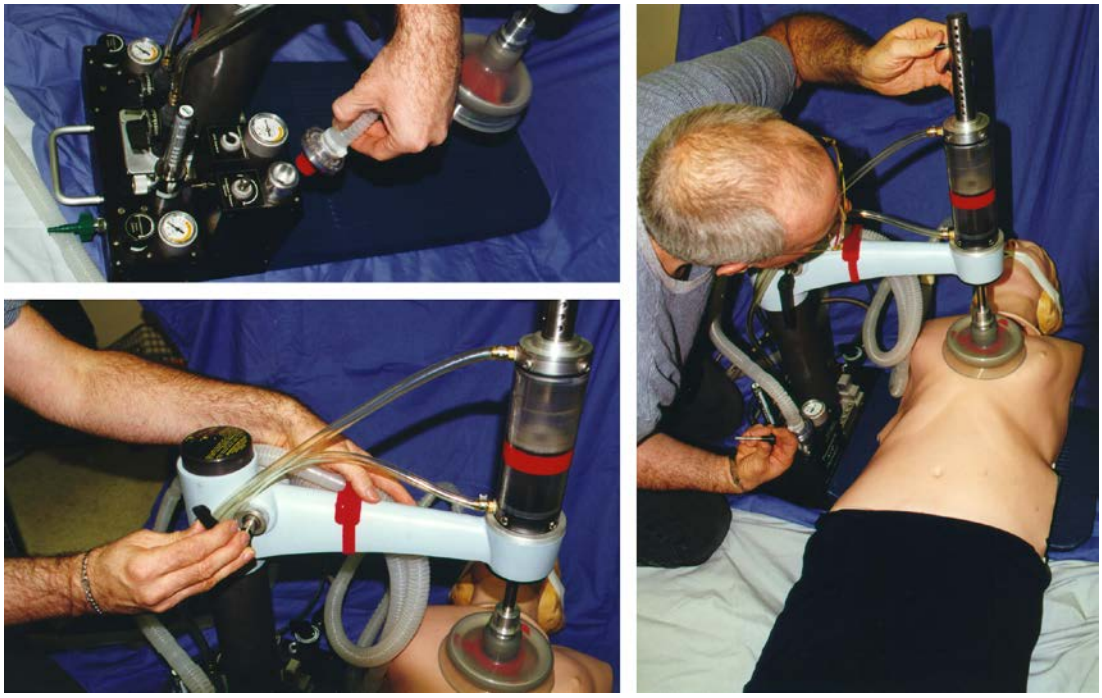

Figure 9-11. Michael Darwin setting up the ACDC Thumper built to his specifications.

Michigan Instruments never did add a suction cup to any of their mass-produced models, but it has been included on the LUCAS system and on the Suspended Animation Thumper (both described below).

Suspended Animation Thumper

In 2003 David Shumaker, David Hayes, and Mike Quinn developed a new portable, collapsible ice bath which had legs raising it to waist height when fully assembled. They commissioned Michigan Instruments to build four Thumpers custom-designed to clamp across the rails of the new ice bath. The aluminum base of the ice bath eliminated the need for a base plate for the Thumper, and the increased length, width, and depth of the bath made it suitable for obese patients.

Figure 9-12 shows the Suspended Animation Thumper on an accessory stand that could be used if the Thumper was not straddling an ice bath. In Figure 9-13, the oxygen intake is visible above an outlet for ventilating the lungs via endotracheal tube. In Figure 9-14, controls can be seen for making independent adjustments to compression depth, decompression force, and ventilation volume. The system is switchable between continuous compressions (no ventilation) and 5:1 ratio of compression cycles to ventilation cycles. All of these features were implemented mechanically, powered by gas pressure. The unit did not contain any electronics.

