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Communication Bandwidth Considerations for Exploration Medical Care during Space Missions

Michael Krihak, Ph.D.
Universities Space Research Association
Ames Research Center, Moffett Field, California

Christopher Middour
Millennium Engineering & Integration Co.
Ames Research Center, Moffett Field, California

David Reyes, MD, MPH
University of Texas Medical Branch
Johnson Space Center, Houston, Texas

Derek Nusbaum, MD, Ph.D., MPH
University of Texas Medical Branch
Johnson Space Center, Houston, TX

Erik Antonsen, MD, Ph.D.
Baylor College of Medicine
Johnson Space Center, Houston, TX

National Aeronautics and Space Administration

Johnson Space Center Houston, Texas 77058

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ABSTRACT

Destinations beyond low Earth orbit, especially Mars, have several important constraints, including limited resupply, limited to no possibility of medical evacuation, and delayed communication with ground support teams. Therefore, medical care is driven towards greater autonomy and necessitates a medical system that supports this paradigm, including the potential for high medical data transfer rates in order to share medical information and coordinate care with the ground in an intermittent fashion as communication allows. The medical data transfer needs for a Martian exploration mission were estimated by defining two medical scenarios that would require high data rate communications between the spacecraft and Earth. One medical scenario involves a case of hydronephrosis (outflow obstruction of the kidney) that evolves into pyelonephritis (kidney infection), then urosepsis (systemic infection originating from the kidney), due to obstruction by a kidney stone. A second medical scenario involved the death of a crewmember's child back on Earth that requires behavioral health care. For each of these scenarios, a data communications timeline was created following the medical care described by the scenario. From these timelines, total medical data transfers and burst transmission rates were estimated. Total data transferred from the vehicle-to-ground were estimated to be 94 gigabytes (GB) and 835 GB for the hydronephrosis and behavioral health scenarios, respectively. Data burst rates were estimated to be 7.7 megabytes per second (MB/s) and 15 MB/s for the hydronephrosis and behavioral health scenarios, respectively. Even though any crewed Mars mission should be capable of functioning autonomously, as long as the possibility of communication between Earth and Mars exists, Earth-based subject matter experts will be relied upon to augment mission medical capability. Therefore, setting an upper boundary limit for medical communication rates can help factor medical system needs into total vehicle communication requirements.

1.0 INTRODUCTION

Exploration missions beyond low Earth orbit present new challenges for maintaining crew health and performance. In particular, long-distance missions (such as those to Mars) will present challenges such as lack of medical evacuation, resupply, and real-time communication. One-way communication from Mars to Earth can experience 22 minutes of latency (and maybe longer, depending on how mission resources such as communication bandwidth are prioritized). Hence, the crew must be able to operate with autonomy when communications are delayed. As long as any communications between Earth and Mars are available, medical staff on Earth will continue to receive crew health data. Since the exploration vehicle will not include a fully equipped emergency room nor will the crew medical officer (CMO) (likely a physician astronaut) have the expertise to diagnose and treat every medical condition that may occur, communications with the ground will be needed to support medical care. Typically, communications would include synchronizing the data from an onboard medical system with the ground medical system, or relaying an image to ground for analysis by a medical expert. However, there may be medical events that require frequent, if not continuous, exchanges between the vehicle and ground. Such urgent events may necessitate high data rate transmissions to send large data sets (e.g., video) back-and-forth as quickly as possible. As a result, data rate estimates for emergency medical conditions should provide an upper limit on rates for medical communication that may drive design requirements for mission or spacecraft communication design.

2.0 METHODS

The medical system data estimates are based on simulated test cases that would require significant bandwidth for communications. The two test cases analyzed in this study are ‘Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock,’ and ‘Death of Crew Family Member.’ The test cases are provided in Appendix A and Appendix B, respectively, and are considered to be ‘worst-case medical scenarios’ from a communications perspective. These narratives are referenced from the Human Research Program (HRP) Exploration Medical Capability (ExMC) Medical Simulations Document [1]. This document is a collection of medical narratives that are decomposed by a medical algorithm to communicate the medical diagnosis and treatment process to the engineering community. Since the two medical scenarios mentioned here are the most data-intensive narratives in the Medical Simulations Document, these situations will consequently place a high demand on communication between the vehicle and the ground. For the purposes of estimating high data transfer rates, each of these test cases was assumed to occur in transit to Mars where there are significant communication latencies (potentially 22 minutes or longer). For each test case, the medically relevant data sources and data types were identified. These data were all assumed to be stored by the spacecraft medical system and then synchronized with the ground system.

2.1 Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock

Decomposition of this test case identified relevant medical data that would need to be stored by the exploration medical system. An assumption was made that any data stored by the medical system would be synchronized with the ground, which formed the basis for the vehicle-to-ground data estimate. The ground-to-vehicle data estimate was based on the test case (see Appendix A) where specific communications via text-based messages or videos were sent to the crew from the ground. Furthermore, this test case was segmented into three distinct periods – the first 72 hours of the medical incident, Day 4 to Day 7, and Day 8 to Day 14 of the incident. The medical scenario assumes emergency diagnosis, stabilization, and initial treatment in the first 3 days, followed by ongoing treatment, patient recovery, and frequent (daily or multiple times a day) monitoring for the following 4 days. Finally, as the patient's health status improves, the final week of care requires less-frequent monitoring during the crewmember's recovery.

For each of these time periods, the data source, data type, and data product sets were identified each time a data transfer occurred. A data transfer included the collection and storage of text, medical device measurements, and audio/video or images into the medical system within the vehicle and subsequent synchronizing with the ground system. In addition, transmissions of similar data types from the ground to the vehicle represented a data transfer. An example template for capturing the data transfers is shown in Figure 1.

Data Sources	Single Data Product Size (Bytes)	Data Type	Frequency of Data Recordings	Total Data Recordings
Vital Signs (HR, T, RR, BP, SpO2, 2-lead ECG)				
Automated (30 sec recording)	125,400	Time series	Every hour	72

Figure 1. Example template for identifying medical data recording and transfers.

The example shown in Figure 1 is for collecting vital signs where time series data recordings are taken every hour for 30 seconds. Using a proxy for a future wearable device that is highly data intensive yields a single data product that was estimated at 125,400 bytes. This process of estimating data product sizes was repeated for each data source identified in the medical scenario. The template in Figure 1 also captured assumptions and references for estimating the data product size and frequency of data recordings. Appendix C provides data assumptions for each of the scenarios. Appendices D and E provide the complete worksheets for each 'worst-case medical scenario.'

2.2 Death of Crew Family Member

The analysis of this medical test case followed a similar approach to the *Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock* medical scenario. Though the *Death of Crew Family Member* medical scenario did not clearly reference the specific data that were captured by the medical system, the assumption is that the store and forward videos, emails and just-in-time training (JITT) videos were critical communications between the ground and the vehicle. Furthermore, CMO exam notes or other data specifically entered into the vehicle medical system were not identified by the test case. Thus, these data were not included in these estimates. However, the size of store and forward videos plus JITT videos were orders of magnitude larger than text files found in exam notes or email messages. Hence, these text data-types were assumed insignificant in estimating the data transmission rates for this test case.

Data-specific assumptions include JITT videos that are 120 minutes in length (as noted in the test case), store and forward videos estimated at 20 minutes in length, and emails that were estimated to be two pages of text. An additional assumption related to the emails was that there would be associated correspondence from the ground or from the vehicle for each originated email. These values were corroborated with ExMC clinicians to take into account a ‘worst-case scenario’ for data telecommunications.

Analysis of this scenario was performed in the same template as the tabular collection of data in Figure 1. The assumptions and references for estimating the data product size and frequency of data collections were also described in the scenario analysis (see previous section on Urosepsis Test Case for details).

3.0 RESULTS

3.1 Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock

Table 1 presents the medical data estimates for this worst-case medical scenario. In determining these values, assumptions about the medical instrumentation were necessary. Since the study aimed to capture worst-case scenarios in terms of data transmissions, instrumentation was identified that would generate some of the largest data sets for a given type of instrument (e.g.. vitals signs monitoring, ultrasound, x-rays). Some examples include real-time vital signs monitoring that records values at 256 Hz for 30 seconds, every hour on average over the first 72 hours. These measurements could be performed continuously for 72 hours, which could affect the estimate to the upside. For video recordings, high-definition videos were assumed to be at 1440 x 1080 pixels per square inch, at 30 frames per second. Some consideration may be given to future high-definition video with denser pixels as technology progresses. Overall, the progress in technology will seemingly have an effect on streaming or storing and forwarding data such as those seen in this medical scenario.

