Review

I left my heart in low Earth orbit: a review of cardiopulmonary resuscitation in space

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Abstract

Introduction
To gain an understanding of the current state of CPR in microgravity with a focus on chest compressions in the event of a sudden cardiac arrest onboard.

Methods
An Ovid Medline search was conducted: 17 articles were found; 12 were excluded; six additional articles were found in the references of the remaining five articles, bringing the total number of articles included to 11. These were then critically analysed.

Results
No CPR method currently reaches the European Resuscitation Council (ERC) guidelines. The Handstand (HS) method appears to be the strongest. Evetts-Russomano (ER) is the second strongest method. Automatic chest compression device (ACCD) performed consistently well.

Conclusion
CPR appears to be far more difficult in microgravity. Inconsistencies in research methodology do not help. The ER method should be used as a first contact method and the HS method should be used once the casualty is restrained. An ACCD should be considered as part of the medical equipment. Further research is needed, directly comparing all positions under the same conditions.

Abbreviations

ACCD – Automatic chest compression device
AED – Automated external defibrillator
AHA – American Heart Association
BLS – Basic life support
CM – Cologne method
CMRS – Crew medical restraint system
CP – Compression product
CPR – Cardiopulmonary resuscitation
ER – Evetts-Russomano method
ERC – European Resuscitation Council
ESAM-SMG – European Society for Aerospace Medicine Space Medicine Group
HS – Handstand method
ISS - International Space Station
RBH – Reverse bear hug method
SCA – Sudden cardiac arrest
SHM – Schmitz-Hinkelbein method
SM – Waist straddling manoeuvre
STD – Standard side straddle method

Introduction

Microgravity or 'weightlessness' describes the lack of gravitational pull experienced by spacecraft in orbit. While technically still in the Earth's gravitational field and therefore falling, the spacecraft's forward velocity allows it to continuously miss the Earth, creating a state of zero gravity.[1]

Space tourism is a growing industry, already offering orbital tourism to wealthy clientele. Orbital flights such as those offered by SpaceX's Crew Dragon spacecraft could reach altitudes of 400 km and involve a stay of up to eight days aboard the International Space Station (ISS) and two days travel, exposing passengers to microgravity for more than a week.[2] Luxury hotels, such as the Aurora station, will host stays of up to 12 days, 320 km above the Earth.[3] Such exposures to microgravity may have profound effects on the cardiac physiology of crew and passengers whose cardiovascular systems have developed under terrestrial gravity for millions of years.

The observed changes in astronauts post-spaceflight, and subjects in earth-based mimics of microgravity, can be explained by the fluid shift from the legs towards the head due to loss of the pressure difference between the upper and lower portions of the body created by gravity.[4] This cephalad fluid shift is interpreted as a fluid-volume overload by low pressure baroreceptors in the vena cava. This induces a reduction in plasma volume and circulating red blood cell mass. Such changes ultimately lead to relaxation of the cardiovascular system. This relaxation manifests in changes such as reduced heart rate, reduced mean arterial blood pressure and atrophy of the cardiac muscle.[5]

Despite these physiological changes, there has yet to have been an incident requiring cardiopulmonary resuscitation (CPR) or the manifestation of underlying cardiovascular disease in spaceflight. However, an isolated episode of ventricular tachycardia was observed in one astronaut during their second month aboard the Mir space-station.[6] This episode, while asymptomatic, signified that the occurrence of serious cardiac dysrhythmias remains a possibility in microgravity.

The lack of observed pathology in space exploration so far is likely to have been biased by the extremely healthy population that make up astronauts, who had to pass rigorous health checks and fitness protocols. The wealthy space tourist, on the other hand, may lack this level of cardiovascular fitness and may be at higher risk of cardiovascular pathology upon entering the microgravity environment.[6,7] The chance of sudden cardiac arrest (SCA) is always present, even in young healthy individuals, under normal conditions.[8]

For this reason, institutions such as the European Astronaut Centre Cologne and the European Society of Aerospace Medicine have worked towards developing a CPR algorithm for space.

