IPRO 319 – Development of Solutions to Improve Survival Rate of Cardiac Arrest Patients

Teams

Cooling

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Mask building

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Summary of Fall Semester – 2008

Objective

To prevent brain damage from occurring when the heart is restarted.

I. Problem

Sudden Cardiac Arrest is a leading cause of death in the United States, accounting for an estimated 325,000 deaths each year according to the Heart Rhythm Foundation. Cardiac arrest is different from a typical heart attack because it involves a complete stopping of the heart. Brain injury is likely to occur if the cardiac arrest is untreated for more than 5 minutes and a person cannot be revived after 10 minutes of no action. This is because the arrest sets off a chain of metabolic reactions, which leads to swelling of the brain tissue. Cardiac arrest results in ischemia reperfusion injury, which is when circulation is restored and high levels of oxygen rich blood rushes back into the brain causing brain damage. Decreasing the metabolism of the victim may result in a decrease of ischemia reperfusion injury. Reducing the oxygen level that enters the body when the victim revives and slowly increasing this level may also reduce reperfusion injury. However, current procedures dictate that 100% oxygen be given to cardiac arrest victim.

II. Goals

The goals of this team are to design a device that can be used within first 10 minutes of the cardiac arrest, is simple and cost-effective in order to minimize the potential for human error, and can be integrated into existing AED devices.

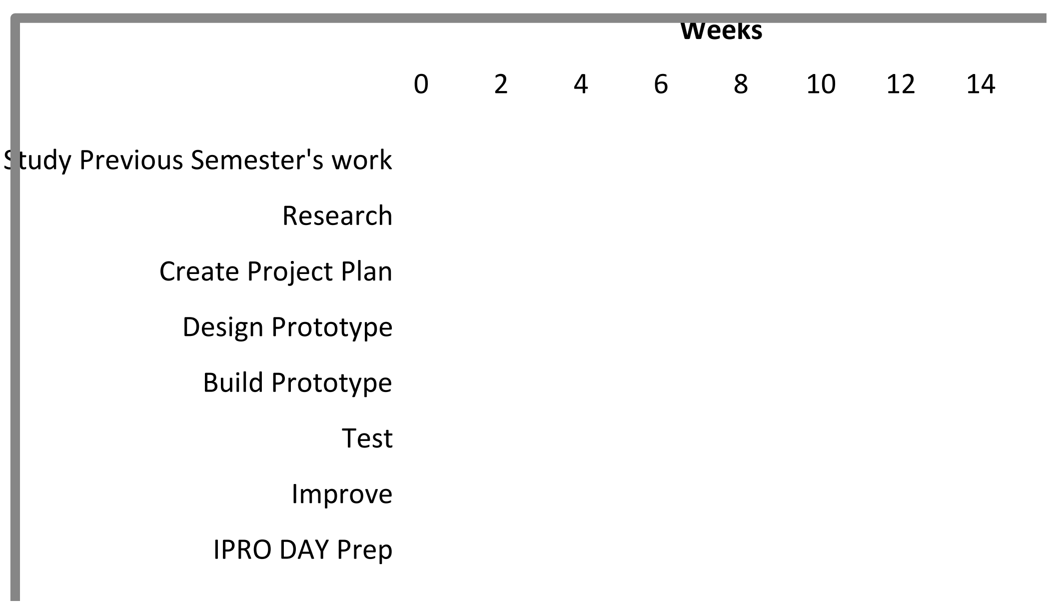
III. Solution

Previous Semester's Work

Last semester's team concentrated primarily on developing a cooling jacket prototype to cool a patient's body. The prototype developed including a basic closed system refrigeration cycle that would circulate coolant through a jacket. The team determined that the best way to accomplish the cooling was by using a chemical called Fluorinert. This substance's boiling point can be adjusted allowing us to set a maximum cooling temp the patient can undergo. Thirty-three degrees is the goal temperature and with Fluorinert, the boiling temperature can be made to be thirty-three degrees so the patient is not cooled below that temperature.