Table 1 considers data use from different perspectives – total data transfer, average data rates, and maximum burst data rate. The total data transfer accounts for the anticipated data transmissions that were in excess of nominal operational medical conditions, due to the worst-case medical scenario. The average data rates are determined over a period of time, and in some cases, represent the nominal data transmission rate during the time the unplanned medical care is being provided. Conversely, the data burst rate attempted to account for a specific window of time, in which time-sensitive, critical data must be transmitted. The maximum data burst rate was an essential aspect of this study, as this transmission rate may delineate an upper boundary of the communication system's performance requirements.

In Table 1, the total data transferred to ground was estimated to be 94 gigabytes (GB), whereas the ground-to-vehicle data transfer was estimated to be 8 GB. Conversion from bytes to gigabytes involved the division of the Total Data Vehicle-to-Ground value by $(1024)^3$ (where 1024 bytes equals 1 kilobyte in binary).

Table 1 – Summary of Medical Data Estimates for the Impacted Renal Stone, Hydronephrosis and Urosepsis with Septic Shock Test Case

Medical Care Time Period	Total Data Vehicle-to-Ground (Bytes)	Average Data Rate Vehicle-to-Ground (kB/s)	Total Data Ground-to-Vehicle (Bytes)	Average Data Rate Ground-to-Vehicle (kB/s)	Estimated Maximum Data Burst (MB/s)
Day 1 to Day 3	1.01×10^{11}	380	9.44×10^{9}	35.6	7.66
Day 4 to Day 7	1.71×10^{8}	4.83×10^{-1}	7.20×10^{4}	2.03×10^{-4}	4.40×10^{-2}
Day 8 to Day 14	2.77×10^{6}	4.47×10^{-3}	1.12×10^{5}	$1.81 \times 10\text{-}^{4}$	3.32×10^{-5}
Total:	1.01×10^{11}	N/A	9.44×10^{9}	N/A	N/A

Next, the average data rates from vehicle-to-Earth and Earth-to-vehicle were considered. According to the medical data summary, the first 72 hours suggest heavy data transmissions between the vehicle and ground during the contingency operations to stabilize and treat the crewmember. During this time period, the average data rate from vehicle-to-Earth was 380 kilobytes per second (kB/s) and the average data rate from Earth-to-vehicle was 36 kB/s. After Day 3, the crewmember's condition was stable and data sent or received starting on Day 4 showed a significant reduction. Similarly, another data reduction was observed starting on Day 8 and hence, another timeframe was identified for data transmissions as the crewmember further recovered. Though this scenario depicts improvement in the crewmember's health, an alternative scenario could maintain high data transfer rates for an extended period of time should the patient's status either not improve or worsen. These data rates were determined by estimating the total data usage during a specified medical care time period, and dividing by the time period. As a result, data rate estimates of vehicle-to-ground and ground-to-vehicle were derived.

Finally, a maximum data burst rate was observed for the medical scenario during the Day 1 to Day 3 time period. These bursts are associated with the transmission of JITT modules, video recordings, or images. An assumption associated with these bursts is that the complete file transfer of the largest data set would occur over a 1-hour interval. The maximum data burst estimate was determined to be 7.7 MB/s. These high data rates are primarily driven by the transfer of ultrasound images

(~28 MB) and video recordings (~90 GB). Taking a sum of these values in Table 1 does not provide additional insights since these are data rates estimated for a specific period.

Note: These bursts could potentially be more frequent over a prolonged period in a scenario where a crewmember remains in poor condition.

3.2 Death of Crew Family Member

Table 2 presents the medical data estimates for the other medical scenario, Death of Crew Family Member.

Table 2 – Summary of Medical Data Estimates for the Death of a Crew Family Member Test Case

Medical Care Time Period	Total Data Vehicle-to-Ground (Bytes)	Average Data Rate Vehicle-to-Ground (kB/s)	Total Data Ground-to-Vehicle (Bytes)	Average Data Rate Ground-to-Vehicle (kB/s)	Estimated Maximum Data Burst (MB/s)
Day 1 to Day 3	9.44×10^{09}	35.6	9.44×10^{9}	35.6	2.50
Day 4 to Day 7	1.51×10^{11}	427	3.77×10^{10}	107	15.0
Day 8 to Day 21	3.77×10^{11}	305	2.64×10^{11}	213	15.0
Day 22 to Day 25	2.83×10^{11}	800	2.17×10^{11}	613	15.0
Day 26 to Day 85	7.55×10^{10}	14.2	7.55×10^{10}	14.2	2.50
Total:	8.96×10^{11}	N/A	6.04×10^{11}	N/A	N/A

The total data transferred to ground was estimated to be 835 GB, whereas the ground-to-vehicle data transfer was estimated to be 563 GB. Once again, conversion of bytes from Table 2 involved dividing the total bytes transferred by 1024^3 to convert bytes to GB. The greatest medical communications occurred from Day 22 to Day 25, when the average data rate from vehicle-to-Earth was 800 kilobytes per second (kB/s) and the average data rate from Earth-to-vehicle was 613 kB/s. The maximum data burst estimate was determined to be 15.0 MB/s. The high data rates are primarily driven by the transfer of video recordings sent back-and-forth between the affected crewmember and their family. JITT videos account for the data burst rates in most time windows, whereas the store and forward video accounts for the maximum data burst early and late in the scenario. The maximum burst rate estimate for all time windows assumed all data are sent in a 1-hour time window for the largest data sets that need to be sent. Furthermore, all these estimates could be projected higher should there be an increased length in time for the crewmember to work through the grief process and/or in the event the crewmember develops severe psychological issues.

A final assumption for both test cases includes future data rate overhead adjustments. Hence, the ExMC team recommends adding an overhead factor for the Consultative Committee for Space Data Systems packet configuration, which will increase the amount of bandwidth needed to transmit these data products.

4.0 FUTURE CONSIDERATIONS

An assumption inherent to the analysis of the two worst-case medical scenarios is that videos are transmitted in a store and forward approach versus streaming the data. Regardless of the approach, the total data transmitted remains the same. However, the transmitted data rate will be affected by the approach. Using High Definition (HD) 1080 video as an example, the video bitrate is in the range of 4,000 to 8,000 kilobits per second (kbps) at 25-30 frames per second (https://support.video.ibm.com/hc/en-us/articles/207852117-Internet-connection-and-recommended-encoding-settings). Since there are 8 bits per byte, HD 1080 video streams around 1 MB/s. Currently, the specific medically relevant videos that should be streamed have not been determined for an exploration mission. In the future, this topic can be considered in the development of mission requirements and/or medical operations.

Another factor to consider in the medical data telemetry operations is latency. By assigning a latency factor to each data product, telemetered medical information can be prioritized. Latency factors may be on the order of seconds for urgent information, but may be on the order of hours when sending non-urgent data. In some instances, the same data product (e.g.. ultrasound video) may be treated differently based on the context of the situation. Currently, these considerations and prioritization of data products have not been addressed.

5.0 CONCLUSION

The Death of Crew Family Member appears to be more data transfer intensive than the Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock medical case, due to the need for additional JITT and several store-and-forward video exchanges between ground and the crewmember.

Even though any crewed Mars mission should be capable of functioning autonomously, as long as the possibility of communication between Earth and Mars exists, Earth-based subject matter experts will be relied upon to augment mission medical capability. Therefore, setting an upper boundary limit to medical communication rates can help factor medical system needs into vehicle communication requirements. Conversely, the recognition of bandwidth limitations can influence the allocation of resources toward the progressively Earth independent treatment of anticipated medical conditions. Finally, knowledge of the medical data communication limitations can also be used to inform the medical risk profile for a given exploration mission.

