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MEDICAL CONSTRAINTS IN SPACEFLIGHT: VENTURING BEYOND LOW EARTH ORBIT

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MEDICAL CONSTRAINTS IN SPACEFLIGHT:

VENTURING BEYOND LOW EARTH ORBIT

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NASA has generated a list of thirty-three gaps in medical capability that need to be addressed in order to extend the current model of medical care used in spaceflight in low-earth orbit to a model of medical care that will be conducive to exploration space missions. The intent of this project was to identify organizations that are doing research and development or have established products that will fulfill the closure criteria of these gaps, enabling NASA researchers to focus on those remaining gaps for which no product exists. The research conducted for this capstone identified existing capabilities relevant to the majority of the gaps within the Exploration Medical Capability (ExMC) portion of the HRP integrated research plan presented in NASA HRP-47065 Rev B.

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LIST OF ABBREVIATIONS

BAMC	Brook Army Medical Center, Fort Sam Houston, TX
CLS	Combat Life Saver
CT	Computed Tomography
EHR	Electronic Health Record
EMR	Electronic Medical Record
ExMC	Exploration Medical Capability
ISS	International Space Station
IVP	Intravenous Pyelogram
LEO	Low Earth Orbit
MAMC	Madigan Army Medical Center, Fort Lewis, WA
MASCAL	Mass Casualty Incident
NASA	National Aeronautics and Space Administration
NEA	Near-Earth Asteroid
RFID	Radio Frequency Identification
SCAD	Scanning Confocal Acoustic Diagnostics
SMEMCL	Space Medicine Exploration Medical Condition List
TAMC	Tripler Army Medical Center, Schofield Barracks, HI
UTMB	University of Texas Medical Branch, Galveston, TX
WAMC	Womack Army Medical Center, Fort Bragg, NC
WRAMC	Walter Reed Army Medical Center, Washington, DC

GLOSSARY

Combat Life Saver – A forty-hour training course taken by non-medical US Army Soldiers to prepare them to care for battle injuries

Conjunction – Astronomical bodies appearing close to one another in the sky as observed from Earth

Low-Earth Orbit (LEO) – An orbit between 80 and 2000 kilometers

Near-Earth Asteroid (NEA) – An asteroid that crosses or comes close to the Earth's orbit

Opposition – Astronomical bodies appearing to be in opposite directions from one another in the sky as observed from Earth

INTRODUCTION

NASA is studying the medical capabilities needed to extend human space flight beyond low Earth orbit (LEO). In the current low Earth orbit medical model, astronauts are trained to respond to basic medical emergencies, with plans in place to return astronauts to Earth (medical evacuation from ISS) using the already docked Soyuz space craft if a medical emergency arises that cannot be remedied by the astronauts themselves.

In the event of a mission to Mars, because of the asynchronous solar orbits of the Earth and Mars of one Earth year for Earth versus 1.88 Earth years for Mars, launch windows from Earth to Mars occur approximately every 26 months. At those times, the relative orbital locations are such that the distance from Earth to Mars is as little as 55–100 million kilometers. At times outside these launch windows, the distance from Earth to Mars is prohibitively far, up to 380 million kilometers when the Sun and Mars are in conjunction. Because of this, launching a rescue mission in support of a serious illness or injury to a crewmember is impossible outside of the rare launch windows. Even within these windows, a rescue mission could take as long as six months after lift-off to reach the ailing crewmember, not accounting for time required to plan the rescue mission and to assemble required personnel and equipment. Aborting the mission and diverting the entire space craft back to Earth would have similar challenges, as the Earth orbits more than 20,000 kilometers per hour faster than Mars, accelerating away at a rapid rate (Secosky & Musser, 1996). Similar statistics could accompany a mission to a Near-Earth Asteroid (NEA) with the exception that the travel time will be much shorter and would be dependent on the destination. The estimate for a round-trip flight to a NEA would be under six months, but would similarly not allow for an emergency rescue.

In order to maintain an acceptable level of safety, it is imperative that the astronauts have medical training beyond the current level provided and that they have medical equipment and decision-making assistance that might be needed in the event of a life-threatening emergency. They must have advanced medical and decision-making capabilities because they will not be able to rely solely on telemedicine in emergency circumstances. The communication lag time between the Earth and Mars ranges from 10 to 20 minutes each way, provided there is no electromagnetic or physical interference that prevents communications entirely (NASA Jet Propulsion Laboratory, California Institute of Technology n.d.). Telemedicine will play an important role, however. The crew must have state-of-the-art telemedicine capabilities that would allow Earth-based specialists to assist in care and decision-making whenever permitted by current communications capabilities and medical acuity.

In the process of this assessment, NASA medical scientists generated NASA HRP-47065 Rev B; a document that details the gaps that exist in transitioning from the current medical model to one appropriate to Exploration Missions (Steinberg, 2010). In that document, the ExMC Element Advisory Committee generated a list of thirty-three specific gaps in medical capability that need to be addressed. The intent of this project is to identify organizations that are doing research and development or have established products that will fulfill the closure criteria of these gaps, enabling NASA researchers to focus on those remaining gaps for which no product exists.