Fall 2008 Work

This semester, the team concentrated on improving the cooling jacket prototype from last semester by performing more tests on coolants. In addition, the team also built a prototype of a breathing mask that will give a cardiac arrest victim a decreased level of oxygen initially and increase this level over time to prevent ischemia reperfusion injury. The breakdown of the work is shown in the following graph.



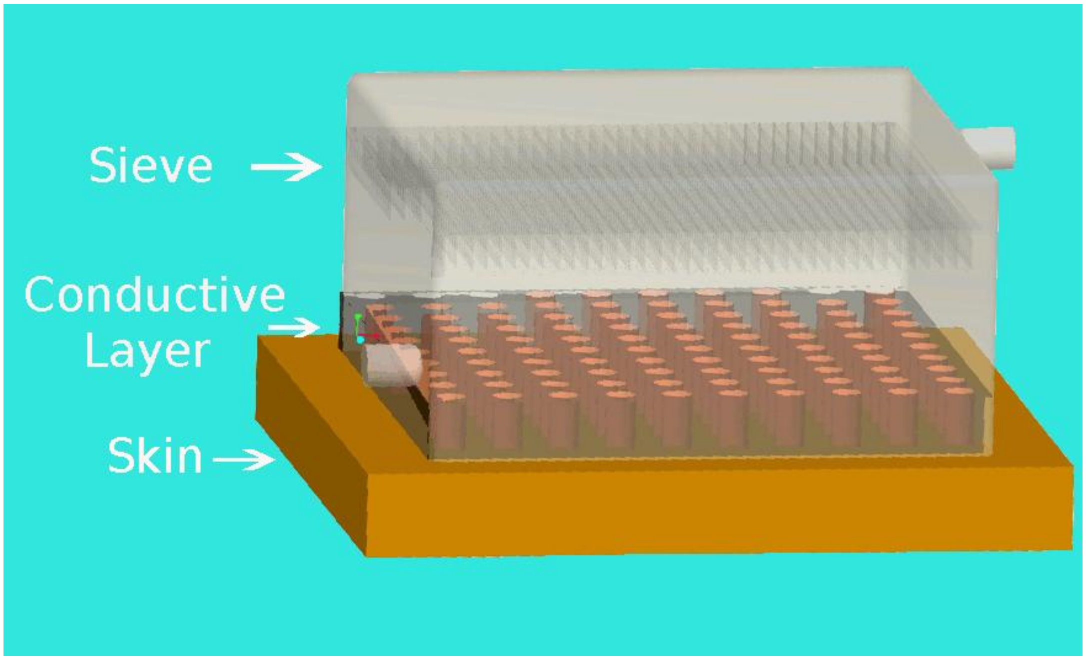
Research

Cooling

External or surface-based temperature modulation is intended to rapidly cool patients in order to reduce cell death and damage caused by acute ischemic events in which blood flow to critical organs such as the heart or brain is restricted, and to prevent or reduce associated injuries such as adverse neurologic outcomes. In general, cooling is used to lower the temperature of the brain to reduce swelling after resuscitation, which leads to brain damage. Currently, hospitals use ice packs to cool patients. This method is not cost and time efficient. A better solution is using a cooling jacket with a refrigerant filling. The type of refrigerant used has to be chosen carefully. The best choice is Fluorinert. Since Fluorinert is expensive, other chemicals with similar physical properties have to be considered. Isopentane is one candidate. The boiling point of isopentane is closer to body temperature, which aids its evaporation and cooling process. One set back of using isopentane is its flammability. If it is used in a closed system as in a jacket though, it is fairly safe and effective.

Various methods of cooling the body internally have been proposed and researched. However, the team wanted to keep the design non-invasive, since interviews with paramedics has shown that they are unwilling to perform invasive procedures. Some hospitals already use chilled saline injections in a patient's blood stream (the body can handle about 2 pints). The insertion of a chilled catheter into a person's vein is also used to chill blood as it passes by. Finally, a company called "RhinoChill" sprays a refrigerant into the nasal cavity, but this is inefficient.