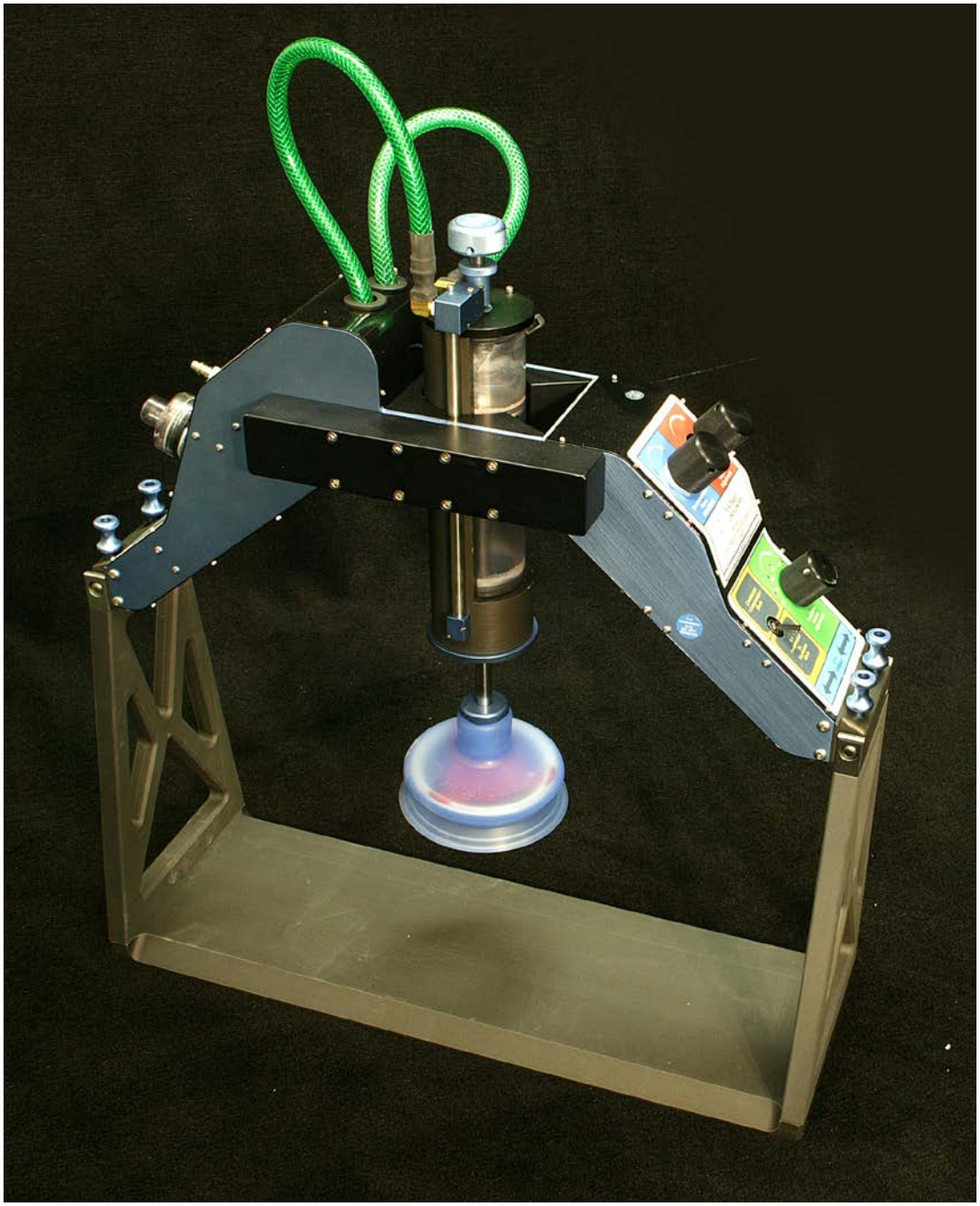

Figure 9-12. The variant of Darwin's ACDC Thumper commissioned by Suspended Animation, Inc, shown here on an accessory stand.

Figure 9-13. Gas intake and outlet on the Suspended Animation ACDC Thumper.

Figure 9-14. Controls on the Suspended Animation ACDC Thumper.

Michael Darwin was a consultant for Suspended Animation while this device was developed by Michigan Instruments. Only four were built. Darwin fully understood the various adjustments, but other operators had trouble with their complexity, especially in stressful situations. The device was used in two cases managed by Suspended Animation before it was superceded by the Autopulse (described below).