6.0 REFERENCES

1. Medical Simulations Document (unpublished) – Exploration Medical Capability Element, Human Research Program, NASA Johnson Space Center

Appendix A

High Communications Bandwidth Worst-Case Medical Scenario

Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock

Italicized text indicates parts of the scenario that involve communication with Earth.

Mission Phase	Level of Care	Occurrence	Operation
Transit	V- Autonomous	Unplanned	Contingency - Directed

<u>Scenario Narrative</u>: Despite nominal health up to this point, the Physician Astronaut starts to develop left-sided low back (costovertebral angle) pain and tenderness that radiates to the groin. The pain quickly ramps up to a 9/10 pain, and is followed by nausea and vomiting. These events were witnessed by the ship's Crew Medical Officer (CMO) who stops to assist the Physician Astronaut. The two head over to the medical bay and the CMO asks the ship's computer to access the Medical System. The system identifies the CMO and allows him access to the Physician Astronaut's, now patient's, health record.

Algorithm Block 1 – Scene Safety	
Summary	• Ambulatory patient with no history of acute injury or exposure
Decision	• Scene is safe, proceed to rapid initial assessment
Info. Source	• CMO situational awareness
Resources	• None
Functionality	• None
Training	• Triage

Algorithm Block 2 – Rapid Initial Assessment	
Summary	• Patient's pain level is described as "severe." • This is corroborated by objective data of nausea and vomiting from the pain. • No mechanism of injury involved (non-traumatic) Patient appears conversant and ambulatory, though uncomfortable.
Decision	• This meets criteria for an Emergent Medical Condition based on severe pain, but is non-traumatic → proceed to assessing ABCs (algorithm 4).
Info. Source	• Reference criteria for emergent/non-emergent conditions, patient's knowledge

Algorithm Block 2 – Rapid Initial Assessment	
Resources	• None
Functionality	• None
Training	• Triage

Scenario Narrative: "Patient appears to be in pain, but is still speaking with CMO, suggesting that she is maintaining her airway and is breathing appropriately and that her blood pressure is sufficient for brain perfusion. The Medical System prompts the CMO to collect vital signs. He gathers the equipment for measuring blood pressure, heart rate, oxygen saturation, temperature, and respiratory rate and places them on patient. He calls out the results as they are gathered and the Medical System automatically saves them to the patient's health record using voice recognition technology. The Medical System displays the data back to the CMO. At this time, blood pressure is 155/90, pulse is 110, respiratory rate is 18, temperature is 99.0°F, and oxygen saturation is 99%."

Algorithm Block 4 – Assess ABCs	
Summary	• The severe nature of the pain prompts the CMO to assess the ABCs of the patient to ensure the patient is stable, as part of the Emergency Medical Condition protocol • This is done in part through observation of the patient (is she talking, labored breathing, etc.) and in part with vital signs • As a part of this, the CMO also creates a new medical encounter in the MS
Decision	• Patient's ABCs appear to be uncompromised based on observation and vital signs • After necessary data is obtained and recorded, proceed to Focused Evaluation (Algorithm 6)
Info. Source	• CMO observations that patient is talking and breathing unlabored • Automated import of vital signs • CMO interpretation of vital sign data
Resources	• Hardware to obtain and import vital signs into MS (HR, BP, SpO2, temperature) • MS can interpret vital signs as normal or abnormal.
Functionality	• MS in appropriate data entry mode for general medical evaluation
Training	• Triage (able to assess patient's airway protection and breathing as appropriate)

Scenario Narrative: "Because of the level of discomfort of the patient, the CMO decides to give the patient an initial dose of pain medication. Directed by the patient and after checking medication allergies, the CMO gives patient 4mg morphine, which eases her pain. The patient then explains her symptoms in more detail, as well as the time course over which they occurred. The CMO decides to perform an exam, so he directs the Medical System to initiate a medical encounter, which prompts it to record all medical interaction between the caregiver, patient, and Medical System. The CMO starts the exam off by gathering the appropriate history from the patient. The Medical System prompts, records, reviews, and summarizes the interview in the patient's medical record. The CMO references the vehicle's historical environment data and his patient's health record via the Medical System.

Algorithm Block 6 – Focused Evaluation	

Summary	• After appropriate subjective data acquisition, the CMO decides to proceed with the examination
	• Appropriate physical examination in this scenario includes the following:
	  o Updated vital signs
	  o General mental status (whether the patient is alert and oriented to person, place, and time)
	  o Examination of the potentially involved systems: back, abdomen, GU
	  o Additional examinations could include cardiovascular and pulmonary systems

Decision	• Patient is tachycardic with mildly elevated BP secondary to pain • Patient has tenderness over left flank with radiation to groin • This improves with administration of pain medication • Vital signs and exam are stable • After documentation of the exam, proceed to data acquisition and differential diagnosis (algorithm 8)
Info. Source	• Automated import of vital signs • CMO interpretation of the physical exam and subjective history given by the patient and reviewed on the Medical System (with or without aid in interpretation by patient)
Resources	• Medical references • Hardware to obtain and import vital signs into the MS (as above) • Digital stethoscope
Functionality	• MS in appropriate data entry mode for general medical evaluation • MS can recommend appropriate physical examination and techniques • MS can interpret vital signs as normal or abnormal
Training	• General physical examination • GU examination

Scenario Narrative: Based on the physical exam findings and vital signs, the Medical System produces a differential diagnosis and presents it to the CMO, who focuses on the higher risk conditions. Each suggested condition contains a link to additional information, such as variation in presentation, diagnostic approach, and treatment modalities, all stored within the Medical System and accessible to the medical provider if desired.

Vehicle System: *The CMO can see that the most likely diagnosis, based on this information, is that the crewmember has a kidney stone. However, there is a need for additional data to confirm and further characterize the diagnosis (such as determine size of the stone and evaluate for hydronephrosis) and to make certain there were no other medical issues, such as acute kidney injury, superimposed infection, or any other surreptitious abdominal, chest, or cardiac issue.*

Ground System: *This data is synchronized with the Earth Medical System so the Crew Surgeons and SME's are aware and can provide their input and guidance to the CMO*. The medical team on Earth relays medical recommendations to the ship's CMO by both audio channels and via the Medical System.*

**First notification and communication with Earth*

Algorithm Block 8 – Data Acquisition and Differential Diagnosis	
Summary	• Incorporating history (age, gender, severe flank pain, risk factors) and exam findings (CVA tenderness with radiation to groin), an appropriate systems or symptoms-based differential (see box below) is generated.
Decision	• Based on the differential, select appropriate further evaluation: ultrasonography, urinalysis, complete blood count, complete metabolic panel, cardiac enzymes, EKG before proceeding with treatment.
Info. Source	• CMO interpretation of subjective (history) and objective (physical exam, images, labs) data (with or without the help of patient) • Ultrasound imagery • Laboratory results • Interpretation of subjective and objective data from Earth-based SMEs
Resources	• Appropriate reference texts, including medical and pharmaceutical references. ▪ *Just in time training (JITT) or easy-to-follow instructions for ultrasound of kidney and bladder** (**may already available on the vehicle, or uploaded from Earth*) • Blood draw supplies, urine sample supplies. • Laboratory equipment • Vehicle to Earth communication and data-transfer capability

Algorithm Block 8 – Data Acquisition and Differential Diagnosis	
Functionality	• MS provides access to appropriate references • MS provides ultrasound training on demand • MS has some ultrasound imaging interpretation capability • MS is integrated with lab hardware to download and interpret lab values • MS provides and updates a differential diagnosis based on input data • MS can locate needed supplies. • *MS is integrated with vehicle electronic and communication systems to enable audio and video communication data transfer, as well as data transfer of laboratory data (including video) to Earth.*
Training	• Handheld use of ultrasound • Blood draws • Lab hardware use • Formulating a differential diagnosis • Ground communication and data transfer procedures

Scenario Narrative: With this new data, the initial list of differential diagnoses provided by the Medical System is reduced. The CMO updates the Medical System to indicate that a kidney stone is the most likely condition, as well as a probable superimposed urinary tract infection based on the results of the urinalysis, and a possible pyelonephritis based on signs of infection on the complete blood count. All of this information was also communicated to the patient. With the help of the Physician Astronaut and now patient, the CMO develops a plan for further diagnosis and initial treatment that includes drawing blood and urine cultures, then treating with antibiotics for a urinary tract infection, and giving medications for pain control.