SIGNIFICANCE

This work was important because the risk of flying a manned space mission outside of LEO to a NEA or to Mars with the current medical equipment set is unacceptably high. In order to conduct this type of mission more safely, the gaps in medical care must be addressed and closed. NASA has identified the gaps that were present in their medical plan for exploration space missions, but locating sources to fill these many gaps required time-intensive research. Because of fiscal constraints, NASA sought to use existing technology wherever possible and to develop novel products only when no similar product already existed from an outside source.

From a public health perspective, this research identified technology that will contribute to the health maintenance and treatment of a small subset of the population, that is, astronauts. The work, however, may also be applicable in other resource-poor environments, including in remote areas of developing countries, because there is a strong emphasis on the technology being small, lightweight, and reliable. Advances in telemedicine and telementoring could also be used to improve assistance to healthcare providers in remote locations by increasing access to expert advice at great distances, streamlining the process that is currently done in Africa (R. Thiel, personal communication, March 17, 2011) and Antarctica (C. Otto, personal communication, April 4, 2011).

BACKGROUND

The NASA Human Research Program's ExMC Element, the group of physicians and scientists tasked with examining current and future medical capabilities during space flight, began by identifying the injuries and medical conditions that have occurred on previous space missions. The list was generated by reviewing the ISS medical checklist, the Space Shuttle medical checklist, and the Lifetime Surveillance of Astronaut Health in-flight occurrence data, along with medical knowledge of conditions that are more likely to occur on future missions (Watkins, 2010). Also included in the input data was the Delphi study, a consensus of NASA flight surgeon opinions along with the opinions of other subject matter experts.

The identified injuries and medical conditions were compiled into the Space Medicine Exploration Medical Condition List (SMEMCL). This list was compiled and prioritized by the ExMC Advisory Committee, which is composed of about twenty members including flight surgeons, physician astronauts, research physicians, engineers, and science managers (S. Watkins, personal communication, June 20, 2011). Each of the listed conditions was then categorized by likelihood of occurrence and severity of impact, including making hard decisions about which conditions must be treated, which would be treated if time and space allowed, and which conditions would receive only comfort care.

Examining the listed conditions, the ExMC then determined which of the potential exploration medical conditions had not yet been addressed by the medical assets and training available on current space missions. A systematic process known as technology watch was the next step. Technology watch is an ongoing careful analysis of emerging technologies that might be employed in mitigating the gaps in medical care (Exploration Medical Capability Element Management Plan, 2008). According to this Appendix, "The aim of this process is to leverage technologies developed by academia, industry, and other government agencies and to identify the effective utilization of NASA resources to maximize HRP return on investment." The ExMC Element concluded the gap identification phase by compiling a list of 33 known gaps in the form of NASA HRP-47065 Rev B, pp 209–88 (Steinberg, 2010).

METHODS

The purpose of this capstone was to take the list of 33 gaps in medical care and equipment, including the many sub-gaps, and to perform research in order to identify quality sources from which those gaps might be resolved or mitigated.

The first step in the process involved teaming with Dr. Sharmila Watkins, MD, MPH, Element Scientist in the ExMC, to generate a list of major medical organizations with an emphasis on resource-poor environment medical care. This list included the World Health Organization (WHO), the Centers for Disease Control (CDC), National Institutes of Health (NIH), Doctors Without Borders, the Gates Foundation, and the military. The initial concept was to fill as many gaps as possible from these sources and use other sources to fill the few remaining gaps. With the exception of the military, however, these organizations do little or no independent research. Instead, they take bids from or place requests to commercial medical developers, so very few gaps were filled from these organizations.

The next phase of research was a systematic search of military web sites. The first step of military research was identifying branches of service: the Marines and Coast Guard do not have their own organic medical assets. The Marines use Navy assets and the Coast Guard uses Public Health Service assets, so the focus was on the Army, Navy, and Air Force. Special priority was given to research units or divisions that have some aspect in common with the space environment. This led to specific searches on Army, Navy, and Air Force aviation research; Army combat medicine research; Navy submarine research; and Joint Forces Special Operations research and education. Using the author's personal experience and knowledge as a military officer, the search proceeded from known initiation points such as aviation research laboratories, submarine research laboratories, and special operations education centers, among others. In each case, the web site was examined for evidence of independent research, including looking for organizational charts indicating a research branch or division, looking for tabs on the web site indicating research, checking all "links" tabs for possible additional sources, and in some cases, calling the institution to determine if independent research was being conducted.

At this point, fewer than ten gaps or sub-gaps had been successfully addressed, so it was clear that a new approach was needed. To determine the next step, each gap was studied, breaking it down into component parts if needed. This was followed by a targeted search, component by component, primarily using the Google search engine. Each search was refined and the resulting pages reviewed in order to eliminate the pages that did not pertain to the gap. The information from the pages that did pertain to specific gaps was used to further refine the search in order to get the best results. When the results were optimized, the information was compared and narrowed down to the best two or three options. "Best" was ultimately a subjective decision; however, it was based on discussion with Dr. Watkins, personal understanding of and experience with remote medical care, personal experience as a military flight surgeon, and medical understanding of the component parts of each gap.