Eventually one of the Suspended Animation Thumpers was sold to the Cryonics Institute. It was still featured on the company web site as of 2017.

LUCAS Manufactured by Jolife

LUCAS is an acronym derived from Lund University Cardiopulmonary Assist System. It was developed by Jolife, a Swedish company that has since been acquired by Physio-Control, Inc.

In 2002, at Alcor, Mathew Sullivan ran across a reference online to the LUCAS, which was being launched in Europe. Photographs and sales literature showed that it was equipped with a suction cup and suggested that it would be lighter and simpler than the Thumper, while its small detachable baseplate would allow it to be used in an ice bath without requiring a lowered section in the side rail.

The LUCAS was not yet FDA-approved, and its future in the United States was uncertain. Charles Platt, who was then Director of Cryopreservation Services for Alcor, contacted the manufacturer in Sweden and negotiated the sale of one unit to Alcor for $20,000, after he signed an agreement that it would not be used on any living person.

The LUCAS turned out to be elegantly designed and easy to use, and was Alcor's CPS device of choice for many years. It did not include any provision for ventilating the lungs, but the manufacturer claimed that chest compressions alone provided sufficient passive ventilation. A view of the LUCAS that Alcor acquired is shown in Figure 9-15.

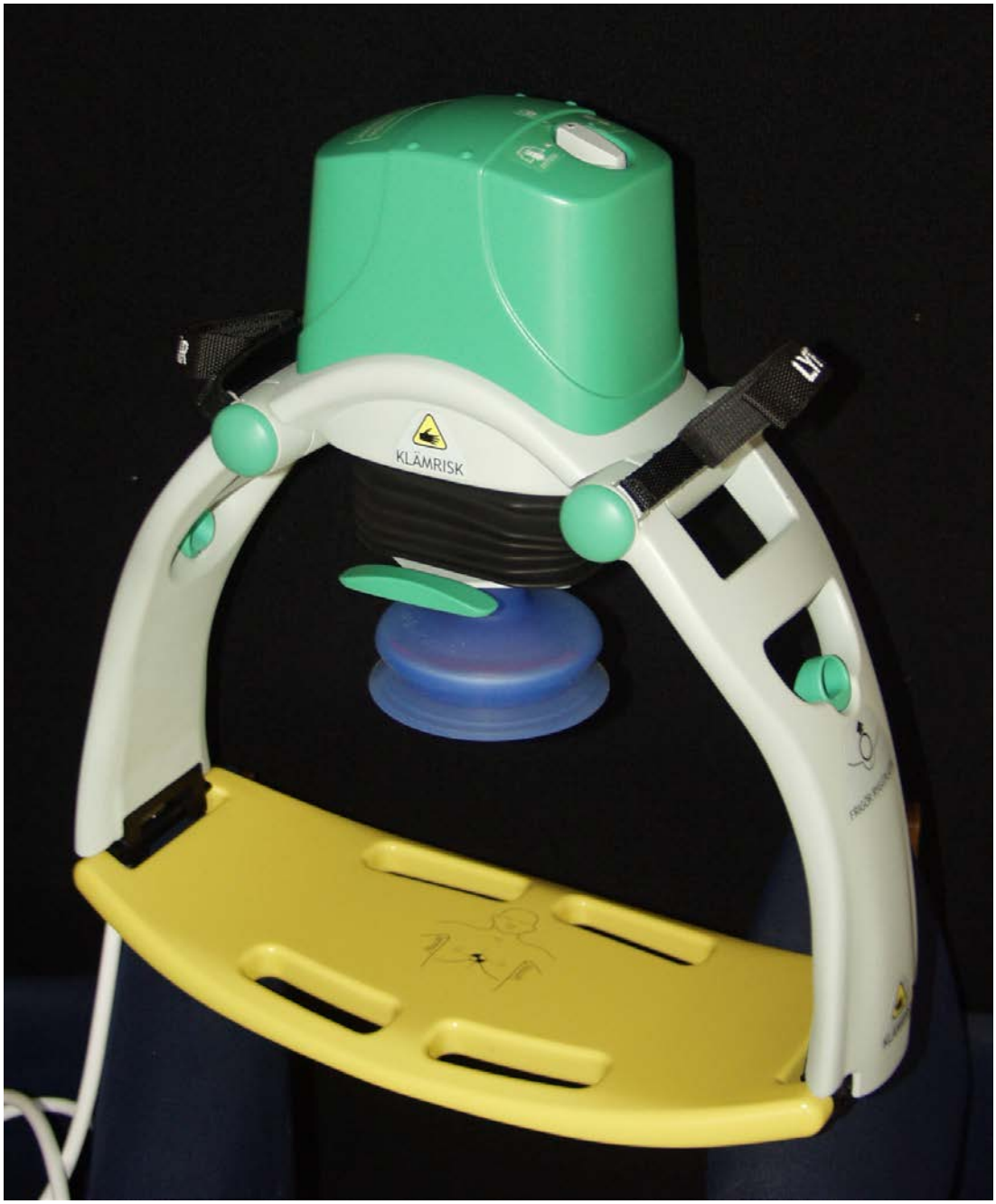

Figure 9-15. The first LUCAS purchased by Alcor.

The primary disadvantage of the LUCAS was that it was still a gas-powered device, requiring heavy oxygen or compressed air cylinders that were

difficult to transport and not always available in remote locations. In addition, the frame of the LUCAS appeared to prevent its use on obese patients. When the manufacturer was queried about this, a representative responded with a humorous and unhelpful comment about the average body weight of Americans vs. Scandinavians.

Late in 2006, the LUCAS finally received FDA approval. It was followed in 2009 by the LUCAS 2, which closely resembled the first model but was electrically powered. It was lighter, quieter, and could run from its own battery, or from a car battery or 110VAC via external adapters. It also allowed a little more vertical room between its suction cup and baseplate, as a concession to obese patients. A photograph of the LUCAS 2, alongside its soft carrying case, is shown in Figure 9-16.

