Exploration Medical Capability (ExMC) Projects

Gap ID	Gap Title	Description	Gap Decomposition Questions
1.01	Inadequate and/or immature information on medical screening technologies for the identification of clinical and subclinical pathology for medical conditions experienced in space flight environments	This is an ongoing gap that the element will continually address. There are no plans to close this gap. Both genetic and phenotypic screening will be addressed by this gap.	• What new screening technologies are available? • What genetic screening techniques are in clinical trials or being researched?
2.01	Lack of knowledge about incidence rates, probabilities, and consequences relative to Loss of Crew and/or Loss of Mission (LOC/LOM) for the medical conditions on the Exploration Medical Condition List	One of the major gaps of knowledge in space medicine is quantification of likelihood and consequence of medical conditions that could occur during space flight. The total combined duration of human space flight is brief and limited. So the body of medical evidence from which to quantify medical conditions is small when compared to the terrestrial medicine body of evidence. The focus of this gap is to generate a list of medical conditions that are of concern for human space flight, and provide quantifiable data and rationale about why the medical condition is of concern.	• How should consequence of a medical condition be factored in with the incidence rate of the medical condition?
2.02	Lack of quantitative knowledge about impact of having a clinically trained crew medical officer on each space flight mission	It has not been quantified yet if inclusion of a physician crewmember with relevant competency maintained over the exploration mission would achieve better care/reduced risk, reduced cost, reduced training time, increased efficiency, reduced need for telementoring and increased autonomy. This gap aims to determine what effect a clinically trained crewmember would have on overall cost and medical care quality.	• How does the medical background of the Crew Medical Officer (CMO) affect crew health and mission end states? • What training and technology gaps exist for each level of clinically trained CMO? • Can one clinically trained CMO individually effectively manage a medical contingency? • For each medical condition, how many support care givers are needed, and

			what level of support caregiver training is required, to manage a medical contingency?
3.01	Lack of knowledge about effectiveness of current NASA medical training programs including crewmember and ground support in diagnosing and treating medical conditions for the best possible outcome	Training of crewmembers and ground support teams is a critical component of a medical health care system. Providing medical hardware and technology is not enough when that equipment is not placed in the hands of a well trained and effective care provider. This gap seeks to explore the effectiveness of current NASA medical training programs and document any inadequacies in those programs based on the many years of short- and long-duration manned space flights.	• How effective are the medical training programs in enabling CMOs to execute and retain the skills to manage a medical event? • How effective are the training programs for ground personnel in supporting the CMO during a medical event? • What is the role of just-in-time training?
3.02	Lack of knowledge about the current state of the art in telementoring/telemedicine as a tool for assisting crewmembers in diagnosing and treating medical conditions that occur during space flight	Telementoring is the delivery of training and mentoring services across telecommunication networks typically in the format of audio and video. As a subset modality of telemedicine, telementoring is focused on providing a means to train operators with the instructor physically located in a remote location. Based on the type of training content, the presentation format may vary. Various formats include teleconference, video conference, or web exchange. Due to the relative novelty of this form of communication, telementoring has only recently started to gain momentum as a means of guiding and training remote operators. As such, effective means of communicating and techniques to convey information are constantly being developed. This gap is focused on understanding the latest telementoring technologies and techniques, as well as media platforms on which the information is presented.	Gap decomposition questions for this gap will be developed after the Telemedicine Summit in November 2010.
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 prevention of medical conditions is the primary approach for having a healthy crew to perform a successful space flight mission. Periodic in-flight health status exams and routine crew monitoring are used in the early recognition of certain conditions on the Exploration Medical Condition List. By catching these conditions early, fewer resources can be used to	• What monitoring or screening technologies, techniques, or methods are needed to enable early recognition of each of the medical conditions?