When determining a sufficient external cooling method, it was determined that cooling only the head is not sufficient since the body will try to self regulate and maintain homeostasis, and not to mention the skull is a very good insulator. Cooling the neck and carotid artery was deemed impossible since calculations showed the temperature would be extremely cold and cause frostbite on the person's neck. Last semester's team wanted to construct a jacket that could be built into an existing gurney with flaps that can be tucked away for typical patients, or used to construct a suit by covering a patient suffering from cardiac arrest. The suit will be made of multiple layers: a 2-sided thermal conductive layer, a molecular sieve, and a nylon fabric outer layer. The thermal conductive layer will come in contact with the person's skin; the refrigerant will come in contact with the other side of the thermal conductive layer, which is now in the interior of the suit. Heat from the person's body will cause the liquid refrigerant to change state and evaporate. The molecular sieve is a layer between the outer nylon fabric and the interior thermal conductive layer. The sieve will restrict the liquid refrigerant from leaking out of the interior of the suit before it evaporates, while allowing only the vaporized refrigerant to pass. Once the vapor passes through the suit, it is pushed through a condenser by the suction power of a pump. The condenser is cooled and the heat is returned to the atmosphere. The vapor condenses into a reservoir and the cycle continues.



This semester created a simulation of human skin using paraffin wax, which has similar thermal conductive properties to actual skin. Water was placed underneath, and housed in an aluminum pan. The water could then be heated and allowed to cool.

The water wall allowed cooling with no assistance, with ice packs, and with isopentane. The following results were obtained:

Trial (1) with Ice Packs: Room Temperature 25˚C

Temperature (˚C)	Time (min)
1	3.44
2	4.48
3	6.01
4	6.11

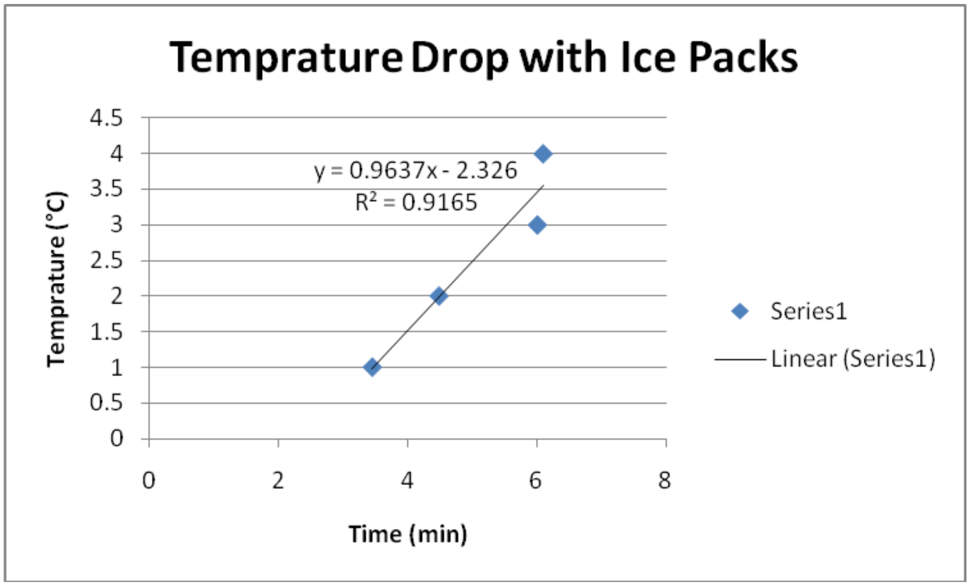


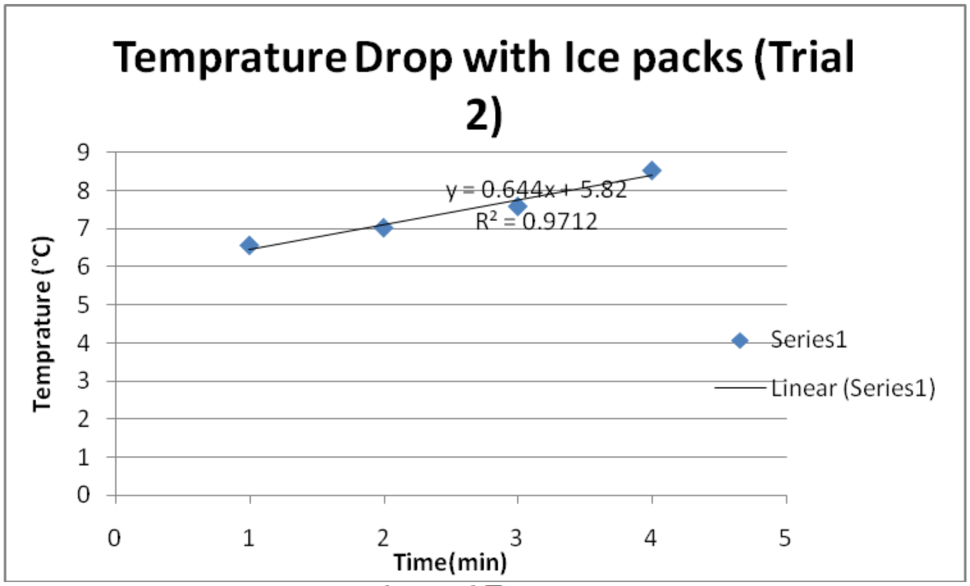
Figure 1 Temperature drop with ice packs

$$Slope = \frac{\Delta y}{\Delta x} = \frac{\Delta T}{\Delta t} = 0.9637°\text{C/min}$$

The slope indicates that the rate of the temperature drop is 0.9637°C/min. In ten minutes, the body temperature drop expected from using an ice pack is 9.6°C.

Trial (2) with Ice Packs: Room Temperature 25˚C

Temperature (˚C)	Time (min)
1	6.57
2	7.03
3	7.59
4	8.53

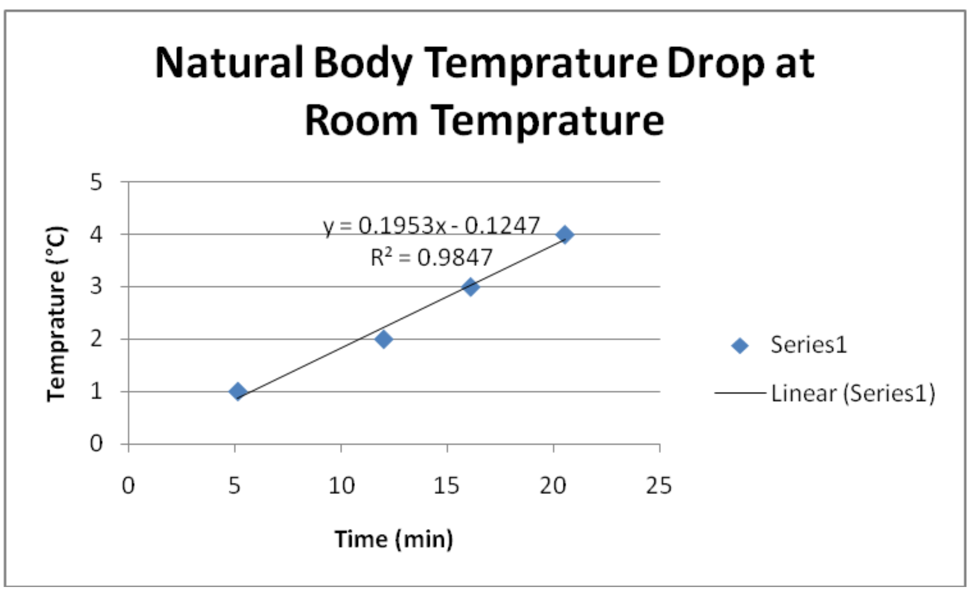


$$Slope = \frac{\Delta y}{\Delta x} = \frac{\Delta T}{\Delta t} = 0.644°\text{C/min}$$

The slope indicates that the rate of the temperature drop is 0.644°C/min. In the ten minutes the cardiac arrest victim has before brain damage starts to take place, the temperature can drop 6.4°C.