Figure 9-16. The LUCAS 2 became a standard item in Alcor standby work.

The LUCAS 2 included a provisition to operate in 30:2 mode, meaning that it would provide chest compressions for 30 cycles, followed by a pause for 2 cycles during which the operator could supply ventilation manually. Unlike the electrically powered Autopulse (see below), the LUCAS 2 could be used in an ice bath without modification, as its electronics were at the top of the unit, a safe distance from water in the bath.

Using the LUCAS 2 is relatively simple compared with early versions of the Thumper (and is almost identical to the procedure for the LUCAS 1). The baseplate, referred to as a back support and colored yellow in Figure 9-16, is placed under the patient. After the operator has checked that the suction cup is fully retracted, the upper portion of the LUCAS is lowered until it clicks into place with the back support. The operator presses the Adjust button, which allows the suction cup to be lowered manually into contact with the chest above the xiphoid process. The operator now presses the Pause button. Internal electronics readjust the height of the cup optimally, if necessary. The user now presses either the Active button for continuous compressions or the Active 30:2 button for compressions that pause to allow manual ventilation.

The operator must check the LUCAS frequently to make sure that its position remains correct, and to monitor the battery charge indicator. Otherwise, the device is designed to run itself without further intervention, and supposedly optimizes its own depth of its own compressions.

A stabilization strap may be added behind the patient's neck while the LUCAS is running, anchoring it so that it is less likely to shift during operation. If the patient will be relocated (which is likely during a cryonics case), the wrists can be anchored to the support struts of the LUCAS using Velcro straps that are provided.

The LUCAS 3 was introduced in 2017 and stores detailed data from each use, which can downloaded via a Bluetooth connection and printed in nicely formatted charts. This feature would be useful for case report writing and quality control, especially in cases where chest compressions may have been omitted or interrupted. The device is sold in a hard-shell polycarbonate case, unlike the soft case of the LUCAS 2. It also has provision to be recharged without removing it from the case. See Figure 9-17.