An example of this method for gap 4.21 *Lack of adequate eyewash capability to treat chemical eye exposure in partial and microgravity environments* went as follows. Initial research showed that there are two main types of eyewash station: gravity-driven and pressure-driven. In an environment without gravity, only the latter was considered. Next, search terms were developed. "Eyewash station" was the starting point. It was also important that the station not require any utilities, so the term "self contained" was added. The station also needed to be small, so the term "portable" was added. This yielded over 600,000 results. The first 15–20 pages were opened and examined. Some, such as employee safety training classes, discussed eyewash stations, but did not make or sell them. Those were discarded. Those that did not specify gravity or pressure function were also discarded. Those with only one choice of pressure eyewash system were considered to be less desirable as they did not allow for multiple size/weight choices. This narrowed it down to 5–6 choices from which two were selected. The web sites did not address the question of how these tanks would be pressurized or if they could be repressurized. Telephone calls to company representatives were placed resulting in the information that the tanks can be pressurized using a bicycle pump. This was determined to be satisfactory and these two companies were included as successful gap closure for the eyewash station portion of the gap.

If the information provided online was straightforward, the product specifications and contact information were gathered and provided to NASA. If the information was unclear or failed to address a key point requested by NASA, the organization in question was contacted by phone or email to clarify and ensure that the best information was included in the final document.

In the case of several gaps, no information was obtained from internet searches. In these cases, a determination was made as to the reason for the absence of the information, considering 1) lack of existence of the information, 2) lack of publication of the information, or 3) information or questions that were too specific for an internet search. In cases of highly NASA-specific challenges, for example information pertaining to the operation of a piece of medical equipment in a microgravity environment, no additional time was spent searching. In cases where lack of publication or need for very specific information were more likely, consideration was given as to who might be able to answer the question. In some cases, professional colleagues, mostly military, were contacted. In other cases, contact was made with organizations that appeared likely to have the best information. Further internet searches provided contact information, and telephone or email contact was made as needed in order to locate each answer. Often, phone leads were followed through several different people or departments in order to find the person with the best information. In each case, on locating the individuals with information most relevant to one of the gaps, their best contact information was obtained and they were informed that it was possible that a NASA Scientist would contact them in the future to clarify a point or ask further questions. They were queried if this was acceptable and in all cases, stated that they had no objections.

After most of the gaps were filled, the results were discussed with Dr. Watkins, who gave further guidance about additional information needed beyond what was listed in NASA HRP-47065 Rev B (Steinberg, 2010). The research was completed on these additional areas and a final written report was submitted to Dr. Watkins on 27 January 2011.

RESULTS

Each paragraph here begins with the gap itemization number as per NASA HRP-47065 Rev B, pp 209–88, followed in bold by the exact verbiage from that document detailing the question to be resolved by research into that gap (Steinberg, 2010). In many cases, the gaps included numerous sub-tasks described within the document itself, but not within the main gap description. Where necessary, this is described in plain type after the boldface quotation.

3.01 Lack of Knowledge about effectiveness of current NASA medical training programs including crewmember and ground support in diagnosing and treating medical conditions to the best possible outcome

Specific quantification about the effectiveness of NASA's current medical training model was not available; however, there was substantial information available from the military about the Army's training models, both for all Soldiers, called Combat Lifesaver (CLS) training, and the far more intensive training undertaken by the Special Forces Medics known as 18 Deltas (18D). Combat lifesaver training, given to all deploying non-medical Soldiers, is primarily focused on diagnosis and treatment of immediately life-threatening traumatic conditions such as arterial exsanguination, tension pneumothorax, and airway compromise. The main medical skills taught in this 40-hour course include tourniquet and pressure dressing application, occlusive dressing application, needle chest decompression, nasal airway insertion, and IV placement, among others. While much of this does not apply to NASA, the successful training of the majority of deploying Soldiers in IV placement is evidence that non-medical astronauts could also be taught proficiency in this skill in order to free the medically trained astronauts to undertake more skill-intensive treatments in an emergency situation. A link to the slides can be found in the references (Maine Patriot, n.d.).

The Special Forces Medical training occurs at the Joint Special Operations Medical Training Center, which is a part of the John F. Kennedy Special Warfare Center and School in Fayetteville, North Carolina. A graduate of the 50-week intensive program is qualified to function in both trauma and medical settings and is comfortable with everything from extreme trauma to IV anesthesia to minor surgical procedures. Graduates earn the designation of 18D. In general, two 18Ds are assigned to each 12-man Special Forces team. Lieutenant Colonel (LTC) Lee, the Deputy Commanding Officer of the training center, provided a copy of the curriculum modules used in their training program as well as a breakdown of the amount of time spent on each module (S. Lee, personal communication, January 19, 2011). This document is classified For Official Use Only (FOUO) so can be neither included nor discussed in this document. It details the number of hours spent on each of the modules, the order of presentation of the material, basic information about the labs undertaken by the students, and has further curriculum information which might be of use to NASA in reviewing and upgrading the astronaut medical training program.