Vehicle System: *The Medical System crosschecks the antibiotic and pain medication with the crewmember's health record to verify that there are no contra-indications for that particular medication.*

Ground System: *The Medical System also receives communication back from Earth-based SMEs regarding recommendations for nephrostomy tube placement given the large size of the stone and the improbability of passing it. These components of the treatment plan are logged into the Medical System, which displays the entered information for review.*

Vehicle System: *The Medical System then coordinates with the vehicle's communication system to synchronize the onboard and Earth electronic health systems. The augmented reality JITT for nephrostomy tube placement is uploaded to the Medical System from the Earth.*

Vehicle System: *The CMO administers more pain medication for the patient, draws blood and urine for cultures, starts antibiotics, watches the JITT training video for nephrostomy tube placement, then proceeds to*

	perform tube placement procedure using the augmented reality feature.
Vehicle System:	*The procedure is video recorded from several angles and from the CMO's perspective and is sent to the medical team on Earth.*
Vehicle System:	*Following tube placement, patient has sizeable relief and urine is seen to drain from tube. CMO repeats kidney ultrasound to confirm appropriate placement of tube and visual confirmation of kidney decompression.*
Ground System:	*The ultrasound images are sent to Earth to confirm appropriate placement by the Crew Surgeons and SMEs. They send back an audio communication confirming that they agree with catheter placement.*

Algorithm Block 9 – Treat and Rehabilitate	
Summary	• The CMO enters the assessment as "impacted stone with hydronephrosis and possible urinary tract infection" and initiates treatment. Given the lack of culture results, antibiotic selection must cover the most common causative agents. • *Nephrostomy tube is placed and appropriate placement confirmed by both CMO and Earth SME.*
Decision	• Prescribe pain medications and antibiotics at the appropriate dose, interval, and route to the patient, taking into account her medical history and allergies (see below). Place and maintain nephrostomy tube to ensure kidney decompression. Monitor as appropriate (including culture results to further tailor antibiotic treatment). Can refer back to Algorithms 7A or 4 if clinical condition changes, depending on the severity of the change
Info. Source	• Pharmaceutical reference • Antibiotic/infectious disease reference • List of available antibiotics/pain medications on the vehicle, location, and previous utilization • Interpretation of subjective and objective data from Earth-based SMEs
Resources	• Medication list • References as above • *Augmented reality, "Just in time training" (JITT) instructions for ultrasound of kidney and bladder* • *Augmented reality, "Just in time training" (JITT) instructions for percutaneous nephrostomy tube placement* • Blood draw supplies, urine sample supplies • Culture laboratory equipment • Nephrostomy tube procedure kit supplies • *Vehicle to Earth communication and data-transfer capability*

Algorithm Block 9 – Treat and Rehabilitate	
Functionality	• MS tracks medication supply and updates estimates of supply availability for the rest of the mission • MS tracks medication usage and can project shortages • MS can locate needed supplies • MS provides procedure training on demand • MS has some ultrasound imaging interpretation capability • *MS is integrated with vehicle electronic and communication systems to enable audio and video communication data transfer, as well as data transfer of laboratory data (including video) to Earth* • MS will re-schedule the patient for follow up visit. • *MS saves encounter after CMO finishes data entry and prepares it for submission/synchronization with the Earth*
Training	• Resource utilization • Use and monitoring of prescription drugs • Selection of appropriate treatment regimen based on a diagnosis • Blood draws • Lab hardware use • Procedure performance • Ground communication and data transfer procedures

Scenario Narrative: Patient's clinical status is rechecked by CMO a short time after initial management is concluded and patient is started on antibiotics and pain medications. At that time, patient is found to be "clammy" and toxic looking. Her breathing appears to be more labored. Because of an apparent worsening clinical status, CMO decides to reevaluate the patient based on the medical management algorithm. Because of the potentially severe medical implications of the new physical exam findings, CMO decides to proceed with Algorithm 4 for further management of the patient. He again gathers the equipment for measuring vital signs and places them on the patient. He calls out the results as they are gathered and the Medical System automatically saves them to the patient's health record using voice recognition technology. The Medical System displays the data back to the CMO. At this time, blood pressure is 90/50, pulse is 122, respiratory rate is 24, temperature is 99.0°F, and oxygen saturation is 96%."

Algorithm Block 4 – Assess ABCs	
Summary	• The potentially worsening clinical status prompts the CMO to assess the ABCs of the patient to ensure the patient is stable, as part of the Emergency Medical Condition protocol. This is done in part through observation of the patient (is she talking, labored breathing, etc.) and in part with vital signs. As a part of this, the CMO an addendum to his original medical encounter in the MS.

Algorithm Block 4 – Assess ABCs	
Decision	• Patient's ABCs appear to be possibly compromised based on observation and vital signs. • After necessary data is obtained and recorded, proceed to Initiate BLS/ACLS (Algorithm 5).
Info. Source	• CMO observations that patient's clinical status is "worsening" with more labored breathing and decreased sensorium. • Automated import of vital signs • CMO interpretation of vital sign data
Resources	• Hardware to obtain and import vital signs into MS (HR, BP, SpO2, temperature)
Functionality	MS in appropriate data entry mode for general medical evaluation MS can interpret vital signs as normal or abnormal.
Training	Triage (able to assess patient's airway protection and breathing as appropriate)

Scenario Narrative: Based on the physical exam findings and vital signs, the Medical System indicates to the CMO that patient has potentially compromised ABCs and that the CMO should consider initiating BLS and/or ACLS. The CMO does so by beginning to inspect visually the patient's airway, which currently looks patent with no obstruction. He continues by observing the patient's breathing, which appears mildly labored, but does not seem to be concerning for imminent collapse. As a part of this breathing observation, the CMO auscultates the patient's lungs and hears fine crackles in the bases bilaterally consistent with new fluid.

Vehicle System: *Based on the new vitals and exam information, the patient's condition is concerning for early septic shock. The CMO begins two antecubital IV's in the patient's arms and starts an infusion of normal saline solution. After 2 liters of IV fluids, patient's vitals are rechecked and patient's blood pressure is found to be 73/42. At this point, the CMO decides to start a vasopressors drug.*

Vehicle System: *He communicates with the Earth SME to ensure that this is an appropriate action and to receive further instruction on how to perform such a task. Once receiving communication with the Earth-based Crew Surgeon, he places an intraosseous access device (IO)* and a peripheral arterial line and starts the new medication.*

*IO is placed because the CMO will be well trained in its use. A central line would be more challenging and require augmented reality, JITT, or other.

Vehicle System: *He also places a Foley catheter into the patient's bladder in order to monitor urine output as a measure of adequate circulation. With the start of the vasopressors, patient's blood pressure begins to improve to 91/53. The CMO checks an arterial blood gas, a chest x-ray, a lactic acid level, cardiac enzymes, and an EKG to assess the patient's peripheral circulatory and overall clinical statuses and to assess proper placement of the IO.*

Vehicle System: *CMO relays all information on blood work results, clinical status, and procedure course back to the Earth Crew Surgeon and SMEs for assessment and further recommendations.*

Algorithm Block 5 – Initiate BLS/ALS	
Summary	• The CMO modifies treatment based on the new vitals and clinical exam findings. New treatment is focused on more emergent ABC management. Patient is given IV fluids and started on vasopressors drugs. *This is done in consultation with Earth Crew Surgeon and SMEs. Medical Encounter is updated*.
Decision	• Administer IV fluids and vasopressors drugs at the appropriate dose, interval, and route to the patient, taking into account her medical history and allergies (as before). Monitor as appropriate, including *consultation with Earth* Will reassess clinical status and consider reinitiating algorithm based on patient's clinical course.
Info. Source	• Pharmaceutical reference • List of available IV fluids and vasopressor medications on the vehicle, location, and previous utilization • *Interpretation of subjective and objective data from Earth-based SMEs*
Resources	• Medication list • References as above • Augmented reality, "Just in time training" (JITT) instructions for intraosseous access device placement** *(this basic procedure should be a part of the Medical System already)* • Augmented reality, "Just in time training" (JITT) or easy-to-follow instructions for peripheral arterial line placement** *(this basic procedure should be a part of the Medical System already)* • Blood draw supplies • Arterial line kit • Central venous catheter kit • *Vehicle to Earth communication and data-transfer capability*
Functionality	• MS tracks medication supply and updates estimates of supply availability for the rest of the mission • MS tracks medication usage and can project shortages • MS can locate needed supplies • MS provides procedure training on demand • *MS is integrated with vehicle electronic and communication systems to enable audio and video communication data transfer, as well as data transfer of laboratory data (including video) to Earth* • *MS saves encounter after CMO finishes data entry and prepares it for synchronization with the Earth*