Figure 9-17. The LUCAS 3 is supplied with a hard-shell carrying case.

By 2017, an active market had developed for second-hand LUCAS 2 devices. Alcor bought seven of them, and it is now a standard item in Alcor standby kits.

When former Alcor Medical Response Director Josh Lado was asked about the issue of accommodating obese patients, he responded that in his experience, seeing LUCAS devices being used in conventional medicine, the only patient who turned out to be incompatible was a body-builder. Heavy musculature prevented the LUCAS from functioning, but adipose tissue would conform with the shape of the LUCAS frame. A LUCAS document claims that the device can be used on patients weighing up to 350 lbs, and includes a photograph to prove it, shown in Figure 9-18. The document points out that that the LUCAS is designed to encircle the chest—not the belly, where more fat typically tends to accumulate. Literature from Michigan Instruments claims that their equipment will accommodate a patient weighing more than 600 lbs, but no photographic documentation has been provided.

The LUCAS 3, which is no longer being marketed as an active compression-decompression device, was not being used by any cryonics organization as of mid-2019.

Figure 9-18. The LUCAS 3 being applied to a patient who is stated to weigh 350 lbs.

Autopulse

The Autopulse is an all-electric device consisting of a thick backboard containing batteries, motor, and electronics. The patient is strapped into place on the backboard, and a nylon belt is wrapped around the chest. The belt administers chest compressions as it is tightened and released by a motor-driven pulley in the backboard. The Autopulse is shown in Figure 9-19.

A sophisticated system of control electronics includes pressure sensors in the backboard to gauge the tension of the belt, and accelerometers that measure the rate of compressions. However, the Autopulse includes no

provision for ventilating the lungs, and is incompatible with an ice bath, because its motor, power supply, and electronics would be submerged under water.

Figure 9-19. The Autopulse. Its chest compressions are administered by a wide nylon belt that slides through the wrapping visible in the photograph.

Suspended Animation made two attempts to modify the Autopulse for use with an ice bath. Figure 9-20 shows a plan by Charles Platt in which the device would be turned upside down and supported on the side rails of an ice bath, with two aluminum struts extending downward and terminating in pulleys. The chest-compression belt would become a serpentine belt, wrapped around the pulleys and the patient. A prototype, shown in Figure 9-21, was constructed but never worked reliably, as the modifications caused the elaborate built-in system of fail-safe sensors to generate error messages.