Trial (1) natural body cooling: Room temperature 25˚C

Temperature (˚C)	Time (min)
1	5.11
2	12
3	16.1
4	20.55

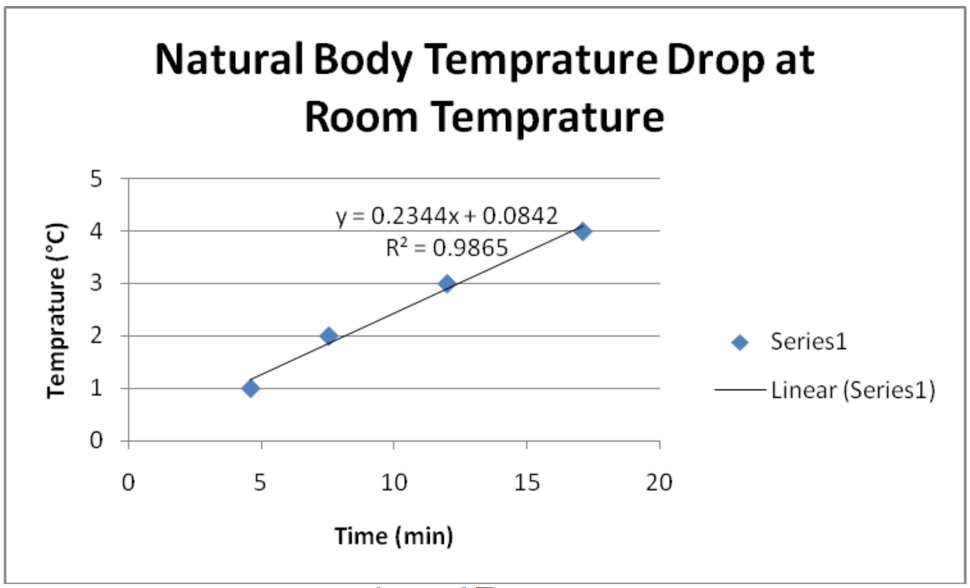


$$Slope = \frac{\Delta y}{\Delta x} = \frac{\Delta T}{\Delta t} = 0.1953°\text{C/min}$$

The slope indicates that the rate of temperature drop is 0.1953 °C/min. In the ten minutes the cardiac arrest victim has before brain damage starts to take place, the temperature can drop 1.9°C.

Trial (2) natural body cooling: Room Temperature 25˚C

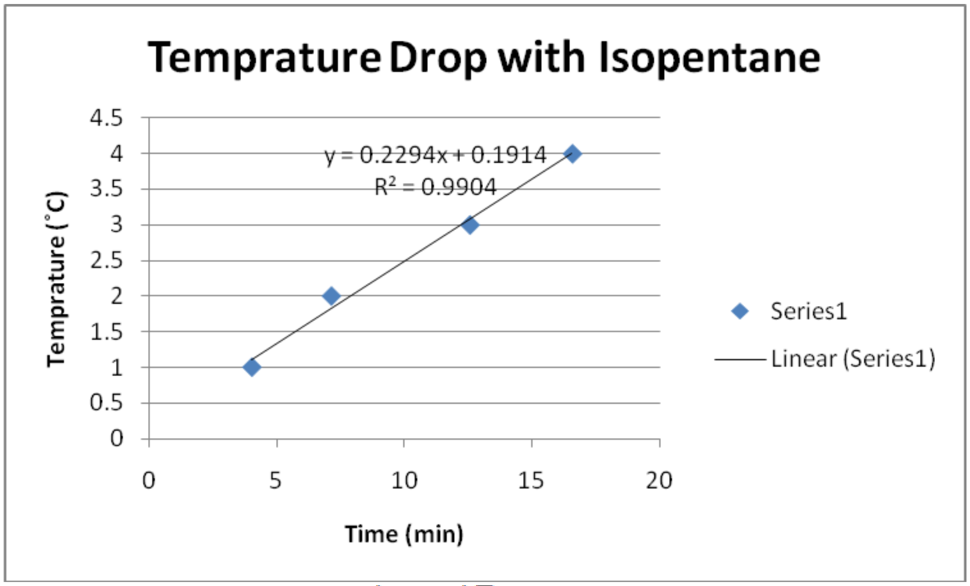
Temperature (˚C)	Time (min)
1	4.58
2	7.53
3	12
4	17.12