Algorithm Block 5 – Initiate BLS/ALS	
Training	• Resource utilization • Use and monitoring of prescription drugs • Selection of appropriate treatment regimen based on a diagnosis. • Blood draws • Lab hardware use • Procedure performance • *Ground communication and data transfer procedures*

Scenario Narrative: Patient's clinical status is again checked a short time after initiating a vasopressor agent. Her breathing appears to be more labored with use of accessory muscles. Because of an apparent worsening clinical status, CMO again decides to reevaluate the patient based on the medical management algorithm. Because of the potentially severe medical implications of the new physical exam findings, CMO again decides to proceed with Algorithm 4 for further management of the patient. He gathers the equipment for measuring vital signs and places them on the patient. He calls out the results as they are gathered and the Medical System automatically saves them to the patient's health record using voice recognition technology. The Medical System displays the data back to the CMO. At this time, blood pressure is 96/57, pulse is 106, respiratory rate is 35, temperature is 102.3°F, and oxygen saturation is 92%."

Algorithm Block 4 – Assess ABCs	
Summary	• The potentially worsening clinical status prompts the CMO to assess the ABCs of the patient to ensure the patient is stable, as part of the Emergency Medical Condition protocol. This is done in part through observation of the patient (is she talking, labored breathing, etc.) and in part with vital signs. As a part of this, the CMO an addendum to his original medical encounter in the MS.
Decision	• Patient's ABCs appear to be possibly compromised based on observation and vital signs. • After necessary data is obtained and recorded, proceed to Initiate BLS/ACLS (Algorithm 5).
Info. Source	• CMO observations that patient's clinical status is "worsening" with more labored breathing and decreased sensorium. • Automated import of vital signs • CMO interpretation of vital sign data
Resources	• Hardware to obtain and import vital signs into MS (HR, BP, SpO2, temperature)
Functionality	• MS in appropriate data entry mode for general medical evaluation • MS can interpret vital signs as normal or abnormal.
Training	• Triage (able to assess patient's airway protection and breathing as appropriate)

Scenario Narrative: Based on the physical exam findings and vital signs, the Medical System indicates to the CMO that patient has potentially compromised ABCs and that the CMO should consider initiating BLS and/or ACLS. The CMO does so by beginning to inspect visually the patient's airway, which again looks patent with no obstruction. He continues by observing the patient's breathing, which appears more labored presently, and concerning that the patient may tire herself out. The CMO auscultates the patient's lungs and hears worsening crackles throughout the entire lung fields bilaterally consistent with worsening fluid.

CMO decides to proceed with intubating the patient for airway protection and prevent of respiratory collapse. He begins by bag-valve-mask ventilating the patient by hand…

Vehicle System: *while communicating current clinical status, labs, and vitals with the Earth-based Crew Surgeon and SMEs to confirm the appropriateness of this plan and to receive recommendations on how to proceed.*

He then initiates rapid sequence intubation with anesthetic and paralytic medications. He places the patient on a ventilator after endotracheal tube placement and places the patient on a maintenance anesthetic, under guidance of the Medical System. He follows up tube placement with an arterial blood gas, chest x-ray, cardiac enzymes, EKG, lactic acid, and coagulation factors to assess proper tube placement and to assess current circulatory status.

Vehicle System: *The patient's clinical status is relayed to the Earth Crew Surgeon and SMEs for assessment, and further recommendations. At this point the decision is made, in consultation with the Earth to proceed with ultrasonic dissolution of the obstructing stone.*

Ground System: *Augmented reality, JITT guidance for the procedure is uploaded to the ship from the Earth.*

Vehicle System: *The CMO successfully performs the procedure under augmented reality guidance. Video of the procedure is relayed to the Earth. Subsequent to this, a repeat ultrasound is performed to ensure that the stone is adequately broken up. These images are relayed to Earth for confirmation.*

Algorithm Block 5 – Initiate BLS/ALS	
Summary	• The CMO modifies treatment based on the new vitals and clinical exam findings. New treatment is focused on more emergent ABC management. Patient is intubated with rapid sequence intubation and given anesthetic and paralytic medications. Patient is placed on a ventilator following intubation for maintenance of respiratory function. Following this, ultrasonic dissolution is performed to break up the patient's stone. This is all done in consultation with Earth. *Medical record is updated and synchronized to the Earth.*

Algorithm Block 5 – Initiate BLS/ALS	
Decision	• Administer anesthetic/paralytic drugs at the appropriate dose, interval, and route to the patient, taking into account her medical history and allergies (as before). *Monitor as appropriate, including consultation with Earth*. Will reassess clinical status and consider reinitiating algorithm based on patient's clinical course.
Info. Source	• Pharmaceutical reference • List of available anesthetic/paralytic medications on the vehicle, location, and previous utilization • Interpretation of subjective and objective data from Earth-based SMEs
Resources	• Medication list • References as above • Augmented reality, "Just in time training" (JITT) for rapid sequence intubation (already a part of the Medical System) • Augmented reality, "Just in time training" (JITT) instructions for ultrasonic dissolution (already a part of the system) • Augmented reality, "Just in time training" (JITT) instructions for ultrasound of kidney and bladder (already a part of the system) • Blood draw supplies • Intubation kit, including suction and oxygen source • *Vehicle to Earth communication and data-transfer capability*
Functionality	• MS tracks medication supply and updates estimates of supply availability for the rest of the mission • MS tracks medication usage and can project shortages • MS can locate needed supplies • MS provides procedure training on demand • MS provides ultrasound training on demand • MS has some ultrasound imaging interpretation capability • *MS is integrated with vehicle electronic and communication systems to enable audio and video communication data transfer, as well as data transfer of laboratory data (including ultrasound and video) to Earth.* • *MS saves encounter once CMO finishes data entry and synchronized with the Earth.*

Algorithm Block 5 – Initiate BLS/ALS	
Training	• Hand held ultrasound use • Resource utilization • Use and monitoring of prescription drugs • Selection of appropriate treatment regimen based on a diagnosis. • Blood draws • Lab hardware use • Procedure performance • *Ground communication and data transfer procedures*

Scenario Narrative: Following intubation and ultrasonic dissolution of the stone, the patient's clinical status stabilizes. CMO was initially performing updated vital signs on the patient every hour with updated labs (complete blood count, complete metabolic panel, plus magnesium and phosphorus levels) to monitor clinical status every 4 hours.

Vehicle System: Information was relayed hourly to the Earth-based medical team for situational awareness, then for reception of any ground-based recommendations should they occur. Chest x-rays and arterial blood gas analysis were performed every 24 hours and this information was relayed to the Earth. The patient was monitored in this way for approximately 48 hours.

At this time, the patient's blood pressure improved and she is able to wean off the vasopressor medication. Her respiratory status also improved and her oxygen requirements are titrated down on the ventilator. She is given a breathing trial and is then successfully extubated.

Vehicle System: Her vital sign checks are spaced further out over the next 96 hours, first to every 4 hours and then to every 8 hours.

Her blood draws are spaced out to twice a day and then to once a day. Chest x-rays and arterial blood gases are stopped.

Vehicle System: Synchronization of the Medical System with Earth is extended to every 4 hours initially, then to every 8 hours. As the patient slowly improves, communication is twice daily for a week, daily for two more weeks, and then synchronized as needed.

Ground System: The Medical System and Earth medical team develop a rehabilitation plan for the patient, which is communicated to the CMO.

Patient is started on physical therapy and incentive spirometry to regain her strength and further improve her respiratory status. The patient recovers and returns to duty as the ship's physician.