3.02 Lack of knowledge about the current state of the art in telementoring/telemedicine as a tool for assisting crewmembers to diagnose and treat medical conditions that occur in space flight

Telemedicine and telementoring have become increasingly common and increasingly possible in recent years with the development of faster, more reliable, and higher quality connections. One of the largest telemedicine organizations in the world is NuPhysicia, which is affiliated with the University of Texas Medical Branch (UTMB) in Galveston, TX (NuPhysicia, 2010). As with any rapidly growing field, the field of telemedicine has its own peer-reviewed journal called *Telemedicine and eHealth Journal* (Liebert Publications, 2010). There, any new advances can be monitored to ensure current state of the art awareness. In this journal, one article, "A Systematic Review of Technical Evaluation in Telemedicine Systems," done in the UK, is of particular interest. It noted a deficiency in standards-based evaluation of telemedicine that needs to be corrected (Clarke & Thiyagarajan, 2008). With industry awareness of this deficiency, it is possible that an extensive, evidence-based evaluation of telemedicine will be undertaken in the future; therefore, this journal should be added to the ExMC technology watch list for future news.

Because of the remoteness of northern Norway, especially in the wintertime, that country has long been a world leader in the field of telemedicine including virtually all disciplines of medicine. The extensive experience of the Norwegians, particularly in reference to the breadth and length of their experience, indicates that they likely have resolved many technical concerns that might be encountered in the telemedicine process (Hartvigsen et al., 2007).

In the NASA Extreme Environment Mission Operations (NEEMO) 7 and 9 missions, Canadian surgeon Dr. Mehran Anvari performed simulated surgery from Hamilton, Ontario, on a mock patient in the underwater Aquarius habitat (Canadian Space Agency, 2004; Canadian Space Agency, 2006). Dr. Anvari also routinely performs telerobotic surgery on patients in the North Bay region of Canada. He published in the Annals of Surgery in 2005, discussing an outline of the remote surgeries performed and the methods and staff required (Anvari, McKinley, & Stein, 2005). The main shortfall of this approach is that it relies in part on a surgeon, albeit less well trained than Dr. Anvari, being present on the operating end. Since it is unlikely that a surgeon will be selected as a participant in an exploration mission, a medically trained mission participant would need to gain some experience in this role in order for this model to be accurate and successful.

A teledermatology contract was awarded to UTMB by Raytheon Polar Services to provide teledermatology services in Antarctica (Sun, Lanier, & Diven, 2010). In this brief article, they outline their main challenges, which related to difficulty in getting biopsy specimens out of Antarctica, difficulties with bandwidth that were often related to sending high resolution digital images, and difficulty accessing satellite signal during certain parts of the day due to the remote location and satellite angle.

3.03 Inadequate means and methods for early recognition of in-flight medical conditions (including behavioral and functional) that can lead to higher consequence outcomes if not treated early

The medical portion of this gap is already in process at NASA.

BMed2 What are the optimal methods to predict, detect, and assess decrements in behavioral health (which may negatively affect performance) before, during, and after spaceflight missions and BMed7 What are the optimal methods for modifying the environment to prevent and remedy behavioral health problems during spaceflight missions?

The issue of behavioral medicine and space flight is a very specific skill set studied by few individuals. A psychiatrist with years of experience related to the effects of isolation and space flight on behavior and with prior NASA experience was located and the contact information provided to Dr. Watkins.

4.02 Lack of non-invasive diagnostic imaging capability and techniques to diagnose identified Exploration Medical Conditions involving internal body parts – This gap includes two major sub-gaps: 1) Identify and use small, portable, open-architecture ultrasound machines and 2) Identify combined Scanning Confocal Acoustic Diagnostic (SCAD) technology integrated with pulsed low frequency therapeutic ultrasound for treatment of fractures.

MAJ Brett Nielson (personal communication, January 4, 2011) and Dr. Brian Koch (personal communication, December 28, 2010), radiologists at Darnall Army Hospital, Ft. Hood, TX, recommend significant training in both acquisition and interpretation of ultrasound images in order for these to be reliably performed by a non-specialist physician. Dr. Nielson notes that the Ultrasound technician course is approximately a year in length and Radiology residency is four years. He recommends three months training at a hospital that places great emphasis on musculoskeletal ultrasound in order to get the needed experience, but notes that the physician-crew member will still not be capable of performing at the level of earth-based specialists. He also recommends screening ultrasounds be performed on each crew member prior to departure in order to assist the physician-crew member in identifying and cataloguing normal variants.

For versatile open-architecture ultrasound machines, the EchoBlaster 64 and 128 (HospitalManagement.net, 2010) and the Ultrasonix 500RP (Fung & Rohling, 2003) meet the minimum requirements listed in the gap description. The EchoBlaster product appears to be much smaller from the web images, though neither product has size and weight specifications listed on their web site. Another small, lightweight (7 pounds) portable ultrasound possibility is the M-Turbo by Sono-Site (Sonosite, n.d). The site does not say whether the unit is open architecture, but does note ease of networking and ability to store images on a flash drive.

SCAD technology for early diagnosis of osteopenia and treatment of fractures is in the research stage. The lead inventor is Dr. Yi-Xian Qin at the State University of New York at Stony Brook. The current model being tested includes the diagnostic modality but does not integrate that with low frequency pulsed emissions for treatment. Dr. Sean Boykevisch, Ph.D., a colleague of Dr. Qin, recommended that Dr. Watkins discuss that integration with Dr. Qin as a possible next step (S. Boykevisch, personal communication, December 27, 2010).