		treat the condition before it fully manifests into a potential worst-case scenario. This gap looks at all the various techniques and methods that can be used to monitor the crew and enable early recognition of medical conditions that could impact mission success.	
4.01	Lack of autonomous medical procedure system that includes decision assistance and integrates with medical hardware including closed loop systems	The current space flight procedure system is a combination of both paper and electronic formats. The procedures themselves are developed and validated on the ground. The burden is placed on the crewmember to collect, analyze, and interpret data to decide which procedural decision pathway to follow. This can be an issue with medical procedures as the crewmembers often are not clinicians. They are given minimal medical training often months before the start of their mission. This gap focuses on reducing the burden of medical data analysis and decision making on the crewmember. In addition, this system could be useful in supporting a physician crew medical officer and offering a secondary set of instructions or assistance for an augmented medical care giver. An autonomous medical procedure system would assist the crewmember in analyzing and interpreting the medical data collected so that the proper decision pathways are followed.	• How should information presentation and analysis of the data be tailored given the clinical skill level of the caregiver? • What technologies exist that can provide intuitive information to assist the care provider during a medical event? • What level of automation or "smartness" should be provided to the care provider given their level of medical expertise?
4.02	Lack of noninvasive diagnostic imaging capability and techniques to diagnose identified Exploration Medical Conditions involving internal body parts	Due to the normal constraints of space flight, most common clinical diagnostic techniques will not be available during exploration missions. That is especially true for imaging diagnostics. Although physicians commonly use X-rays, Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI), ultrasound, and other techniques, perhaps only ultrasound may be compatible with space flight. Flight surgeons have requested improved imaging hardware operating in the visible portion of the electromagnetic spectrum to acquire digital images of skin and body orifices. Work under this gap will initially focus on	• How can the role of diagnostic imaging be expanded to monitor/facilitate treatment, determine countermeasure efficacy, predict patient medical outcomes, assess mission/crew safety risk, and assist with key mission planning decisions? • How can minimally trained flight crews obtain images of sufficient diagnostic quality, particularly given the organ shifts associated with spaceflight? • How can computationally intensive

		identifying space flight medical conditions where imaging-based diagnosis and/or treatment is required, developing an evidence base for determining which technologies are required, and assessing the space flight readiness of the identified technologies. Once the appropriate technologies are identified and readiness determined, a plan will be developed to not only integrate the technologies to the greatest extent possible, but also the groups working on those technologies. Those groups include GRC, JSC, and ARC, as well as the NSBRI. Relevant work being performed with non-NASA funding will be identified and NASA work will be leveraged with those efforts.	imaging and image processing techniques be implemented with radiation-tolerant hardware/software that will survive the deep space radiation environment? • To what extent can pre- & postflight demonstrations of ground-based enabling imaging technologies, using flight crews as subjects, elucidate the development of flight technologies?
4.03	Lack of capability to treat back/neck pain and injuries in the space flight environment	This gap primarily addresses the possibility of a back or neck injury occurring during lunar surface exploration. The type of injury will most likely be mild-to-moderate ligament or muscle strains.	• What is the etiology of back/neck pain in space flight? • What space flight-friendly treatments are available for each source of back/neck pain? • How do we prevent back/neck injuries from occurring?
4.04	Lack of smart hardware for ventilation with variable oxygenation capability that mitigates localized oxygen build up	The proper and adequate operation of a ventilating device and variable oxygen delivery is a skill that takes many hours of training. The Crew Medical Officers (CMO) on exploration missions will more than likely be given very limited medical training overall and even more limited training on ventilation and variable oxygen delivery. The training opportunities to teach the CMO on how to operate a ventilator will not be adequate enough to provide terrestrial standard of care during a medical contingency. The purpose of this gap is to develop hardware that can assist the caregiver in decision support involved with operating a ventilator and variable oxygen delivery device. Carbon dioxide monitoring capabilities may	

		also be investigated in this gap should relevant medical conditions call for CO_2 regulation. The entire smart system will also need to minimize volume, mass, and power consumption. Developing a smart hardware system reduces the cognitive burden on the CMO to operate the ventilator, thereby reducing the risk of an inadequately trained operator. The smart hardware can manage the ventilation of the patient while the CMO performs other medical tasks. This also allows CMO training to focus their limited resources on other aspects of their CMO training for tasks that technology cannot overcome.	
4.05	Lack of minimally invasive in-flight laboratory capabilities with limited consumables required for diagnosing identified Exploration Medical Conditions	Analyzing bodily fluids (urine, blood, saliva) on the exploration missions will reduce launch/return mass/volume and provide data in near real time in lieu of postflight results. A system to perform this analysis in flight is necessary to meet these requirements. NASA conducted several trade studies analyzing the hardware available and developed an Excel-based tool to quantify the ability of hardware to meet mission requirements. To reduce system mass and volume, NASA is investigating the development of concepts and hardware for reusable systems of this type. Such miniaturized systems are dependent upon space medical standards and requirements that will be determined based on expert opinion, risk assessments, and evidence bases. These standards and requirements are critical for engineering and medically qualifying the appropriate system for remote space applications. Since no in-situ medical diagnostic device that involves blood or urine fluid analysis is currently operational, it will be important to establish that such a device may be operated routinely. In addition to microfluidic processing systems, noninvasive monitoring devices may also be considered.	• What conditions and/or measurements can be diagnosed with less invasive measurements (e.g., saliva, breath, sweat, interstitial fluid) or noninvasive measurements (e.g., optical, electromagnetic) through the skin? • Are less invasive measurements as effective as current blood- (or urine) based methods in terms of ease of use and reducing consumables? • What new measurement capability could be applied to further reduce consumables? • If blood measurement is necessary, are there emerging technologies that can be applied to provide a sample that would be less painful/less invasive than a finger stick?