Appendix B

High Communications Bandwidth Worst-Case Medical Scenario

Death of Crew Family Member

Mission Phase	Level of Care	Occurrence	Operation
Transit – IVA	IV- Semi autonomous	Unplanned	Assisted

<u>Scenario Narrative</u>: One month out from Martian orbital insertion of flyby mission, crewmember receives notice via spouse and flight surgeon that 11-year-old child admitted to hospital for difficulty breathing.

Algorithm Block 1 – Scene Safety	
Summary	Mild symptoms of guilt and helplessness in CM
Decision	Scene is safe, proceed to initial assessment
Info. Source	Situational Awareness
Resources	None
Functionality	None
Training	Triage

Algorithm Block 2 – Rapid Assessment	
Summary	CM child is in the hospital for breathing difficulties
Decision	This is non-emergent but resources to assist CM should be mobilized
Info. Source	Criteria for emergent / non-emergent conditions
Resources	CMO, FS, BHP office, store and forward video comm, e-mails, BHP self-help modules for CM, BHP review modules for CMO
Functionality	None
Training	Triage

<u>Scenario Narrative</u>: BHP arranges store and forward video communication in CM child's hospital room and facilitates any needed adjustments to CM schedule. BHP sends email to CM offering support and offering to assist with family on earth as needed. FS and spouse hold store and forward video conferences as requested by CM over next week (every 2-3 days) with nightly email updates on child's status from the FS and spouse. CMO meets with CM to establish supportive relationship as needed. CMO communicates with BHP and FS with updates as needed (1-2/week).

After a few days, the child's respiratory status has worsened. The child is intubated and placed on a ventilator in the ICU. FS/BHP sends email to CMO, and commander notifying them of situation and suggesting CMO utilize Just in Time Training software to strengthen skills needed for counseling. Comm between Spouse and CM increases to nightly while FS meets with CM as needed to help with any medical questions. FS/BHP again messages CM offering support, and recommends regular meetings with CMO on as needed bases. FS/BHP offers support to CMO and prepares any needed resources for uplink. FS/BHP assists with CM schedule changes and arranges comm with family. FS/BHP continues to reach out to spouse to offer support as needed (q3-4 days). BHP notifies CM to observe fitness for duty in CM and need to modify schedule.

Algorithm Block 7A – Obtain History	
Summary	• Past psych history of CM: no chronic or acute problems • PMH: no acute or chronic problems • CM exhibits significant feelings of helplessness, anxiety, and frustration, lapses of concentration • CM concerned over not being there for family • CM would like continue to work as this is therapeutic but appreciates efforts to allow time in schedule for family conferences
Decision	• Continue with as needed FS/BHP conferences (q3-4d) • Continue with daily family conferences in hospital • Continue with PRN Q3-4d meetings with CMO for counseling • Continue weekly BHP—> CMO emails and PRN conference (q weekly) • Continue ground support of family via BHP/FS • BHP support self-assessment of CM as fit for duty, but continue to monitor via commander, CM, and CMO
Info. Source	• Patient verbal account • CMO • Patient emails • Family members • Commander account • FS accounts • Store and forward video • Other CM

Algorithm Block 7A – Obtain History	
Resources	• JITT for CMO • CMO • store and forward video conference capability to hospital • Store and forward video conference to private conference rooms • Store and forward video conference to home with spouse • Email capability • FS • BHP staff • JITT for CM self help
Functionality	• MS opens new encounter for the CM for a psychiatric chief complaint • MS provides easy access to historical document review • MS records interview and displays it in the encounter and allows CMO/FS/BHP to manually edit voice-to-text input • MS suggests needed data to the CMO
Training	• Psychological monitoring, surveillance, mental status • Knowledge of appropriate listening and counseling techniques for grief and helplessness feelings

Reference Information - Appropriate Questions and Review of Systems	
Chief Complaint Agnostic	The chief complaint for an unplanned event is often the predominant symptom. Feelings of helplessness, grief, and frustration are common. Family will also need significant assistance on ground. In this case questions are less important than listening and responding. Using frameworks for therapy of grief and guilt may be helpful but most communication is informal self-care and buddy care. Review of family structure, dynamics, location, and status is also helpful. Always review: PMHx, PSHx, PPHx, ROS, medications, allergies; social history as needed
Psych related	General: • Mood • Mental status • Family structure
ROS	Mood, affect, activity level, sleep amount, eating amount, thoughts on current situation

Narrative: Over the next several days, the child's respiratory status continues to worsen and she is requiring increasing levels of oxygen and is finally placed on ECMO. During this time, the blood pressure starts to drop and requires several liters of IV fluids and ultimately the child is placed on vasopressors. During this time, the CM continues to receive updates and discuss with FS/BHP/Spouse on the same as needed schedule.

After more than a week in the hospital, the child's blood pressure and breathing status begin to stabilize, but her renal function appears to be worsening because of ischemia and acute tubular necrosis from the previous low blood pressure. The CM, who has been in regular contact with the treating physician, makes the decision with the spouse to start the child on dialysis. The patient, upon improvement, is ultimately weaned off vasopressors and ECMO.

However, after a week and a half in the ICU, the child's breathing status starts to worsen again. The child's blood pressure begins to drop and she starts spiking fevers. The child is started on antibiotics and cultures are obtained, which grows MRSA from the blood, presumably from a dialysis catheter infection. The child's blood pressure continues to drop despite adding a second and then a third vasopressor. After about 2 weeks in the ICU, the child goes into cardiac arrest. She is resuscitated, but is found to have bilateral middle cerebral watershed infarcts. During this time, CM store and forward video communication will need to be increased and CMO check-ins will need to be more frequent (daily). BHP will arrange to suspend CM's duties and provide resources for communication and family support as the child's condition deteriorates. BHP will have daily conferences with CMO to begin anticipatory guidance and extra training for an anticipated negative outcome. BHP will provide continuous support to the ground based family along with FS presence in the hospital to facilitate timely updates to the CM and carry out any requests the CM has regarding the patient.

The child is found to be without spontaneous respirations, has no corneal reflex, and does not withdraw to pain off sedation. At this point BHP would request 1-2 crew initiated direct store and forward video link to assist with support as medical team is no longer able to offer primary support. Over the next 48 hours, the CM is in communication with spouse, FS, and child's medical team as often as comm delays allow to discuss what to do from an end of life standpoint. The decision is ultimately made to withdraw care. BHP would also have twice-daily store and forward video linked conferences with CM, and multiple e-mails to CM, CMO, and commander. Multiple hours of store and forward video comm between CM and family/friends with BHP supporting will be the bulk of communications.

Algorithm Block 7B - Physical Exam	
Summary	After appropriate subjective data acquisition
Decision	Intense symptoms of grief, helplessness, and acute depressed mood signify an acute grief reaction. CMO, BHP and Commander support crewmember and will shift critical duties from CM to others as needed. Non-critical tasks may still be performed by CM as the CM desires or shifted to others. Non critical comm will cease to free up space for comm with BHP, family, spouse, friends and CM.

Algorithm Block 7B - Physical Exam	
Info. Source	• Patient verbal account • CMO • Patient emails • Family members • Commander account • FS accounts • Store and forward video • Other CM
Resources	• JITT for CMO • CMO • store and forward video conference capability to hospital • Store and forward video conference to private conference rooms • Store and forward video conference to home with spouse • Email capability • FS • BHP staff • JITT for CM self help
Functionality	• MS in appropriate data entry mode for psychological examination • MS has templates for psych examination findings • MS can take voice input to enter data into the medical encounter document • MS can receive, record, and display automated assessments
Training	• Psychological assessment • Acute grief reaction management

Scenario Narrative: Following the passing of the child, the CM increases the frequency of communicating with family and the BHP group will help support spouse and the rest of ground family. A store and forward video link to memorial service will be provided. BHP will likely have tapering communications as needed with CM, spouse and CMO starting with 2/week and tapering off to baseline (once every 2 weeks) over the course of about 2 months. The latter session may be linked with PMCs to facilitate a team approach as grief reaction stabilizes over time. BHP will continue to provide support for ground family and spouse as needed. CMO will meet with crewmember once weekly, likely coordinated with BHP store and forward video uplinks, and provide email/store and forward video updates to BHP throughout this period. Gradually CM duties will be reinstated as tolerated and as CM adapts to new circumstances and as work focus and vigilance, is restored.