$$Slope = \frac{\Delta y}{\Delta x} = \frac{\Delta T}{\Delta t} = 0.2344°\text{C/min}$$

The slope indicates that the rate of temperature drop is 0.2344°C/min. In the ten minutes the cardiac arrest victim has before brain damage starts to take place, the temperature can drop 2.3°C.

Temperature (˚C)	Time (min)
1	4
2	7.12
3	12.56
4	16.58



$$Slope = \frac{\Delta y}{\Delta x} = \frac{\Delta T}{\Delta t} = 0.2294°\text{C/min}$$

The slope indicates that the rate of the temperature drop is 0.2294˚C/min. In the ten minutes the cardiac arrest victim has before brain damage starts to take place, the temperature can drop 2.29°C.

The isopentane cooling did not go as planned and produced similar results to cooling with no assistance at room temperature. This was most likely due to the copper not having a good contact with the wax and air, which is a good insulator, was present in the gap. Future work should involve actually putting the copper into the wax. This could be accomplished by reforming the wax, but setting the copper in place as it cools.

Shaking

Pigs and mice were shaken and found to benefit from this treatment after cardiac arrest. This approach to helping cardiac arrest victims was decided by the team to not be explored this semester. The reasoning behind this is that there are plenty of research institutes already performing research into this and overall trying to implement this into a prototype for the semester seemed to be redundant.

Breathing

The composition of air is 78% Nitrogen, 21% Oxygen, 0.9% Argon, and 0.03% Carbon Dioxide. Human exhalation contains about 14% oxygen and 4.4% carbon dioxide. Breathing in air with oxygen concentrations below 19.5% can have adverse physiological effects and those with less than 16% can become life threatening. However, this is over a long period of time, so more research will need to be done for lower levels of oxygen given to a person for a short period of time.

Most breathing gases are a mixture of oxygen and one or more inert gases.

- Hypoxic mixes contain less than 21%, but a boundary of 16% is used.

- Trimix is a mixture of oxygen with nitrogen and helium, which has reduced nitrogen narcosis and avoids oxygen toxicity.
- Heliox is a mixture of oxygen with helium (21% O2 and 79% He), but other combinations are possible, and this eliminates nitrogen narcosis, and is currently used in medicine to help breathing. Nitrogen in the gas is replaced with helium, which reduces airway resistance because of the lower density of helium, so less mechanical energy is needed to ventilate the lungs.
- Hydreliox is a mix of oxygen with helium and hydrogen. Oxygen saturation measures the percentage of hemoglobin binding sites in the bloodstream occupied by oxygen.