4.06	Lack of capability to stabilize and treat bone fractures	Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density will stabilize at a lower level or continue to diminish. It is also unknown if fractional gravity, present on the moon and Mars, would mitigate the loss. This level of bone loss does not create an unacceptable risk of fracture for ISS missions, but longer missions could create higher fracture risk (excerpt from the IRP). Current casting methods are problematic for the anticipated operational environment during lunar mission sorties and long-duration stays. Modifying existing casting methods or identifying a new technology for casting is essential for meeting this gap.	• How should long bone fractures be treated in micro and partial gravity? • How should short bone fractures be treated in micro and partial gravity? • How should flat bone fractures be treated in micro and partial gravity? • How should distal bone fractures be treated in micro and partial gravity? • Does stabilization hardware allow for proper personal hygiene for full duration of treatment in micro and partial gravity?
4.07	Lack of wound care capability to improve healing following wound closure	Explore the development of methods and technologies for wound care capabilities.	• Is wound healing repressed in a space flight environment? • What technologies, techniques, or methods are available to accelerate wound healing?
4.08	Lack of capability to treat muscle, ligament, and tendon injuries	With longer missions and more labor intensive tasks expected during exploration missions, the likelihood of musculoskeletal injuries such as sprains and strains is expected to increase. Standard terrestrial therapeutic response to treating sprains and strains is to provide cold compress or heat treatment to the affected area. Cold compress and/or heat treatment is desired that can be stowed in its inactive state in the vehicle's ambient environment, activated to provide the desired therapeutic relief, recharged using available vehicle resources, and restored in its inactive state for future use.	
4.09	Lack of medical suction and fluid containment capability for chest tube and airway	There is currently no medical suction capability that would work in the space operational environment. Medical suction clears the airway, empties the	• How should vacuum levels be adjusted for reduced gravity? • Will "pusher" fluids be required in

	management	stomach, decompresses the chest, and keeps the operative field clear.	reduced gravity?
4.10	Lack of rapid vascular access capability for space flight	In a medical contingency, the ability to gain access to the patient's vascular system to provide medications or fluids can be critical. This task is difficult to accomplish even for skilled medical care providers. This gap is focused on finding technologies or techniques that can allow a medical care provider to safely and rapidly establish vascular access in a patient that is easy for a layperson to operate, minimizes trauma, and minimizes the infection rate. This assessment will consider conventional intravenous (IV) and intraosseous (IO) vascular access methods as potential treatment modalities.	• Is there a technical solution, procedural solution, or both for gaining rapid vascular access during space flight?
4.11	Lack of dental care capabilities	Development of methods/technologies for dental conditions; technology development effort to provide dental care technology. Future solicitation will not start until FY13.	
4.12	Lack of in situ intravenous (IV) fluid generation and resource optimization capability	Medical operations concepts for both International Space Station (ISS) missions and exploration missions include pharmaceuticals that can only be given intravenously. Additionally, several conditions may require intravenous fluid to maintain hydration and electrolyte balance. Because of the volume and mass that would be required to treat all conditions specified, NASA prefers to generate sterile water for injection in situ on an ad hoc basis. Currently, no proven technology exists that can do this in a space flight environment.	• What are the effects on the shelf life of solutions due to environmental radiation exposure to the container? • What is the maximum capacity of the system for each possible contaminant? • What packaging design should be used to enclose each purification system before use (to avoid contamination)? • What is the shelf life of the purification system as packaged? • What are the effects of temperature on stored system shelf life? • What are the effects of temperature on the operating systems filtering capacity? • What are the effects of microgravity on microbe size and mobility (in regards to sterile filtration)?