Algorithm Block 8 – Data Acquisition and Differential Diagnosis	
Summary	The psychological diagnosis of acute grief reaction is made and the CMO must use various therapy frameworks to assist with stabilizing CM emotional status. Ground assistance from BHP in store and forward video comm, CMO guidance and BHP aid to ground based family members will be critical.
Decision	Obtain appropriate assessments, reassessments, and therapeutic interventions to maximize feelings of control, minimize feelings of helplessness, guilt, and to provide as much availability of CM and family to each other as possible.
Info. Source	• Patient verbal account • CMO • Patient emails • Family members • Commander account • FS accounts • Store and forward video • Other CM
Resources	• JITT for CMO • CMO • store and forward video conference capability to hospital • Store and forward video conference to private conference rooms • Store and forward video conference to home with spouse • Email capability • FS • BHP staff • JITT for CM self help
Functionality	• MS provides access to appropriate references • MS provides psych assessment training on demand • MS has some psych assessment interpretation capability • MS provides and updates a differential diagnosis based on input data • MS provides suggested frameworks for therapy
Training	• Psychological assessments • counseling • Collection and documentation of relevant information for e mail downlink to BHP personnel • Formulating a differential diagnosis

Reference Information – Differential Diagnosis for Bereavement
• Uncomplicated Bereavement • Complicated Bereavement • Major Depressive Disorder • Major Depressive Episode • Suicidality • Homicidality • Depression • Anxiety

Reference Information – High Risk Features
• Suicidal thoughts • Functional impairment • Aggressive behavior • Guilt about things other than actions taken or not taken by the survivor at the time of the death; • Thoughts of death other than the survivor feeling that he or she would be better off dead or should have died with the deceased person; • Morbid preoccupation with worthlessness; • Significant psychomotor retardation (e.g., it's hard to get moving, and, what movements there are, are slow); • Prolonged and serious functional impairment; and • Hallucinatory experiences other than thinking that the crewmember hears the voice of or transiently sees the deceased person's image.

Algorithm Block 9 – Treat and Rehabilitate	
Summary	• The CMO enters the assessment as "uncomplicated bereavement" and stabilizes the condition with therapy and communication based interventions. Expert consultation requested as needed for further details.
Decision	• Institute therapeutic frameworks as needed
Info. Source	• DSM V • BHP ground personnel • Medical team for CM child
Resources	• Store and forward video • References as above • Virtual Reality gear

Algorithm Block 9 – Treat and Rehabilitate	
Functionality	• MS tracks medication supply and updates estimates of supply availability of medications for the rest of the mission • MS can flag an encounter for ground review to solicit expert consultation; experts can transmit their recommendations in a way that is recorded to the patient's medical chart and readable by the CMO • MS will re-schedule the patient for follow up visit
Training	• Resource utilization • Use and monitoring of mental status, mood, and prescription drugs

Reference Information – Medications for Deep Space Depressive Episode / Bereavement	
Anxiolytics	TBD
Antidepressants	TBD
Selection of medication will depend on contraindications and severity of condition. In general Bereavement is self-limited and medications should be reserved only for short term sedation of dangerous behavior that threatens wellbeing of afflicted CM or remaining crew or prolonged reactions concerning for major depressive disorder	

APPENDIX C

Data Assumptions

Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock

Data Assumptions for First 72 Hours	
Data Types	**Assumption for Data Size**
Vital Signs (HR, T, RR, BP, SpO2, 2-lead ECG)	Assumes an hourly 30-second recording of Astroskin data
Medical Exam Notes (Text)	Assumes 1,500 words on patient history, exam notes on physical & mental status, differential diagnosis, 2 bytes per character for Unicode
Medical Training Module (JITT)	20-minute video at high definition video rate: 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec
Plans, Assessments, Consultations, etc.	Assumes 2,000 words text for the following subjects: updated health/treatment plans, assessments, recommendations; SME consultation/procedure instructions; SME interpretation subjective/objective data; SME rehabilitation plan
Procedure Video Recording	1-hour high-definition video: 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec
Ultrasound	Assumes 20 ultrasound still images in DICOM format, plus 10 minutes video at high-definition rate: 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec
Labs	Assumes 40 numerical measurements total (32-bit float) * 20 bytes overhead assumed per measurement
X-rays	Assumes 5 x-ray DICOM images at 4 megapixels each
ECG	30-second recording of 12-lead ECG at 500hz, 60 sec HL7 file

Data Assumptions for Days 4-7	
Data Types	**Assumption for Data Size**
Vital Signs (HR, T, RR, BP, SpO2, 2-lead ECG)	Assumes a 30-second recording of Astroskin data every 4 hours
Medical Exam Notes (Text)	Assumes 1,000 words 3 times per day on exam notes on physical & mental status, differential diagnosis, 2 bytes per character for Unicode
Plans, Assessments, Consultations, etc.	Assumes 500 words text 3 times per day for the following subjects: updated health/treatment plans, assessments, recommendations; SME consultation/procedure instructions
Labs	Assumes labs 2 times per day (40 numerical measurements total (32-bit float) * 20 bytes overhead assumed per measurement)
X-rays	Assumes 5per day x-ray DICOM images at 4 megapixels each

Data Assumptions for Days 8-14	
Data Types	**Assumption for Data Size**
Vital Signs (HR, T, RR, BP, SpO2, 2-lead ECG)	Assumes a 30-second recording of Astroskin data every 4 hours
Medical Exam Notes (Text)	Assumes 1,000 words 3 times per day on exam notes on physical & mental status, differential diagnosis, 2 bytes per character for Unicode
Plans, Assessments, Consultations, etc.	Assumes 500 words text 3 times per day for the following subjects: updated health/treatment plans, assessments, recommendations; SME consultation/procedure instructions
Labs	Assumes labs 2 times per day (40 numerical measurements total (32-bit float) * 20 bytes overhead assumed per measurement)
X-rays	Assumes 5per day x-ray DICOM images at 4 megapixels each

Death of Crew Family Member

Data Assumptions for Days 1-3	
Data Types	**Assumption for Data Size**
Video (Ground to Vehicle)	Assumes single 20-minute video at high definition rate (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Video (Vehicle to Ground)	Assumes single 20-minute video at high definition rate (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Email (Ground to Vehicle)	Assumes 13 emails averaging 600 words each (in Unicode byte format)
Email (Vehicle to Ground)	Assumes 3 emails averaging 600 words each (in Unicode byte format)

Data Assumptions for Days 4-7	
Data Types	**Assumption for Data Size**
Video (Ground to Vehicle)	Assumes nightly 20 minutes video (4 total) at high-definition rate (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Video (Vehicle to Ground)	Assumes nightly 20 minutes video (4 total) at high-definition rate (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Email (Ground to Vehicle)	Assumes 6.5 emails per day (26 total) averaging 800 words each (in Unicode byte format)
Email (Vehicle to Ground)	Assumes 6 emails per day (24 total) averaging 800 words each (in Unicode byte format)
Medical Training Module (JITT)	Assumes two 120-minute training videos at high definition rate

Data Assumptions for Days 8-21	
Data Types	**Assumption for Data Size**
Video (Ground to Vehicle)	Assumes 4 daily sessions of 20 minutes each (28 total) of high-definition video (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Video (Vehicle to Ground)	Assumes 4 daily sessions of 20 minutes each (28 total) of high-definition video (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Email (Ground to Vehicle)	Assumes 11.8 emails per day (154 total) averaging 600 words each (in Unicode byte format)
Email (Vehicle to Ground)	Assumes 10.7 emails per day (140 total) averaging 600 words each (in Unicode byte format)
Medical Training Module (JITT)	Assumes two 120-minute training videos at high definition rate

Data Assumptions for Days 22-25	
Data Types	**Assumption for Data Size**
Video (Ground to Vehicle)	Assumes 5.75 daily sessions of 20 minutes each (23 total) of high-definition video (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Video (Vehicle to Ground)	Assumes 4.5 daily sessions of 20 minutes each (18 total) of high-definition video (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Email (Ground to Vehicle)	Assumes 32 emails per day (128 total) averaging 159 words each (in Unicode byte format)
Email (Vehicle to Ground)	Assumes 10.7 emails per day (140 total) averaging 183 words each (in Unicode byte format)
Medical Training Module (JITT)	Assumes two 120-minute training videos at high definition rate