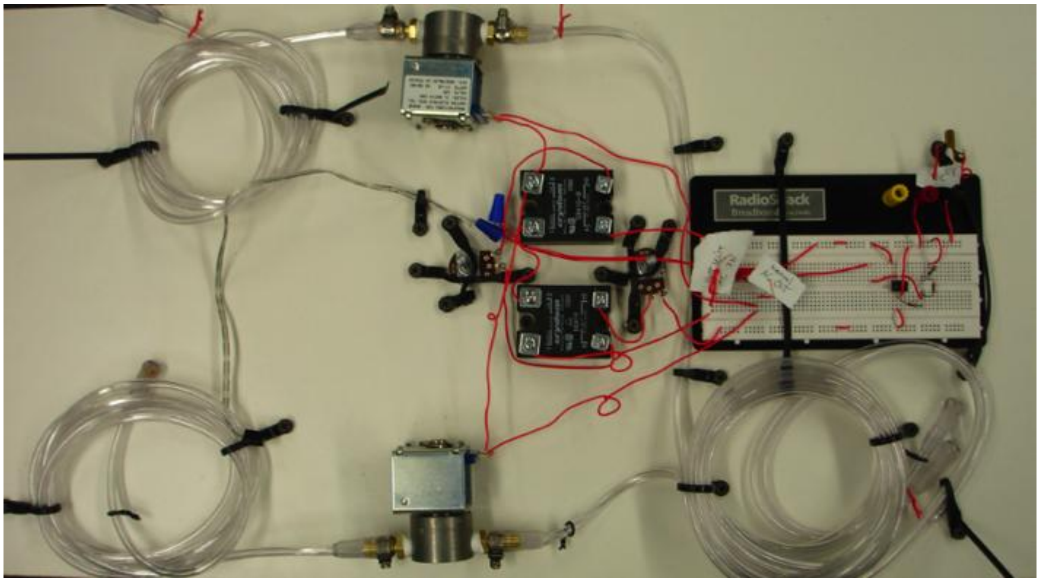
An arterial (blood taken away from the heart) oxygen saturation below 90% is termed hypoxemia, which is calculated from the inspired oxygen partial pressure. Venous oxygen saturation is measured to see how much oxygen the body consumes. Saturation below 60% indicates that the body is in lack of oxygen, at which point ischemic diseases begins to occur. A non-invasive method to detect changes in blood hemoglobin concentrations associated with neural activity is to use near infrared spectrometry. Helium or hydrogen could be used as the other gas component.

In addition, H_2S gas used in mice to induce hibernation was researched, but it is found to be toxic to larger animals. It can still reduce oxygen amounts during the initial breathing time after resuscitation and further studies on humans can be explored.

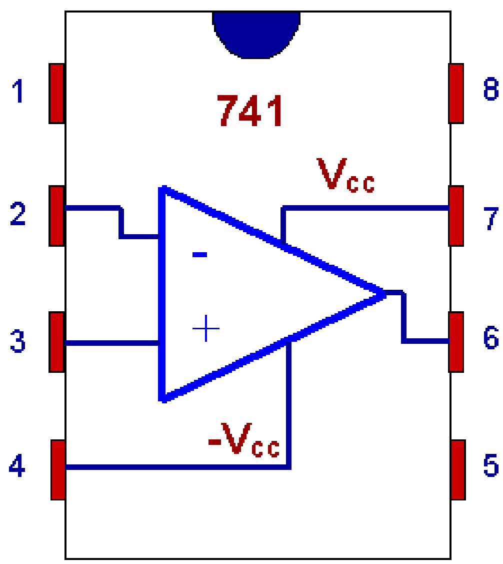
The effects of various O2 levels are listed in the table below.

Percentage Oxygen	Effect on People
20.9-23.5%	Maximum permissible oxygen level. No effect.
20.9%	Percentage of oxygen found in normal air. No effect.
19.5%	Minimum permissible oxygen level. No effect.
15-19%	Decreased ability to work strenuously. May impair coordination and may induce early symptoms with individuals that have coronary, pulmonary, or circulatory problems.
12-15%	Respiration and pulse increase; impaired coordination, perception, and judgment occurs.
10-12%	Respiration further increases in rate and depth; poor judgment and bluish lips occur.
8-10%	Mental failure, fainting, unconsciousness, an ash-colored face, blue lips, nausea, and vomiting
6-8%	Recovery with treatment.
4-6	Coma in 40 seconds, convulsions, respiration ceases, Death

The mask prototype that was constructed this semester is very basic. It uses a very simple Op-amp circuit to control the relays. Currently the oxygen sensor for the breathing chamber will output between 5 and 20 millivolts depending on the oxygen concentration. The op-amp will amplify this to approximately 4 volts in order to control the relays. Aside from the op-amp there are two potentiometers. One is located before the first relay and the second is located after the first but before the second. These should only be temporary. Their purpose was to demonstrate a decrease or increase of oxygen levels by allowing manual voltage control to each of the solenoid valves. Ideally this will eventually be done automatically or through a circuit such as a wheat-stone bridge.