4.04 Lack of smart hardware for ventilation with variable oxygenation capability that mitigates localized oxygen build up

A simple potential remedy to the need for oxygen generation is an oxygen concentrator similar to those used by oxygen-dependent outpatients, such as the Freestyle Oxygen Concentrator by Air-Sep (AirSep, 2010). This product is 2kg and produces an approximate oxygen concentration of up to 90%. It can run off either continuous power or batteries, with a battery life of 2–3 hours. Its operating temperature range is 5–40˚C. Temperatures outside that range can affect performance.

Significant adaptation would be needed in order for this product to be useful in an environment requiring exogenous air packs, such as on the surface of Mars or a NEA, because the device depends upon extracting and concentrating oxygen already present in the ambient air in order to produce concentrated oxygen. A coupling device allowing it to extract oxygen from the air in an air pack would be needed in order for it to function away from the spacecraft.

4.05 Lack of minimally invasive in-flight laboratory capabilities with limited consumables required for diagnosing identified Exploration Medical Conditions

– This gap includes sub-gaps addressing: 1) Lab-on-a-chip or nanoscale testing, 2) specific reference to 5-part white blood cell (WBC) differential and WBC subtyping, to include CD4, T helper and natural killer cells, 3) blood chemistry.

The ideal version of laboratory capability for space flight would be a lab-on-a-chip or microfluidic system. Currently, the research in this area is focused almost exclusively on virus and cancer detection, with little mention of standard chemistry or hematologic analysis. Some rare research in medical chemistry analysis is ongoing at Rice University by McDevitt Labs (Rice University, n.d.). Their web site discusses clinical chemistry including pH, electrolytes, metal cations, sugars, biological co-factors, toxins, proteins, antibodies, and oligonucleotides, but does not mention specifically which of each component can be tested, what the current state of development is, and when they anticipate general availability.

The only group in the world currently working on microfluidic hematology is at the University of Southampton in Great Britain. Their nano group has developed a three-part white-blood-cell differential (T lymphocytes, neutrophils, monocytes) (Michaels, 2009; University of Southampton, n.d.).

Beyond microfluidic technology, current small, portable lab devices that may be useful include iSTAT from Abbott Labs, which covers chemistry, hemoglobin and hematocrit, blood gas, cardiac markers, and coagulation analysis, among others, but does not perform any WBC testing (Abbott Laboratories, n.d.). Each test requires a separate, non-reusable cartridge and different cartridges are required for each test panel. The device is handheld. A second potential device is the Piccolo by Abaxis (Abaxis, 2010). This device analyzes chemistry and lipid panels, but not cardiac or hematology panels. It measures 6x8x12 inches and weighs 12 pounds. The cartridges are also non-reusable.

For CD4 analysis, the World Health Organization (WHO) recommends standard microscopy for labs with low sample throughput, as would certainly be the case on an exploration space mission (World Health Organization, 2010). Such a system would require an optical microscope, a centrifuge, and other laboratory consumables such as beads. The current technology approved by WHO is generated by Cyto-Spheres [Coulter Corporation, USA] and Dynabeads® [Dynal Biotech, Norway].

For hematology with a five-part differential, there are ample possibilities; however, all of the standard machines designed for humans are massive, ranging from 50–100 pounds: well outside the weight limit that an exploration mission would allow. The smallest was the Abaxis VetScan, which, as the name implies, is a veterinary device. It is still heavy at 25 pounds, but smaller than its human counterparts (Diamond

Diagnostics, 2010). For hematology, the best option is to partner with Southampton to develop a five-part differential in the nanotechnology format.

4.06 Lack of capability to stabilize and treat bone fractures

In the US Military, the standard splint used by Combat Medics, Corpsmen, Flight Surgeons, Flight Medics, and Special Forces Medics is the SAM splint. SAM splints are made of a deformable metal that can be shaped to conform to the injured limb, so require no water and can easily be applied in an aviation/aerospace environment. They are lightweight, easily portable, and can be cut to size if needed using standard trauma shears (SAM Medical Products, 2010). While normally removed and replaced with a plaster splint or cast, they are safe to leave in place indefinitely as long as the injured individual is careful.

4.07 Lack of wound care capability to improve healing following wound closure

Physician Assistant Jenna Smith at Tripler Army Medical Center (TAMC) in Hawaii is a specialist in wound care who works in TAMC's wound care clinic. Per Ms. Smith, the most important elements of wound care are maximizing nutrition, providing for debridement, and controlling moisture balance (J. Smith, personal communication, December 29, 2010). She continues by stressing importance of soaking the wound with a cleansing solution, which might be feasible in a microgravity environment by sealing Tegaderm on all four sides leaving a pocket into which to inject the solution. Walter Reed Army Medical Center (WRAMC) has a wound care web site with additional information (Walter Reed Army Medical Center, n.d.).

4.08 Lack of capability to treat muscle, ligament, and tendon injuries

– This gap is specifically looking for alternatives to heat and ice packs.