Data Assumptions for Days 22-25	
Data Types	**Assumption for Data Size**
Video (Ground to Vehicle)	Assumes weekly 20-minute high-definition video (8 sessions over 60 days) (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Video (Vehicle to Ground)	Assumes weekly 20-minute high-definition video (8 sessions over 60 days) (HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec)
Email (Ground to Vehicle)	Assumes 0.5 daily emails averaging 3,200 words each (in Unicode byte format)
Email (Vehicle to Ground)	Assumes 0.5 daily emails averaging 3,200 words each (in Unicode byte format)

APPENDIX D

Medical Scenario Worksheet – Impacted Renal Stone, Hydronephrosis, and Urosepsis with Septic Shock

High Communications Bandwidth Worst Case Medical Scenario

Test Case: Impacted Renal Stone, Hydronephrosis and Urosepsis with Septic Shock

Mission Phase/Level of Care: Transit/V

			First 72 hours				Day 4-7				Day 8-14					
Data Sources	Size of Single Data Product (bytes)	Data Type	Frequency of Data Recorded (First 72 Hours)	Total Data Recordings (First 72 Hrs)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Frequency of Data Recorded (Day 4-7)	Total Data Recordings (Day 4-7)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Frequency of Data Recorded (Day 8-14)	Total Data Recordings (Day 8-14)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Assumptions	Data Size Assumptions/References
Vital Signs (HR, T, RR, BP, SpO2, 2-lead ECG)																
Automated (30 sec recording)	125,400	Time series	Every hour	72	9,028,800		Every 4 hours	24	3,009,600		Every 8 hours	21	2,633,400		*Assume continuous monitoring capability will exist.*	Based on 30 second recording of Astroskin
Medical Exam Notes (Text)																
Patient History	8,000	Structured, unstructured text	Once	1	8,000										*Assume 5 pages total*	500 words with 8-character avg word length (2 bytes per character for unicode) = 8000 bytes
Exam notes on physical & mental status	8,000	Structured, unstructured text	4x/day	12	96,000		3x/day	12	96,000		Twice a day	14	112,000		*Assume 5 pages total*	
Differential Diagnosis	8,000	Structured, unstructured text	Once	1	8,000										*Assume 5 pages total*	
Medical Training Module																
Audio/Video	9,437,184,000	Video	Once	1		9,437,184,000									*Upload from ground, according to scenario; assume 20 minute module*	HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec
Plans, Assessments, Consultations, etc.																
Health/Treatement Plans, Assessments,	8,000	Structured, unstructured text	4x/day	12		96,000	3x/day	9		72,000	Twice a day	14		112,000	*Assume 5 pages text*	
SME Consultation/Procedure Instructions	8,000	Structured, unstructured text	2-3x	3		24,000									*Assume 5 pages text*	
SME Interpretation Subj/Obj Data	8,000	Structured, unstructured text	2-3x	3		24,000									*Assume 5 pages text*	
SME rehabilitation plan	8,000	Structured, unstructured text	2-3x	3		24,000									*Assume 5 pages text*	
Procedure Video Recording	28,311,552,000	Video	2-3x	3	84,934,656,000										*Assume a 1-hour recording for greatest data usage estimate*	HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec https://en.wikipedia.org/wiki/H.262/MPEG-2_Part_2
Ultrasound																
Images	29,360,128	DICOM	2-3x (20 images)	60	1,761,607,680										*Assume 20 images*	DICOM Ultrasound image: 28 MB (on average) Oracle White Paper (2010) http://www.oracle.com/us/industries/healthcare/058477.pdf
Recording	4,718,592,000	Video	2-3x	3	14,155,776,000										*Assume 10 minutes*	HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec
Labs	3,200	Tabular	Every 4 hours	18	57,600		Every 12 hours	8	25,600		Daily	7	22,400		*Assume 40 measurements total*	40 numerical measuments (32-bit float) * 20 bytes overhead assumed per measurment
X-rays	8,388,608	DICOM	Daily (5 images)	15	125,829,120		Daily	20	167,772,160		None				*Assume 5 images*	DICOM x-ray image: 4 Megapixels (which I believe equals 8 MB) Ref: Indian J Radiol Imaging. 2012 Jan-Mar; 22(1): 4–13.
ECG	1,022,460	Time series	Once	1	1,022,460										*Assume 12-lead and a 30sec recording*	Based on CARDIAX 12-lead, 500hz, 60 sec HL7 file: 2,044,940 bytes = 34082 bytes/sec

APPENDIX E

Medical Scenario Worksheet – Death of Crew Family Member

High Communications Bandwidth Worst Case Medical Scenario

Test Case: Death of Crew Family Member

Mission Phase/Level of Care: Transit/IV

			Days 1 - 3				Days 4 -7				Days 8 - 21 (worsening respiratory & ICU				Days 22 - 25				Days 26 - 85					
Data Sources	Size of Single Data Product (bytes)	Data Type	Frequency of Data Recorded (Days 1-3)	Total Data Recordings (Days 1-3)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Frequency of Data Recorded (Days 4-7)	Total Data Recordings (Days 4-7)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Frequency of Data Recorded (Days 8-21)	Total Data Recordings (Days 8-21)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Frequency of Data Recorded (Days 22-25)	Total Data Recordings (Days 22-25)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	of Data Recorded (Days 26-85)	Total Data Recordings (Days 26-85)	Vehicle-to-Ground Total Data Set (bytes)	Ground-to-Vehicle Total Data Set (bytes)	Assumptions	Data Size Assumptions/References
Store and Forward Video Recording	9.44E+09	Video																					Assume 20 min recordings	HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec https://en.wikipedia.org/wiki/H.262/MPEG-2_Part_2
Ground to Vehicle			every 2-3 days	1		9.44E+09	nightly	4		3.77E+10	nightly (spouse) + daily (FS)	28		2.64E+11	hours w/spouse + service	23		2.17E+11	CMO to BHP (weekly)	8		7.55E+10		
Vehicle to Ground			every 2-3 days	1	9.44E+09		nightly	4	3.77E+10		nightly (spouse) + daily (FS)	28	2.64E+11		BHP + 2 hours w/spouse + service	18	1.70E+11		BHP to CMO & CM (weekly)	8	7.55E+10			
Email	3,200	Structured, unstructured text																					*Assume 2 pages total, worst case*	200 words with 8-character avg word length (2 bytes per character for unicode) =
Ground to Vehicle																								
BHP to CMO			daily	3		9,600	daily	4		12,800	daily	14		44,800	multiple	16		51,200	2 per week	16		51,200		
FS to CMO			daily	3		9,600	daily	4		12,800	daily	14		44,800										
BHP to CM			once	1		9,600	daily	4		12,800	daily	14		44,800	mulitple	16		51,200	2 per week	16		51,200		
FS to CM			nightly	3		3,200	nightly	6		19,200	twice daily	28		89,600										
Spouse/Family to CM			nightly	3		9,600	nightly	4		12,800	daily	70		224,000	as much as possible	96		224,000						
Physician to CM							daily	4		12,800	daily	14		44,800										
Vehicle to Ground																								
CMO to BHP							daily	4	12,800		daily	14	44,800		multiple	16	51,200		2 per week	16	51,200			
CMO to FS							daily	4	12,800		daily	14	44,800											
CM to BHP							daily	4	12,800		daily	14	44,800		multiple	16	51,200		2 per week	16	51,200			
CM to FS							daily	4	12,800		daily	14	44,800											
CM toSpouse/Family			nightly	3		9,600	nightly	4	12,800		nightly	70	224,000		as much as possible	96	307,200							
CM to Physician							daily	4	12,800		daily	14	44,800											
Medical Training Module (JITT)																								
Audio/Video	###########	Video					one for CM; one for CMO	2		###########	one for CM; one for CMO	2		###########	one for CM; one for CMO	2		###########					*ground, according to scenario; assume 120-minute module*	HD Video 1440 × 1080@30fps = 60 Mbit/s = 7.5 MB/s = 7,864,320 Bytes/sec