Total Body Hypothermia for Prolonged Space Travel

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PROLONGED MANNED space flights will be possible in the coming decade. Engineering developments in rocketry have placed increasing demands on life support systems as time of flight has increased. The purpose of this paper is to review a significant number of advances in the general field of hypothermia. These newer developments may serve as a guide in providing biomedical systems which can protect man in exploring the vertical frontier.

During the past 12 years, open heart surgery has made possible rapid strides in our understanding of hypothermia. Use of cooling is now accepted as a protective means in heart surgery allowing total cardiac arrest. This immobile period enables the surgeon to correct congenital deformities. Today extracorporeal systems combined with cooling are in routine use in most medical centers.

Use of total body hypothermia has also been accepted following brain trauma in which cerebral edema is a factor. A third clinical application is the use of regional kidney hypothermia in surgery to protect function allowing correction of renovascular obstruction, kidney homotransplantation, or radical urological surgery to kidney parenchyma. We have recently devised a heat exchanger which allows rapid and efficient cooling of the kidney during surgery.[2]

METABOLIC REQUIREMENTS IN SPACE

Metabolic studies under investigation in simulated space cabins have revealed significant data. Calculations for requirements of food, oxygen and water are available.[3] Using basal consumption rates of 200 ml. of oxygen per minute per 70 kilogram man, it is estimated that 400 ml. per minute of oxygen are required for sedentary activity in a space vehicle. This quantity amounts to approximately 1.13 lbs. of oxygen per man per 24 hours. The expiration of carbon dioxide and its abrogation in a closed environmental system is also significant. Approximately 2 lbs. per man per 24 hours is exhaled. Approximately 2 lbs. of lithium hydroxide is required to neutralize 2 lbs. of carbon dioxide.

A balanced diet, emphasizing dehydrated foods will be indicated. By packaging food in plastic or foil, bulk and weight are reduced to 1.14 lbs. per man per 24 hours. Water is necessary to support the metabolic processes in man. While higher volumes (3 liters) may be indicated to prevent hypodynamic urolithiasis,[4] a minimum requirement of 2 liters per day is necessary.

It is estimated that a deep one way space probe to Mars will require approximately 8 and ½ months (250 days). Calculations of requirements for food, oxygen and water plus the apparatus necessary to neutralize exhaled carbon dioxide amounts to 2700 lbs./man over the 8 and ½ month period. If a three-man space crew is anticipated, then weight necessary for life-support systems during this voyage approaches significant figures in terms of weight and bulk.

ADVANTAGES OF HYPOTHERMIA

One of the greatest advantages of total body cooling is reduction in metabolism that accompanies lowering of body core temperature. It is estimated that at 30°

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Centigrade metabolic processes at the cellular level are reduced to 50 per cent. With linear reduction in temperature, there appears to be a logarithmic reduction in metabolism.[5] It is obvious that the saving in weight is one that follows an exponential curve and amounts to significant figures when calculated on the basis of weeks or months. In an hibernating animal with a body core temperature of 4° Centigrade, oxygen consumption is reduced to approximately 3-8 per cent of normal.[6] Accordingly, other metabolic requirements including food and water are markedly reduced. In a space vehicle with a three-man crew it would be desirable to place one man at a time into a state resembling hypothermia so that metabolic processes could be significantly lowered.

It is in the field of shock, however, that hypothermia can best be proposed. Numerous investigators have previously pointed out the protective effects of total body cooling during bacteremic shock. Our data[7, 8, 9] also supports the protective effects of hypothermia as a therapeutic adjunct in the treatment of shock due to bacterial invasion in the blood stream. The mechanism for protection appears to be a reduction in oxygen requirements. A second mode of action appears to be diminished bacterial growth during hypothermia.

The literature is also replete with instances in which high temperatures are better tolerated if moderate hypothermia is employed before exposure to severe heat[10] rather than normothermia. In the field of traumatic shock, it has been reliably reported that total body hypothermia will protect a severely injured patient during the interval following injury until he is able to undergo reconstructive surgery. The statistics of casualties in Indo-China[11] support the argument for hypothermia in traumatic shock. The hazards of travel into the vertical frontier may present sudden changes in velocities possibly approaching speeds in excess of 25,000 MPH. Man will have to devise methods of substantially increasing his tolerance to high "G" forces. A number of independent workers have suggested that as a therapeutic adjunct, hypothermia will protect experimental animals enabling tolerances (increased "G" forces) up to 2,300 "Gs" to be maintained for periods as long as 15 minutes.[12]

Our recent experience in dysbarism deserves mention.[13, 14] From our preliminary data, it seems that animals undergoing experimental decompression sickness in a positive pressure chamber will succumb during normothermic conditions. However, if moderate hypothermia (90° F) is induced, survival as monitored by blood pressure and plasma volume is maintained. When the animal is warmed, the result is death. The mode of death in normothermic animals appears to be twofold: if bubbles are produced rapidly, the immediate demise of the animal leads us to postulate that death is due to pulmonary blockade resulting from large macroscopic gaseous emboli. However, in animals undergoing a progressive but slower demise over a six hour period, etiology of death appears to be a loss of plasma volume in the neighborhood of 33 per cent of pre-operative plasma volume. During this post-chamber period, blood pressure is markedly reduced, and pulse is increased.

