UPDATED FEATURES FOR ENHANCED PORTABLE LIFE SUPPORT SYSTEMS IN SPACE. P. A. Johnson[1] and J. C. Johnson[2], [1]Faculty of Medicine & Dentistry, University of Alberta (116St 85 Ave NW, Edmonton AB, Canada; paj1@ualberta.ca), [2]Faculty of Engineering, University of Alberta (116St 85 Ave NW, Edmonton AB, Canada; jcj2@ualberta.ca).

Introduction: In addition to restricted access to lifesaving medical equipment in space, there is an increased risk of cardiac arrest in space under near vacuum and microgravity conditions. Moreover, in space, the human physiology is highly vulnerable to demands such as exposure to inert gases and extremely low atmospheric pressure. For astronauts, space suits and 8-hour lifespan Portable Life-Support Systems (PLSS) are used to meet these demands during extravehicular activity. All of these conditions not only increase the likelihood of medical emergencies but also situations requiring cardiopulmonary resuscitation (CPR), which is not conceivable due to limitations in current space suit design.

Conventional PLSS systems are designed to accommodate several essential functional components enabling extravehicular activities. Of these, maintaining a constant internal pressure is critical – specifically in environments such as the surface of the moon or in orbit – where pressure external to the space suit can be assumed to be equivalent to that of a vacuum. Moreover, space suits serve several key basic functions to support life including the supply of oxygen and elimination of carbon dioxide through the PLSS, which is essential in space where there is no breathable oxygen, and also regulation of internal temperature under significant temperature extremes in space. However, these functionality requirements can be quite impeding if there is ever a need for CPR particularly because enhancing ventilation or chest compressions are more difficult based on these features.

Situations requiring CPR. Inert gases are profuse in the atmosphere of different planets and moons and even minimal exposure may be toxic. On the moon, argon gas is the most abundant in composition. Inert gas asphyxia can result if oxygen is depleted and another gas in the atmosphere is inhaled: argon, helium, nitrogen, etc. These gases can result in asphyxia, which can then lead to cardiac arrest. There have been simulations where exposure to these gases have resulted in death. If detected early however, this condition can be corrected with timely CPR interventions.

Cardiac arrest may also result from other causes, which may or may not be a product of exposure to stresses in space. Asphyxia can also result if there are leaks or damages in the space suit which result from external threats in the environment. As space is a vacuum, exposure to an extremely low-pressure environment induces an expulsion of air from the lungs resulting in the inability to inspire for normal breathing and by consequence asphyxia and cardiac arrest. Another possibility may be sudden or spontaneous medical emergencies resulting changes in environment which is inevitable despite screening and prognostic or preventative measures.

Novel upgrades to PLSS systems: Innovation in space suit design over the recent years have focused on enhancing mobility, operational performance and safety. Little research has focused on technology to improve ventilation or chest compressions for astronauts in the case of medical emergencies. We examined a technical modification to the conventional design to incorporate components which facilitate ventilation and chest compression for resuscitative interventions.

Ventilation design. Ventilation is of utmost importance when considering CPR. Under normal conditions, it is possible to observe the return of spontaneous circulation (ROSC) provided adequate ventilation is supplied, even without delivering chest compressions intermittently. We propose the installation of mask ventilator based on a similar design to modern snorkels. This tubing can be connected to a ventilator which can switch between ventilation modes providing both positive pressure ventilation (PPV) and continuous positive airway pressure (CPAP). Moreover, the mask ends of these ventilator devices can be individualized if they are 3D printed based on the facial features of the astronauts. Not only would this allow for ease of positioning as the astronaut is likely unconscious, it would also maximize the efficiency of ventilation preventing the loss of air to the environment within the space suit by optimizing sealing between the ventilator and the astronaut.

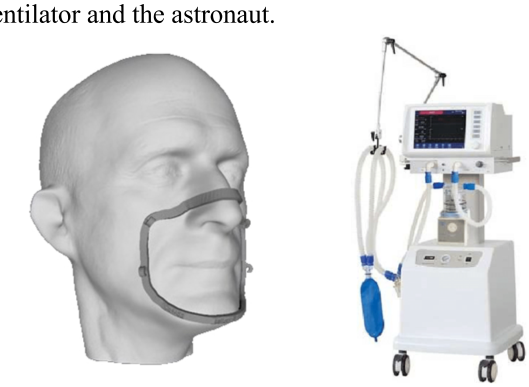

Figure 1: 3D-printed mask ventilator design.

For this procedure, a reserve amount of air should be made available for CPAP during CPR either in a separate compartment or drawn from the PLSS. Furthermore, based on the availability of personnel at the time of intervention, ventilation should be prioritized and thus the accessibility of this ventilation device should pre-position or allow the supporting member to have a fine control of placement for the device. Upon recovery, there should also be a functionality which ensures CPAP is switched to PPV should ROSC be observed and the astronaut remains unconscious or in need of mechanical ventilation.

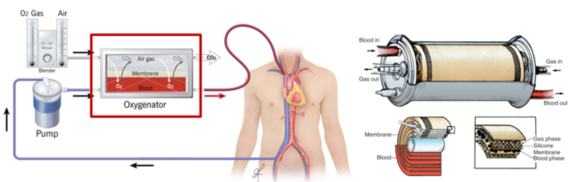

Figure 2: Combined CBP-ECMO technology.

Incorporation of technology utilized for cardiopulmonary bypass pump (CBP) and extracorporeal membrane oxygenation (ECMO) may be a significant advancement to current PLSS design. While both of these extracorporeal techniques require surgery and have yet been demonstrated feasible in space, a device using its membrane oxygenation technology has recently been proposed for its effectiveness in emergency and critical medical situations. This membrane oxygenator device could potentially replace the existing PLSS design as it saturates the blood with oxygen and expels carbon dioxide similar to CBP and ECMO. Additionally, this device could reduce several functions such as protection against asphyxia and compression in the vacuum. However, this device has its limitations as it would be invasive and require surgical interventions prior to the space flight and at present, remains theoretical.

Chest compressions design concept. In order to establish simultaneous chest compression with ventilation, it is necessary to consider resources, personnel availability, and compression technique. Under standard conditions, chest compressions are delivered using a 3:1 protocol where 3 chest compressions are provided per one breath or ventilation. The conventional design for space suits are akin to inflatable balloons and require the conservation of a higher internal pressure within the suit than the environment. As a result there is a lower feasibility of performing manual chest compressions in space. With compartmentalized units within the space suit dedicated for pressure regulation, it may be possible to administer chest compressions by de-pressurizing the space between the astronaut and the space suit to not only bring back heart rhythm but also aid with breathing. Particularly, by de-pressurizing space in the diaphragmatic area and pressurizing compartments near the respiratory orifices, it may be possible to reverse conditions resulting in asphyxia. With the limitation that manual chest compressions are more difficult without an adequate amount of force and pressure generation during compressions, another option may be to deliver chest compressions by connecting the space suit to an automated chest compression system, which can be controlled by supporting personnel.

Conclusions: It may be possible to advance space suits further for missions in space to prepare for the risk of medical emergencies such as asphyxia or cardiac arrest. It was suggested that installing a mask ventilator system and chest compression system within the conventional space suit would improve response in such emergencies.

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