COLLECTIVE REVIEWS

Extraterrestrial Hemorrhage Control: Terrestrial Developments in Technique, Technology, and Philosophy with Applicability to Traumatic Hemorrhage Control in Long-Duration Spaceflight

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It is likely humans will venture beyond the relative safety of low earth orbit (LEO) during the next century, in space-faring journeys termed exploration class missions (ECMs).[1,2] These missions will include manned missions to the Moon and, ultimately, Mars. Such a mission to Mars could entail a period of years in which space travelers would be unable to quickly return to Earth in the event of a serious surgical condition.[3,4] These medical care challenges are greater than the engineering ones.[4-6] Space medicine will always be limited by logistical factors such as limitations in weight, volume, power, and crew training. It will be driven by a focus on conditions that are most likely to occur, or would have the most impact on the crewmembers and mission. A human surgical event has not yet occurred in space, though injury has been ranked at the highest level of concern regarding the probable incidence versus impact[7] and is considered a critical problem for which no reliable countermeasures exist in the National Aeronautics and Space Administration (NASA) Bioastronautics Critical Path Roadmap for long-duration, human space exploration.[8]

On earth, hemorrhage has been identified as the leading cause of potentially preventable injury-related death.[9] Bleeding to death accounts for 80% of intraoperative trauma deaths,[10] with more than one-half of these arising from abdominal injuries.[11] Although many deaths result from anatomically complex wounds, many are still relatively simple wounds in otherwise healthy victims in whom appropriate interventions were delayed.[12] Hemorrhage control must remain within the capabilities of space medicine. In this regard, exploration class space travel represents a unique paradigm.

Travel beyond low earth orbit will represent the ultimate remote medical setting, yet a traumatic event in space is very likely to occur within or adjacent to the space vehicle or surface habitat, greatly increasing the chances the injured astronaut will survive to "the hospital." In this case, advanced medical technology might be prepositioned. The health and safety of astronauts who venture beyond earth's orbit will depend on future advances in engineering, medicine, biology, informatics, and robotics.[13] A previous article reviewed fluid resuscitation in weightlessness.[2] This article reviews basic approaches to hemorrhage control both within and exterior to the major body cavities, and focuses on the foreseeable challenges for future trauma care during space flight. With mission profiles that will include human activities or even habitation on extraterrestrial surfaces, future planners will also have to consider the possibility of injury and treatment in reduced gravity environments such as the Moon ($\frac{1}{6}g$) or Mars ($\frac{1}{3}g$).

Currently available hemorrhage control in space

A major traumatic hemorrhage in space on any of the current man-rated space vehicles would be catastrophic

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Abbreviations and Acronyms

CMO	=	crew medical officer
EVA	=	extravehicular activity
IR	=	interventional radiology
MIS	=	minimally invasive surgery

because medical care systems are limited. Resuscitative procedures are limited by available supplies and equipment and training of the personnel involved. On the International Space Station, medical care has largely focused on stabilization and expeditious evacuation back to definitive care on earth.[4,14-16] Medical specifications for the International Space Station mandate the ability to comply with standard advanced trauma life-support techniques.[17,18] Initiating an intravenous infusion, performing endotracheal intubation, and placing a chest tube are technically and logistically within the skill level of the onboard crew medical officer (CMO), and have been found to be feasible during evaluations in the temporary weightlessness of parabolic flight.[19] CMOs are not required to be surgeons, or even physicians, and currently receive only 34 hours of medical training.[20] Even in low earth orbit, the International Space Station has only 50% to 70% real-time communication coverage. A Mars expedition would confront the issue of communication delays requiring 8 to 40 minutes for a round-trip,[14,20] making real-time contact with surgical consultants impossible.

Cardiovascular physiology in prolonged weightlessness

In weightlessness, a multitude of physiologic changes occur that are likely to impair the ability to withstand injury.[4,14] These include reductions in circulating blood volume, reduced red cell mass, cardiac atrophy and reduced cardiac outputs, alterations in vascular tone and neuroendocrine function, loss of the protective bony mass, and possible immune suppression.[4,13,14,21-23] What degree of partial gravity, if any, would ameliorate these changes is also unknown.[20]

Astronauts lose 10% to 23% of their circulating blood volume during space flight, resulting in an earth-equivalent hypovolemic state.[24-27] A further "anemia of space flight," with a decreased red cell mass, is consistently seen after long-duration space flight and would aggravate the effects of blood loss. Mean decreases in red cell mass approximate 10% to 20% of preflight.[28-30] During space flight, the working parameters of the neurohumoral and cardiovascular system are reset. Research suggests that there may be a global resetting of the autonomic nervous system with either a beta compared with alpha receptor bias, or impaired receptor sensitivities, resulting in an overall attenuation of the cardiac chronotropic response.[7,23,31-34] The resultant attenuation of aortic, cardiopulmonary, and carotid baroreflex responses to hypotension would presumably decrease the ability of astronauts to respond appropriately to hypovolemic stress.[30,35]

Trauma in space

The majority of trauma in space is likely to be blunt in nature.[4,14] Extravehicular activity (EVA or "space-walk") is believed to be one of the riskiest activities. There are potential risks of penetrating space injuries during EVA from micrometeorites,[20] the lethality of which would depend on the body area of impact, impact size and integrity of the suit pressure seal, and proximity to airlock ingress. Blunt trauma may differ from the typical decelerative injuries seen after terrestrial vehicular crashes, with crushing injuries more likely.[20] This is from the movement of high mass structures during EVA performed for space flight construction.[14] In such settings, astronauts might be dehydrated, losing an additional 0.7 to 2.2 kg of fluid in the Russian EVA experience.[23] In animal models, premorbid dehydration markedly compromises the ability to survive hemorrhage.[36,37] Severe head injuries, which typically occur in 60% of severe terrestrial blunt trauma,[38] might also be less frequent because of the protection offered by the rigid space helmet. If death and disability from serious head injury are reduced, this will magnify the importance of providing effective hemorrhage control in space.

Bleeding characteristics will differ in weightlessness. The majority of surgical bleeding results in fluid domes that remain at the site of bleeding or adhere to adjacent objects such as gloves and instruments, rather than free bleeding.[25,39,40] The force and volume of venous bleeding increase in space as compared with 1*g*, possibly because of the lack of venous wall compression.[4,41,42] Russian reports of increased parenchymal congestion and blood pooling in the abdominal viscera during the year-long MIR mission[43] suggest that intraabdominal hemorrhage might be increased as well.