With regard to gamma and cosmic ray exposure, it has been previously reported that the astronaut may be protected by hypothermia during the period of entrance into the Van Allen Belt. This same protection by hypothermia may be afforded if solar flares are encountered. The tolerance range for lethality in radiation exposure may be increased many fold if the temperature of space crew members is lowered into the moderate hypothermia range. This decrease in radiosensitivity has been previously reported in animals undergoing profound hypothermia. Storer and associates[15] observed that mice cooled in sealed tubes to 5° Centigrade exhibited survival rates several times greater than animals irradiated at normothermia. Clinical studies now underway in the irradiation of patients with cancer also support this thesis. If oxygenation is increased in a positive chamber,[16] for example, placing a patient under 3 atmospheres of oxygen, then sensitivity of tumor tissues is significantly enhanced by X-ray. Decreasing oxygen requirements by lowering temperature, (hypothermia) reduces cellular metabolism thus decreasing tissue sensitivity to gamma irradiation.

DISADVANTAGES OF HYPOTHERMIA

It is now evident that profound hypothermia is a stressful therapeutic entity. A number of investigators have reported the difficulty with which profound body cooling is produced. During induction of hypothermia, methods that have been used to date are both crude and somewhat inefficient. Surface cooling has gained a large number of supporters and is being used in many centers throughout the country. In selected patients, heat exchangers appear to be useful in regional cooling of certain body areas. A blood heat exchanger employing veno-veno cooling is an efficient method with regard to patient safety and adaptability. By using this technique, it is possible to obtain temperatures in the region of 20-22° C. with rapidity.

Cooling into the intermediate range (20-26° C.) has produced cardiac arrhythmias. This difficulty has prevented wide use of total body cooling for routine surgical procedures in the poor risk patient. Because cardiac arrhythmias during hypothermia have been difficult to control, it is doubtful that cooling to a more profound level would be indicated in any single member of a space crew. A great deal of technical experience is necessary to induce and control deep hypothermia. Although a number of drugs are available to diminish sensitivity of the myocardium, this danger would far outweigh its use in routine fashion by the inexperienced. Metabolic acidosis is another difficulty that usually arises with chronic and profound hypothermia. This state has been combated by supporting respiration with positive pressure apparatus and also by infusion of alkalinizing solutions.

HIBERNATION

Bigelow[17] and a number of other investigators believe that a state resembling hibernation is the key modality for protection of humans during stress. Hibernation (4° C.) is a non-stressful modality and results in tremendous savings in metabolism that have been mentioned previously. However, humans are non-hibernators, and much research needs to be performed before the chemistry of hibernation will be completely elucidated. A simulated condition resembling hibernation will probably be a biomedical solution to many of the manned space problems which may be encountered. If a drug could be synthesized that would produce a state resembling hibernation in humans, then space travel would revert to an engineering problem—namely one of hardware with technical advances in rocketry guidance and systems to reach the planets.

While the field of suspended animation has gained some followers in the past few years, a great deal of difficulty has been encountered in preservation of organs at extremely low temperatures (below freezing) over long periods of time. Suspended animation probably will be useful for preservation of individual organs. However, in deep space probes, the entire space crew must be considered.

SUMMARY

It is evident that probes into space may present a number of difficult and as yet unsolved biomedical problems. Since engineering feats in rocketry could conceivably exceed biomedical support, research in the area of life support systems must continue in order to stay abreast or ahead of engineering flight capabilities. By further elucidation of the chemistry and physiology of hibernation, it is possible that synthesis of drugs for induction of humans into a state resembling hibernation may be possible. This non-stressful modality could be used by one member in rotating fashion in a space vehicle having a multiple crew. The great advantage of reduction in cellular metabolism in logarithmic fashion with linear reduction in temperature probably far outweighs its disadvantages.

In a simulated hibernating state, cardiac arrhythmia is not encountered. The lowered body core temperature may protect the space crew member from shock whether it is secondary to increased "G" forces, dysbarism, thermal stress, bacteremia or trauma. The increased tolerance to radiation exposure during cooling is worth mentioning.

Propulsion, guidance, shielding, navigation, and a myriad of other space flight problems still make it safe to say that life support systems are not the limiting factors in space flight to date.

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