The aim of this review is to understand how prepared the field of space medicine is to manage an event, such as an SCA during spaceflight, with basic life support (BLS). A specific focus has been placed on chest compressions. Other features of SCA response, such as ventilation and drug administration, were beyond the scope of this review.

Methods

A keyword search was conducted on OVID Medline for articles with the terms "Microgravity" AND "Resuscitation" in their titles/abstracts. This produced 17 results. Articles not written in English were excluded to avoid any misinterpretation of content. Articles were then read in depth and 12 were excluded due to either not being related to the subject matter (e.g. assessing airway management rather than chest compressions), being preliminary studies of chest compression techniques (which are evaluated better in more recent studies) or for solely using older CPR guidelines such as American Heart Association (AHA) 2000 guidelines (which make comparisons with more recent studies difficult). Six additional articles were found through exploring the references and citations of the relevant studies to bring the total number of articles included to 11.

Results

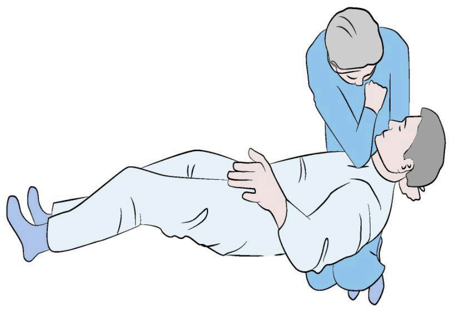
It would be impossible to carry out CPR in the same fashion as usual due to no gravitational pull holding the casualty in place. Chest compressions, without prior anchoring, would cause the casualty and rescuer to move apart and prevent anything close to lifesaving CPR.[9] The variety of different CPR techniques developed for microgravity take this into account, either through the rescuer directly anchoring themselves to the casualty, or through restraint together on the crew medical restrain system (CMRS), which is a foldable stretcher/examination table.[9] Currently, seven CPR positions have been developed for microgravity:

1. Standard side straddle (STD) method: This technique much resembles the position used for terrestrial CPR, apart from the fact that the casualty and rescuer are both restrained to the CMRS.
2. Waist straddling manoeuvre (SM): The rescuer performs compressions from on top of the patient, placing their knees either side of the patient's legs. Both rescuer and casualty are fastened together on the CMRS.
3. Reverse bear hug (RBH) method: This technique is an adaptation of the Heimlich manoeuvre where both arms perform compressions on the chest of the casualty.
4. The handstand (HS) method: With this method, the casualty is above the rescuer with their back against a solid surface. The rescuer places their feet on the opposite surface, with both hands above their head on the patient's sternum, and flexes and extends their legs to perform compressions. The patient can be free floating or restrained to the CMRS. **(Figure 1)**

5. The Evetts-Russomano (ER) method: The rescuer must place themselves on top of the casualty, with their left leg over the casualty's right shoulder and their right leg over the left side of the casualty's torso, locking their ankles around the casualty's back to create a base to perform compressions against. This position does not require the CMRS. **(Figure 2)**

6. The Schmitz-Hinkelbein (SHM) method: The casualty is positioned lying across the rescuer's knees. Chest compressions are performed similar to the STD method. **(Figure 3)**

7. The Cologne method (CM): Similar to SHM, but one arm is used to stabilise the patient while the other performs compressions via the elbow. **(Figure 4)**



On Earth, adequate chest compressions are determined by guidelines, such as those published by the ERC. CPR should aim to have a rate of 100-120 compressions per minute and a depth between 50-60 mm.[10] Braunecker et al[11] demonstrated in their systematic review that four of the five initial techniques could reach an adequate compression rate in microgravity. RBH was the only technique which could not (94.7 ± 5.4 /min). With regards to compression depth, HS achieved the greatest depth (44.9 ± 3.3 mm), then the RBH and ER techniques (39.8 ± 6.3 mm and 35.6 ± 6.7 mm, respectively). The conventional terrestrial techniques of SM and STD performed the worst (30.7 ± 11.9 mm and 19.8 ± 11.2 mm, respectively).