CPT Amy Morreau, Physical Therapy Officer-in-Charge at Brooke Army Medical Center in San Antonio, suggests that, aside from the standard reusable blue gel packs for heat and cold therapy, creams like Biofreeze or Icy Hot could be used, though they do not have the same degree of therapeutic effect as ice or heat (A. Morreau, personal communication, January 24, 2011). She also recommended an expert with superior training in this field, and the contact information for that individual was provided to Dr. Watkins.

4.10 Lack of rapid vascular access capability for space flight

The most commonly used device in the military for rapid access with suboptimal veins is the FAST-1 intraosseus device, which is a device intended for placement in the sternum. A study was conducted on the frequency of successful placement of the device as determined at autopsy of military service members in whom device placement was attempted (Harcke & Mazuchowski, n.d.). Of the 81 cases examined with the device present on arrival, 75 were correctly placed in the manubrium, three were placed in the body of the sternum, and three were not in bone. The authors note that there were a number of patients with evidence that the device had been attempted and removed. They were unable to conclude in those patients whether the device was removed because it was no longer needed or whether it was removed because placement was unsuccessful. The device manufacturer is Pyng (Pyng, 2010). Additionally, as mentioned under gap 3.01, non-medical personnel can be taught to be comfortable and skillful in IV placement, which frees the medical personnel to concentrate on higher-level medical decision-making. The US Army does this routinely as a part of the Combat Lifesaver program (Maine Patriot, n.d.).

4.12 Lack of in situ intravenous (IV) fluid generation and resource optimization capability

The US Army Institute of Surgical Research (USAISR), in conjunction with UTMB-Galveston, has developed a program to guide clinical decision-making in reference to fluid management in burn patients in the first 48 hours after injury (Health.mil, 2010; U.S. Medicine: The Voice of Federal Medicine, 2010). While this is clinically very different from most of the situations that astronauts would expect to encounter, the concept could be adapted to provide decision support in a variety of other situations.

4.13 Lack of capability to diagnose and treat a renal stone

Confirmation of a clinical diagnosis of renal stones is best made using Intravenous Pyelogram (IVP) or Computed Tomography (CT), neither of which is currently available on orbit. Ultrasound is good for localizing hydronephrosis, but can miss smaller stones, especially in the ureters. Madigan Army Medical Center (MAMC) Urologist Dr. Tim Bishop notes that all lithotripters are big and bulky and all require anesthesia or at least sedation (T. Bishop, personal communication, December 29, 2010). If NASA opts to develop a smaller, lighter unit, he recommends integrating fluoroscopy into the unit, as is often done in the current larger units, in order to allow for IVP for better stone localization. Brooke Army Medical Center (BAMC) Urologist Dr. James Lees noted that in a microgravity environment, the retroperitoneal kidneys would remain in a fixed location, but the ureters would be free floating within the peritoneum and would be "impossible" to hit with a shock wave (J. Lees, personal communication, January 5, 2011). Missing the stone would have "disastrous consequences," according to Dr. Lees. A system for fixing the ureter in space would therefore be imperative before attempting lithotripsy. In order to minimize weight and bulk, combination devices will be preferable, such as a combination ultrasound/lithotripter (Olbert et al., 2003).

A later study done by the capstone author for Dr. Watkins demonstrated that in underserved and remote areas throughout the world, very few patients receive lithotripsy and most recover from their stones without incident (Fondy, 2011). For this reason, watchful waiting should also be taken into consideration.

4.14 Lack of efficient medical consumable inventory tracking system that provides data on overall usage and usage rate and integrates securely with vehicle inventory management system

– This gap specifically asks for information on Radio Frequency Identification (RFID) tracking.

Womack Army Medical Center (WAMC) at Ft. Bragg, NC, has been using RFID tracking for all of their medical durables since 2003. The system they use enables them to find specific pieces of equipment, track patients during a Mass Casualty (MASCAL) event, exchange supplies (cross level) between units, find specific models of equipment in the event of a recall, and allow medical maintenance to do tracking for routine maintenance (Versus, 2010b). Mr. Dale Nuxall in WAMC's logistics and warehouse element states that the system they use to accomplish this is Versus (Versus, 2010a). WAMC does not currently use an RFID tracking system for medications but they are installing one right now. The tracking system for medications will track the packaging of the pharmaceutical, but not the individual tablets.

4.15 Lack of Medication usage tracking system that includes automatic time stamping and crew identification

– This gap includes specific evaluation of RFID usage with medications as well as other modalities.

Jena University Hospital in Germany has been using RFID to track medications used within the hospital for a number of years; however, their system is confined to the patients in their intensive care unit (Wessel, 2006). Individual packaging is tracked, but not the pills themselves.

WAMC currently uses a human- and bar code-driven system for medication tracking.

While Kodak applied for and received a patent for RFID tags to be placed directly onto individual pills, there is no system in place where this is occurring or even in a test phase. All online references to this were in the 2007 timeframe when the patent was obtained. If Kodak has continued working on this after obtaining the patent, they have not published any updates.