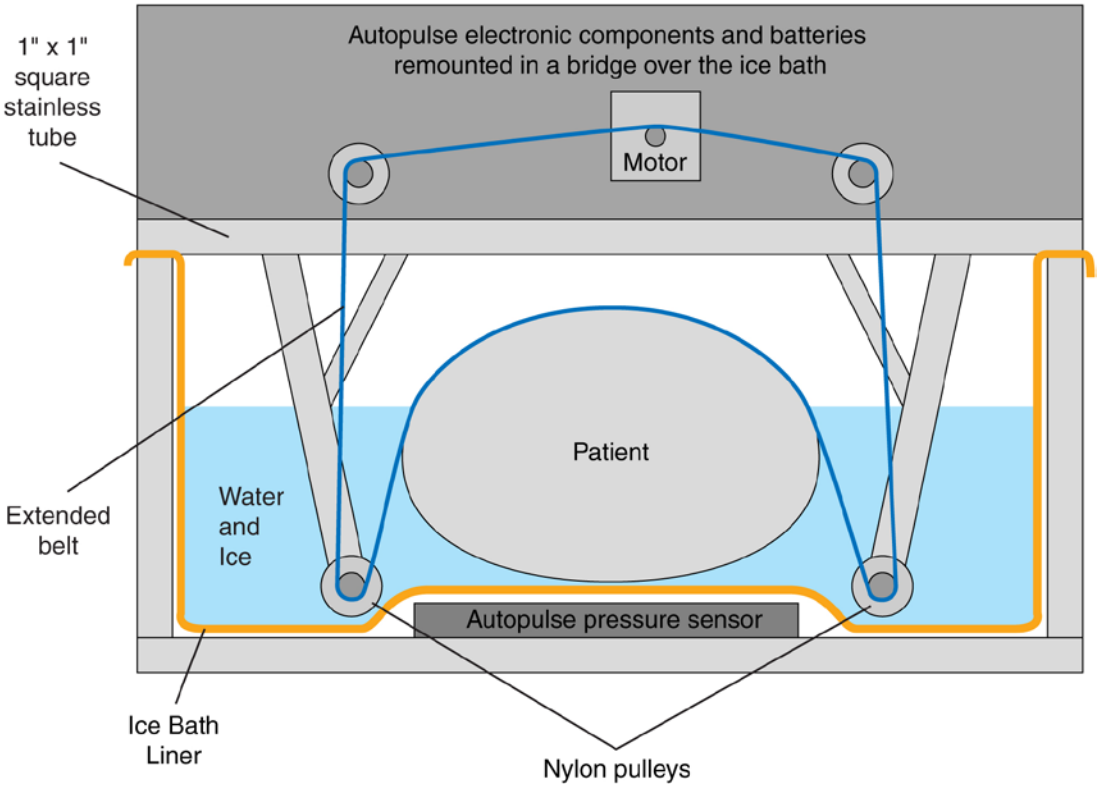

Figure 9-20. A plan for mating an Autopulse with an ice bath.