Braunecker et al[11] used compression product (CP), calculated by multiplying the compression depth by the rate, as a surrogate measure for the cardiac output from CPR. The CPs for the five given techniques were then compared against the minimum CP required for each guideline. All CPR methods achieved a CP above the minimum required by their respective guidelines (some studies used the AHA 2000 guidelines or the ERC 2010 guidelines which required minimum compression products of 4000 and 5000 mm/min, respectively). HS had the highest compression product (69.3% above minimum CP), with ER second (33.0% above minimum CP). The CP produced by SM was judged as satisfactory according to the authors (29.7%), while RBH and STD were both described as not achieving a sufficient CP (15.2% and 4.3%).

Schmitz et al[12] evaluated the two novel methods of CPR, SHM and CM in an underwater mimic of the microgravity environment. Both techniques achieved compression rates within ERC guidelines (111.1 ± 6.3/min and 102 ± 8.3/min, respectively). Instead of measuring compression depth directly, the authors reported the proportion of chest compressions that were performed at sufficient depth (65 ± 23% and 28 ± 27%, respectively).

Another CPR method under microgravity may be performed mechanically through an automatic chest compression device (ACCD). In a parabolic flight study, Forti et al[13] achieved a compression depth of 49.9 ± 0.7 mm and a compression rate of 101 ± 0.5/min with the ACCD. Both these parameters meet the ERC guidelines.

Discussion

Many challenges exist in developing a clear BLS algorithm for space. Firstly, the identification of someone that is having a cardiac arrest. The characteristic noisy fall that alerts bystanders to someone having an arrest on Earth cannot take place in microgravity. Cardiac arrest detection would be hindered further by the background noise in a spacecraft and obstructed view of passengers from the compartmented layout of most spacecraft.[9]

Automated external defibrillator (AED) deployment, although equally important under microgravity and on Earth, can only be used on a casualty restrained to the CMRS. This is due to the risk of accidental shock of other crew members or damage to the fuselage.[14]

Microgravity-induced physiological changes could also result in CPR becoming a more physically taxing process. These changes include quicker onset of fatigue, reduced skeletal muscle mass and altered muscle metabolism.[15–17] CPR may only be effective for short periods of time before the rescuer would become too exhausted to produce effective chest compressions.

Inconsistencies in CPR method assessment also contribute to the lack of clarity. Some studies used parabolic flight, in which microgravity can only be simulated for approximately 20 seconds.[11] The increased fatigability of certain CPR techniques may not present in this narrow window.[9] Others used underwater CPR. This method may have advantages, such as allowing measurement of CPR parameters for longer periods, but could be a less accurate mimic of microgravity due to water resistance and the continual existence of terrestrial gravity.[12]

It is also unclear what features make a good CPR technique. Technically no method reaches the ERC guidelines for both rate (100-120/min) and depth (50-60 mm). Braunecker et al[11] tried to compensate for this by using the surrogate measure of CP. CP had many limitations as, according to the author's own calculations, all five assessed CPR techniques reached a CP above the minimum required by their respective guidelines, yet only some techniques were described as being satisfactory without clarification of the cut-off points for a strong or weak CP. Additionally, CP ignores the individual importance of compression rate and depth being within guidelines. A poor compression depth and a fast compression rate (both of these harmful to the survival of the casualty) might produce a high CP, masking the poor utility of a technique in real-life scenarios.[10]

In terms of both depth and rate, HS appears to be the strongest CPR method. Additionally, the usage of leg muscles for generating compressions would mean that CPR could be carried out consistently for longer. However, this method does not allow transport of the rescuer and casualty to the CMRS (where medical equipment would be stored) without the interruption of compressions.