4.18 Lack of adequate biomedical monitoring capability for exploration EVA Suits and **4.19 Lack of biomedical monitoring capability for performing periodic clinical status and contingency medical monitoring**

There are numerous organizations that are working on biomedical monitoring in various situations. Worcester Polytechnic Institute is working on monitoring capabilities for use by Soldiers under/with their combat gear for monitoring during wartime situations (Worcester Polytechnic Institute, n.d.). According to their web site, they are working on one device that fits under the combat helmet and another which is worn like a wristwatch.

A second source is several affiliates of the Cleveland Clinic. First is Farm, a 50-person, Boston-based medical development firm specializing in the design and development of medical devices and patient monitoring devices (Farm Design, Inc., 2011).

Another pair of Cleveland Clinic Affiliates doing this type of research are The Lerner Research Institute (Cleveland Clinic Lerner Research Institute, 2011) and the Department of Clinical Engineering in the Division of Operations. They both have expertise in electronics design and prototyping, physiology, and particularly patient monitoring.

A final contact for this gap is Blue Highway, which is a subsidiary of Welch Allyn located in Syracuse, NY (Welch Allyn, 2011). Per their literature, they are engaged in diverse, leading edge healthcare ideation to proof-of-concept to deployment.

4.20 Lack of a system to manage medical data collected from the patient in space flight that integrates with ground operations

– This gap specifically seeks new developments in medical records management.

While there is a great deal of national discussion and attention focused on development and implementation of Electronic Health Records (EHRs), there do not appear to be any dramatic new developments; just steady progress toward more complete, more user-friendly systems. Of note, the old term Electronic Medical Record (EMR) has been replaced by the more complete term EHR, referring to all health and wellness information rather than just hospital and clinic notes. The National Institutes of Health most recently published foundational information on EHRs in 2006 (National Institutes of Health, 2006). While this document is by no means reflective of the current state of the art in EHRs, it is a solid starting point. A branch of the Department of Health and Human Services called the Office of the National Coordinator for Health Information Technology (HITECH) has a searchable list of EHR products that they have certified as meeting certain standards (U.S. Department of Health and Human Services, 2010; HealthIT.HHS.gov, 2010).

4.21 Lack of adequate eyewash capability to treat chemical eye exposure in partial and microgravity environments

There are two major types of eyewash devices on the market: gravity-driven and pressure-driven. Clearly, the only type that is appropriate for the space environment is pressure-driven. The Bradley Corporation Pressurized Eyewash Stations feature a tank that is pressurized by a hand-operated bicycle-type pump (Bradley Corporation, 2010). The tank can be easily repressurized at any time. Another similar option is Speakman line of products (Speakman Company, 2010). Neither of these companies has collection devices that would be functional in a microgravity environment, but all eyewash stations listed have dual heads that would allow rinsing both eyes at the same time.

These heads would have to be fitted with a goggle-type device to allow for collection of the water during use.

4.22 Lack of capability to treat radiation sickness

– This gap specifically addresses the need for blood products.

One of the greatest concerns in acute radiation sickness is bone marrow destruction and life-threatening need for blood product transfusion. Standard blood products are not practical due to their short shelf life, need for refrigeration, and need for multiple blood types. The only currently available artificial blood for transfusion is Hemopure, which is manufactured and used in South Africa (OPK Biotech, 2010). It is shelf stable for three years and requires no refrigeration. It is universal to all blood types. It was rejected by the FDA due to possible kidney/liver damage. However, the Hemopure web site states that “93% of the patients in the Hemopure group and 88% of the control group patients experienced at least one adverse event (AE), and 23% of the Hemopure patients and 18% of the control group patients experienced at least one serious adverse event (SAE).” In the future, there may be possibilities with Oxycyte, a perfluorocarbon-based therapeutic oxygen carrier that is in Phase II trials in Switzerland and Israel (Oxygen Biotherapeutics, 2010). Several other attempts at blood substitutes within the US have been unsuccessful.

Another research endeavor to follow is that of freeze-dried platelets being undertaken by the Defense Sciences Office (Defense Sciences Office, n.d.). They have developed a preservation method for freeze-drying platelets that allows them to remain stable at room temperature for up to two years.

4.23 Lack of capability to auscultate internal sounds of the body in a space flight environment

The Naval Submarine Medical Research Lab has published on a noise reduction stethoscope with telemedicine port for use in areas with high ambient noise, specifically aimed at submarine use (Russotti, Jackman, Santoro, & White, 2000; Naval Submarine Medical Research Laboratory, n.d.). The US Army Aeromedical Research Laboratory has also developed a noise-immune stethoscope, primarily aimed at helicopter medical evacuation use (Gaydos, Williams, Reeves, & Kelley, 2010). Either of these products is a likely candidate for use in the space environment.

4.26 Lack of knowledge for treating pulmonary or systemic disease due to non-terrestrial dust exposure

– This gap specifically seeks an Inhalational Immunologist.

While clearly the microgravity-specific aspects of this gap have not been studied outside of NASA, the Navy Medical Research Unit—Dayton is doing some interesting research on inhalation related to the current military deployments in the Middle East (Navy Medical Research Unit—Dayton, n.d.). This includes research on sand deposition, burn pits, various fuels, and other inhalational hazards. Inhalational Toxicologist Dr. Michael Gargas, Director of Environmental Health and Toxicology, runs the Environmental Health Research Department and is willing to partner with NASA and possibly to direct aspects of his research if that is mutually desirable (M. Gargas, personal communication, October 22, 2010).