4.13	Lack of capability to diagnose and treat a renal stone	Kidney stone formation and passage has the potential to greatly impact mission success and crewmember health during long-duration missions. Alterations in hydration state (relative dehydration) and bone metabolism (increased calcium excretion) during exposure to microgravity may increase the risk of kidney stone formation and it is unclear which mitigation strategy would be the most effective. Lithotripsy is a medical procedure that uses shock waves to break up stones that form in the kidney, bladder, ureters, or gallbladder.	• What cutting-edge technologies are being developed for the diagnosis and treatment of kidney stones, and how effective and flight-feasible are they? • Can a non-expert diagnose and treat kidney stones in a space operational environment?
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	When shuttle and ISS medical kits are returned to Earth, fewer medical consumables remain in the medical kits than would be expected based on reported use by the astronauts. This gap is significant because the possibility exists that exploration missions could be undersupplied and run the risk of being unable to treat an ill or injured crewmember, particularly given the small volume available for the medical kits. Work under this gap will identify current practices, develop controls, processes, and technical solutions to accurately track the inventory of medical consumables including pharmaceuticals.	• How do analog institutions track medical consumables to the dose level? • How do analog institutions handle privacy issues? • How do tracking technologies vary with storage requirements? • How do analog institutions track liquid medications to the dose level?
4.15	Lack of a medication usage tracking system that includes automatic time stamping and crew identification	When shuttle and ISS medical kits are returned to Earth, fewer medical consumables remain in the medical kits than would be expected based on reported use by the astronauts. This gap is significant because the possibility exists that exploration missions could be undersupplied and run the risk of being unable to treat an ill or injured crewmember, particularly given the small volume available for the medical kits. Work under this gap will identify current practices, develop controls, processes, and technical solutions to accurately track the inventory of medical consumables	See ExMC Gap 4.14

		including pharmaceuticals.	
4.16	Lack of technique or procedure to draw injectable medication into a syringe without bubble formation or bubble removal before medication delivery	Preparation of injectable medications in a non-micro gravity environment simplifies removal of air bubbles within the syringe. This luxury is lost in microgravity as isolation of bubbles becomes difficult due to the absence of a force greater than the surface tension of the medication. The consequence of injecting an air bubble into a crewmember could be harmful. This gap's focus is to develop a technology or technique to prepare an injectable medication without air bubbles for safe delivery to a crewmember.	• How can bubbles be prevented from entering the syringe under reduced gravity/pressure conditions? • How can bubbles be eliminated if introduced into the syringe under reduced gravity/pressure conditions?
4.17	Lack of adequate protection for medications to preserve stability and shelf life during long duration space flight missions	It is currently unknown how effectively the packaging of medications preserves the stability and shelf life of the contents from the effects of space flight. Space flight adds the elements of microgravity and radiation that are not applicable on the surface of Earth. This gap seeks to address materials or products that can mitigate space flight effects and assist in the preservation of medications.	• How can the efficacy of medications be maintained in space flight environment? • Can medication efficacy be maintained beyond the manufacturer's expiration date? • What materials or packaging/preparation techniques can be used to maintain medication stability? • Is the efficacy of medications compromised during space flight?
4.18	Lack of adequate biomedical monitoring capability for exploration EVA suits	The crewmembers' physiological data, if monitored regularly, can indicate to the flight surgeons if there is a medical problem. During EVAs and periodic intravehicular activities (IVA), the flight surgeons need the ability to monitor key physiological signals that indicate the crew's work load and other physiologic parameters. The current system for donning the sensors is time consuming and inconvenient, requiring shaving, application of electrodes, and signal checks. A more efficient system will save crew time and reduce the overhead of stowing additional supplies. This system will be achieved through the integration of small, easy to use biomedical sensors that will have the ability to measure, store, and transmit physiologic	• What biomedical monitoring technologies can achieve an accurate and stable signal, maximize crewmember comfort, and minimize artifacts, consumables, and the time required for donning and doffing? • What do other operational groups (first responders, war fighters, high elevation climbers) do for biomedical monitoring? • What new biomedical monitoring technologies are available?