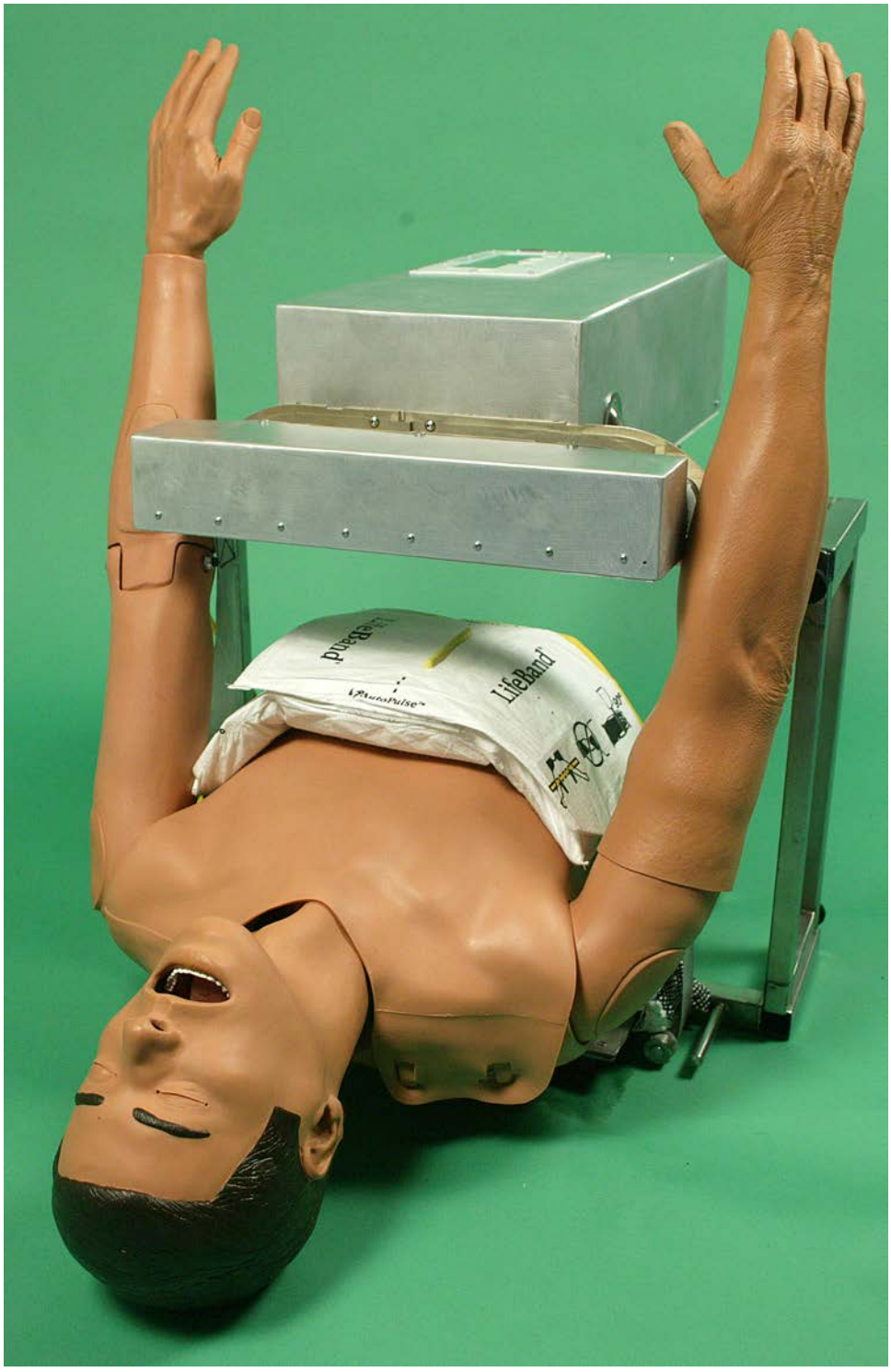

Figure 9-21. A prototype built from the plan in Figure 9-20.

Gary Battiato at Suspended Animation developed a different modification in which the Autopulse was placed under the ice-bath liner, and its chest-compression belt extended upward through two vinyl sleeves that were glued to the liner to prevent water from reaching the device. This design was used with mixed results.

Suspended Animation was still using an Autopulse during 2017. Based on field work that was done on cases shipped to Alcor, two employees at Alcor believe the Autopulse can inflict damage, such as broken ribs, when used on an elderly person for a long period of time. If the ribs perforate organs or vessels in the chest, this kind of damage will interfere with subsequent whole-body perfusion.

We are not aware of any study making a formal comparison between the force administered by LUCAS and Autopulse. Possibly either of the devices can cause significant damage during prolonged use. They were never really intended for the very long periods of compressions that may occur during transport of a patient in a cryonics case.

Cautions Regarding Mechanical Chest Compressions

- Injury. Regardless of whether a chest-compression device is driven electrically or by compressed gas, it is sufficiently powerful to cause injury to the patient or even to the operator if used incorrectly.
- Small patients, including children, may be unsuitable. Using the Thumper, the operator has discretion to reduce the chest compression depth in ratio with the thinness of the body. Using the LUCAS, the system may refuse to enter the “pause” mode or “active” mode after the suction cup has been positioned. Three quick beeps indicate an error state.
- Large patients are unsuitable for the LUCAS if the frame of the device cannot be closed around the body without compressing the suction cup.

- Correct position on the chest is essential. Read instructions provided with the device, and do not proceed if you are uncertain. If a patient has any kind of lubricant on the chest (such as is used by ultrasound technicians), this must be removed to prevent the suction cup from sliding around.
- Chest fatigue occurs while any chest-compression device is running. The resilience of the chest gradually diminishes, so that it doesn't "bounce back." Consequently, compressions become less effective.

Other Mechanical Devices for CPS

Three devices have been found that seem to have been developed to compete with Jolife and Michigan Instruments. They are summarized briefly below. As of mid-2019, none of them had been adopted or tested by a cryonics organization, and their relative advantages are unknown.

The **Brunswick Heartsaver** was demonstrated in 2016 at the EMS World Convention. YouTube videos are online, but the device may not have been marketed. It is driven by compressed gas and provides ventilation as well as chest compressions.

The **Lifeline Arm** was introduced by Defibtech, which already markets defibrillation products. It appears to be a copy of the LUCAS, at a lower price. The unit is battery-driven. It uses a pad to apply chest compressions, not a suction cup. See Figure 9-22.

Figure 9-22. The Lifeline Arm appears to be a LUCAS imitation.

The **Corpuls CPR** was developed by a German company that has been making defibrillators since 1982. Their web site provides no specifications, but the unit appears to be electrically powered. It uses a disc to apply chest compressions, not a suction cup. See Figure 9-23.