Regarding locating an Inhalational Immunologist, one possibility is Dr. Matthew Poynter at the University of Vermont, Cellular and Molecular Biology Department (M. Poynter, personal communication, January 27, 2011). His main research focus is the effect of vehicle exhaust fumes on asthma. Another possible source for an Inhalational Immunologist is in the Department of Immunobiology at the Yale University School of Medicine (Yale School of Medicine, 2010). Their publications indicate an interest in inhalational immunology.

5.01 Lack of medical data management infrastructure for Exploration Missions

This gap seeks a technologic solution to integrate all medically relevant computer data systems into one system. Chris Hass, a vice-president of a technology firm in the Boston area, has an extensive network of professional contacts, particularly in the health information technology field (C. Hass, personal communication, January 8, 2011). He has numerous ideas about who might best be able to integrate these systems and recommended discussing with the Global Category Manager for Welch Allyn Monitoring, who has experience with both medical monitoring and NASA.

DISCUSSION

In order to maximize the likelihood of success of a space exploration mission outside of the Earth-Moon system, it is imperative that steps be taken to improve the medical capabilities available to the astronauts during the voyage.

The initial concept was to conduct an internet search of a number of well-known major medical organizations to see what research they were doing and how it correlated with the NASA-generated gap list, then locate and add a few additional organizations to fill in gaps that were not covered by the initial list of organizations. The original guidance was to try to keep the list to 15–20 organizations, starting with WHO, CDC, NIH, Doctors Without Borders, the Gates Foundation, and the military. Within the military, particular focus was to be given to Aviation, Submarine, and Special Operations research. A diligent search of each of those organizations filled only 3–4 gaps, and those only partially.

There were two causes for this shortfall. First, a number of those organizations do no or very little original research. Since the total focus of this research was on finding the product or technique developer, organizations that use research performed by other groups were discarded. This entirely eliminated CDC, Doctors Without Borders, and the Gates Foundation, and left one result each from WHO, the CDC, NIH, Army Aviation, and Navy Submarine. Unfortunately, the Army and Navy research filled the same gap (noise-reduction stethoscope). Early in the project, there was difficulty establishing communication with Special Operations due to their extremely closed community. The second cause of this shortfall is that the remaining organizations, all military, do extensive research, but very specifically geared toward their needs. Sometimes these needs overlap with NASA's needs, but most often, it was not germane to the gaps. Expanding to other military units outside of the three specialties already mentioned did not improve the results. The determination was made that the original search plan was flawed and would need to be abandoned.

Rather than approaching the search from the perspective of knowing the source and then determining which gaps that source could fill, the technique was altered to search for the specifics of the gap with no preconceptions of which organization might be doing research in that field and might appear as a search result. The major challenge to this technique was coming up with search terms that were specific to the gaps in question and would produce relevant results. Another major drawback was that using the Google search engine yielded thousands and even tens of thousands of results for some gaps. Even with refined searching, it was rarely possible to narrow the list down to a number that would allow opening and reviewing every result. Finally, this technique also resulted in a dramatically higher number of sources than the originally-planned 15–20. It did, however, produce numerous positive results and was a generally effective technique for filling the gaps.

It was generally effective rather than extremely effective because using a non-space- related search engine to find results that would be pertinent in microgravity proved problematic for some specific topics. For those, military colleagues in various Army Medical Centers were contacted. After a brief explanation of the mission background leading to the gap question, one or more specific gap questions were posed to each of these specialists in their field of expertise. These physicians were generally very interested in being of assistance and appreciated being able to think creatively about their specialty in a microgravity environment.

From this process, one can conclude that there is not a single best technique for performing this type of research. Rather, the best technique is to have an overall strategy, but use a variety of different approaches in order to maximize both the quantity and the quality of results.

This research identified existing capabilities relevant to the majority of the gaps within the ExMC's portion of the HRP integrated research plan presented in NASA HRP-47065 Rev B (Steinberg, 2010).

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VITA

Susan Fondy was born in Syracuse, New York. She attended the State University of New York at Binghamton where she graduated with a Bachelor of Science in Biology degree in 1989. She obtained her Medical Doctor degree from the State University of New York at Stony Brook in 1994. Her initial residency was in Pediatrics at the Medical College of Virginia, Richmond, Virginia. For the next seven years, she wandered the country as a locum tenens pediatrician. Because of the horrific events of September 11, 2001, Dr. Fondy made the decision to join the United States Army where she was commissioned at the rank of Major in 2004. Since that time, she has served with the 10th Mountain Division, the 101st Airborne Division, Womack Army Medical Center, and the 21st Combat Support Hospital. Her awards include the Bronze Star Medal, the Defense Meritorious Service Medal, the Meritorious Service Medal (1 Oak Leaf Cluster), the Air Medal, and the Army Achievement Medal. In 2009, she was honored with the Army Aviation Association of America's Medicine Award, presented to the top Flight Surgeon each year. She currently lives in Dickinson, TX.

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