		parameters during operational and ambulatory scenarios. Such a system would also provide a wealth of data for the medical and research communities. Plans for overall medical and research biomedical sensing would be coordinated with the HHC element.	
4.19	Lack of biomedical monitoring capabilities for performing periodic clinical status evaluations and contingency medical monitoring	The crewmembers' physiological data, if monitored regularly, can indicate to the flight surgeons if there is a medical problem. During periodic IVA activities, the flight surgeons need the ability to monitor key physiological signals that indicate the crew's work load and other physiologic parameters. The current system for donning the sensors is time consuming and inconvenient, requiring shaving, application of electrodes, and signal checks. A more efficient system will save crew time and reduce the overhead of stowing additional supplies. This system will be achieved through the integration of small, easy to use biomedical sensors that will have the ability to measure, store, and transmit physiologic parameters during operational and ambulatory scenarios. Such a system would also provide a wealth of data for the medical and research communities. Plans for overall medical and research biomedical sensing would be coordinated with the HHC element.	• What biomedical monitoring technologies can achieve the required accuracy and stability during both ambulatory and contingency operations, while also minimizing consumables, inconvenience (shaving, skin prep), and time? • What biomedical monitoring system architecture/design (including mix of wired versus wireless, disposable versus reusable, autonomous versus assisted) would best meet the monitoring needs for the various Space Medicine Exploration Medical Condition List (SMEMCL) conditions, and for the expected usage rates for other non-contingency activities? • What do other remote and resource-poor groups (submarines, Antarctic stations) do for periodic clinical status evaluations? • What new biomedical monitoring technologies are available?
4.20	Lack of a system to manage medical data collected from the patient during space flight that integrates with ground operations	A system needs to be developed to integrate and manage the medical data captured by the diagnostic and therapeutic devices in a manner such that the medical data and information will be available, secure, and at full integrity.	• What should the architecture be for the integrative platform (e.g., black box, open format)? • How will the platform integrate existing medical records from preflight and ground collected data and new flight data?

			• Will the medical data management system make medical action recommendations?
4.21	Lack of adequate eye wash capability to treat chemical eye exposure in partial and microgravity environments	Standard treatment of a chemical exposure to the eye involves a constant flushing of the eye with clean water. The space flight and vehicle environment may not allow for constant flushing of the eye due to usage of valuable water resource and containment of the contaminated water after flushing. Technology needs to be developed to allow for flushing of the affected eye(s) for the required period of time, minimizing overall water usage while being operable in the various gravity environments experienced during exploration missions.	• How can a contaminant in the eye be rendered harmless? • What are viable methods for neutralizing a contaminant or removing contaminant/particulate matter from the eye, and how are the methods affected by partial and/or micro gravity?
4.22	Lack of capability to treat radiation sickness	Treatment of radiation sickness involves a broad scope of resources. Most of these resources are available for space flight from a technical feasibility perspective. One treatment resource that has not been developed is blood products or substitutes to replace blood cells damaged by radiation sickness.	• What new methods to diagnose and treat radiation sickness are being developed? • What research studies are required to demonstrate the safety and efficacy of a diagnosis and/or treatment method for radiation sickness?
4.23	Lack of capability to auscultate internal sounds of the body in a space flight environment	Analysis of body sounds for abnormalities is standard medical practice for diagnosing a medical condition. This gap addresses the need to isolate internal body sounds in a potentially noisy ambient environment and capture the auscultation data to be managed and transmitted to the appropriate destination for analysis.	• Are there technological improvements/innovations to key stethoscope components that can improve current instrument performance? • Are there options besides auscultation (e.g., ultrasound) that can be used to listen to the internal sounds of the body?
4.24	Lack of knowledge to treat conditions on the Exploration Medical Condition List in remote resource-poor environments	This gap seeks to understand how medical conditions are treated in the remote parts of planet Earth. These environments have similar operational constraints in that resources are limited. Understanding how medical care is conducted in these locations will aide in the development of a medical system for the remote environment of outer space.	• Is our method of treatment for each of the medical conditions on the SMEMCL consistent with how similar conditions are treated in remote terrestrial, resource-poor environments?

4.25	Lack of capability to deliver medication to crewmember in pressurized suits	Given the possibility that vehicle failures could result in the crew needing to remain in pressurized suits for up to 144 hours, and given that medical operations may need to provide medications via injection during that time, NASA must develop reliable methods for delivering such medications through the suit. A key assumption is, if the crew is in their suits, the cabin atmosphere is likely to be absent or at a greatly reduced pressure. Such a condition could lead to bubbles in the medication and pharmaceutical freezing.	
4.26	Lack of knowledge for treating pulmonary or systemic disease due to non-terrestrial dust exposure	The goal of this gap is to understand the effects of short- and long-term exposure to nonterrestrial dust on human systems and develop treatments to mitigate the effects.	• What symptoms do the body systems exhibit when exposed to lunar dust? • Do conventional treatments work as effectively on symptoms of lunar dust exposure?
5.01	Lack of medical data management infrastructure for Exploration Missions	In space flight, there is a large amount of data generated to understand and monitor the health and safety of the crewmember. Because of the large volume of data, a data management infrastructure needs to be deployed to allow users access to the data. The system needs to be available, secure, and ensure data integrity. Users can gain valuable insight into the health and safety of the crew to maintain their health status and ensure mission success.	