Above is a picture of the current prototype layout. The two solenoids valves need a 120VAC power supply and are control by the two solid-state relays. The op-amp requires both a negative and positive power supply. The op-amp is a standard 741 chip and adheres to the following pin layout.



The remaining pieces of the prototype include a mixing chamber where the gas from the two tanks are released into and allowed to mix.

The future goal of this prototype would be to have it attached to an AED machine while being able to automatically adjust the mixing chamber's oxygen concentration based on the sensor's reading. Another aspect the prototype should include is the ability to gradually increase the O2 concentration over time.

A brief breakdown of how the device will work:

- The patient suffers cardiac arrest
- A bystander will grab the AED breathing combination device and put the mask on the patient along with the AED paddles
- The bystander then only has to press one button and the AED will attempt to resuscitate the patient. If successful the breathing mask will then create an appropriate breathing mixture.
- The mask itself should be able to detect the patient's current oxygen level and match the O2 concentration or create a determined minimum standard O2 concentrated breathing mixture.
- The mask system will constantly detect differences in the patients O2 levels and adjust the breathing mixture accordingly gradually increases it over time.
- Once the patient reaches full O2 concentration in the bloodstream the mask system can be removed.

Budget

Item	Quantity	Price
Oxygen Tank	2	$198.00
Oxygen Tube	7 feet	$24
Macro line Nylon 11 Tubing	5 feet	$5.00
High Concentration Oxygen Mask	2	$35.70
Solenoid Valves	2	$66.50
Solenoid Controllers	2	$44.68
Oxygen Sensor	1	$70.00
Thermometer	2	$35.00
Isopentane	1	$50
Total		**$443.88**

Obstacles:

Breathing Mask

Research on Hydrogen Sulfide has not been tested on humans to see if it will induce hibernation. In addition, EMPs are reluctant to change the way heart attack victims are treated. Human testing is not possible by the team. Some complications occurred with the construction of the breathing mask as well. We were unable to locate an oxygen sensor that would accurately measure oxygen levels in a person's blood stream below 70%. Another complication is that the design of the circuit is very basic at the moment. Ideally an integrated digital circuit with a control computer should be used to monitor the two oxygen levels and interpret this data to accurately distribute and control the oxygen level in the mixing chamber and patient.

Cooling Jacket

Obstacles faced in making the cooling jacket are that humans naturally maintain homeostasis, and this has to be overcome to cool the body. In addition, a cardiac arrest also causes reduced blood movement, which may lower the effectiveness of cooling, since the cooled blood may not be able to reach the brain if the heart is not beating. In addition, the device needs to be simple, compact and durable for real world use. Emergency medical personal may also need to be questioned in order to find the optimal solution that would be most effect in the real world, especially if they are needed to operate the cooling jacket. Lastly, a way to test the cooling jacket on humans or a similar animal needs to be found which is both ethical and will give accurate results.

Recommendations

Try to study research done on the effects of Hydrogen Sulfide on humans over various periods of time. Look at other chemicals that can be used to induce hibernation in humans to reduce oxygen intake and increase chances of survival. Also, continuation of the prototype design is strongly considered. Add complexity to the circuit to create a more automated system instead of having a completely analog system. Testing with fluorinert as a cooling fluid should be investigated as well.

References

http://www.heartrhythmfoundation.org/facts/scd.asp
http://ehs.ucdavis.edu/hs/ConfSpace/index.cfm
http://www.americanheart.org/presenter.jhtml?identifier=4481
http://www.measurementcomputing.com/index.html
http://www.miamiheartresearch.org/pgzmotion/

Resources

Suppliers:
www.grainger.com: for solenoid and solenoid controls
www.digikey.com: for relays
www.homedepot.com: various prototype construction components
www.radioshack.com: various circuit components
http://store.gomed-tech.com: oxygen tank supplier
http://www.rebreatherexpress.com: oxygen sensor supplier

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