Figure 9-23. The Corpuls CPR, developed in Germany.

During 2006, at Suspended Animation in Florida, Charles Platt designed and fabricated a simple, unpowered device using two levers to reduce the strength needed for manual chest compressions. A prototype made from ABS plastic is shown in figure 9-24. It was never tested extensively, and was abandoned when company management was unwilling to finance further development.

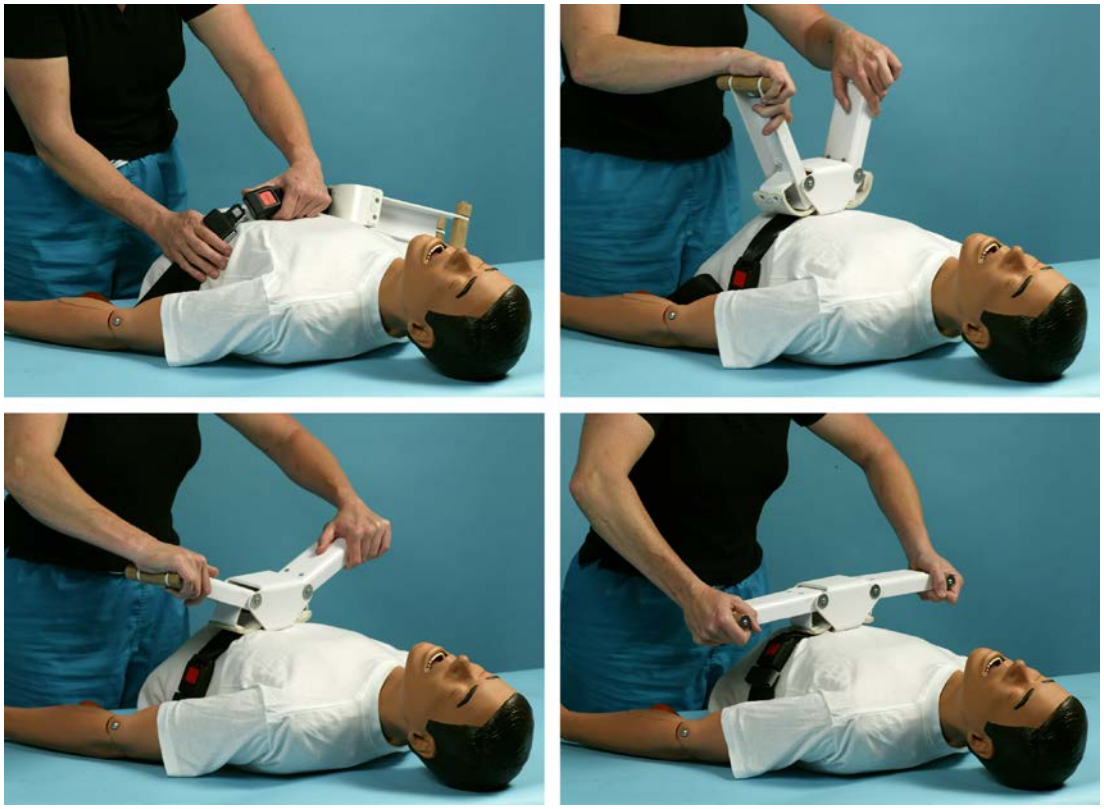

Figure 9-24. This prototype of a device to reduce the strength needed for chest compressions was envisaged as being mass produced and commercially available for less than $30. It could be kept in the homes of cryonics organization members and people with a high risk for cardiac arrest.

Sources

Information about specific products was derived from manufacturers' web sites.

PDFs of the following printed materials describing the history of chest compressions can be found online:

"Cardiac Massage: A Method Rescued from Oblivion" by Philippe Juvin and Jean Marie Desmonts. *Anesthesiology*, the Journal of the American Society of Anesthesiologists, Inc, September, 1998.

"The Introduction of Closed Chest Cardiac Massage" by Steven F. Bolling MD. *Annals of Thoracic Surgery*, 49:154-6, 1990.