On the other hand, the ER and RBH methods do allow transportation. Although, perhaps not as strong a technique as HS, the ER method still produces a strong compression depth and rate, while the RBH method could not produce a sufficient compression rate. For these reasons, the European Society for Aerospace Medicine Space Medicine Group (ESAM-SMG) recommended the usage of ER as a first contact CPR technique, allowing a second rescuer to transport the rescuer and casualty to the CMRS without chest compression interruption. Once secured to the CMRS, ESAM-SMG recommends switching to HS, if the dimensions of the spacecraft allow.[14] However, it must be noted that the ESAM-SMG guidelines were written before the SHM and CM techniques were developed. While the CM technique appeared weak in the underwater study, the SHM technique needs to be compared against ER in order to determine which is the superior first contact CPR technique.[12]

The decrease in CPR sustainability, due to microgravity-induced physiological changes, could be overcome by the deployment of an ACCD when the casualty is secured to the CMRS, as these devices do not tire. The usage of an ACCD was 'weakly' recommended by the ESAM-SMG's guidelines due to the lack of evidence in microgravity when the guidelines were written.[14] However, Forti et al[13] demonstrated in their parabolic flight study that ACCD could consistently produce high quality compressions. In addition to this, there were no pauses or missed compressions, another issue that may be prevalent when CPR is performed by humans and may result in reduced CPR quality.[10] This was highlighted by the multiple periods of no-flow time (no chest compressions for >2 seconds) during the underwater study of SHM and CM.[12] ACCDs do have limitations, such as the evidence that they may delay time to first chest compressions and AED deployment.[18] For this reason, a standard operating procedure would need to be developed for the implementation of the ACCD and AED for treating an SCA on the CMRS.[9] ACCD presents additional logistical challenges. In spaceflight, weight is a key factor for deciding what to include in the medical equipment, the added load of 3.5–8.0 kg of an ACCD may not be justifiable.

Further studies need to compare all seven current CPR positions, under conditions close to microgravity, for longer periods than offered by parabolic flight in order to demonstrate the sustainability of the different CPR techniques (as well as their rate and depth). Such a study could perhaps be achieved with a body suspension device which allows different conditions of gravity, including microgravity, to be applied to the rescuer for extended periods of time.[9]

This article, while achieving its primary aim of evaluating chest compression technique in space, does not take into account other aspects of the BLS response, such as ventilation. In addition, while CPR in space is still a relatively unexplored research area and, thus, does not have much literature behind it, a more comprehensive literature search could have been carried out through using other databases as well as using synonyms for keywords. However, it is unlikely that a different conclusion would have been reached. Additionally, while this review aimed to standardise the studies evaluated in terms of the guidelines for which CPR is performed, some of the data included in the CP study had been from studies where CPR was performed under AHA 2000 guidelines, which required a lower compression depth and rate.

Conclusion

The growth of space tourism means more people will be subjected to microgravity-induced stress on their cardiovascular system increasing the likelihood of an onboard SCA. If such an event were to occur, it remains unclear whether the current available CPR methods may be effective. Current evidence suggests use of the ER method upon first response. After restraint to the CMRS, the rescuer should switch to the HS method and apply the AED. An ACCD should seriously be considered as a component of the onboard medical equipment, in case of having to perform CPR for extended periods. More research should be conducted in order to clearly demonstrate which CPR methods would work best in the microgravity environment.

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Figures

Figure 1. Handstand (HS) method being performed on a mannequin aboard the International Space Station (ISS) in 2002. (Image from NASA)

Figure 2. Evetts-Russomano (ER) MicroG CPR technique being performed on a mannequin during parabolic flight (ESA 2000). With thanks to Professor Thais Russomano for providing the image for this article

Figure 3. Schmitz-Hinkelbein method (SHM), (reprinted with permission ©MedizinFotoKöln)

Figure 4. Cologne method (CM), (reprinted with permission ©MedizinFotoKöln)

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I have just finished my 2nd year of Medicine at the University of Bristol. Space has always been a passion of mine. I have combined this interest in space with medicine through a student choice project in my 1st year on the physiological changes observed in humans in microgravity; and this INSPIRE article with a focus on how resuscitation is impacted by microgravity. I look forward to seeing where I can pursue my interest in space and physiology in the next stage of my medical career.