Telemedicine Operational Concepts for Human Exploration Missions to Near Earth Asteroids

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1 INTRODUCTION

1.1 Purpose

The purpose of this document is to present the operational concepts for the telemedicine system needed to support human exploration missions to Near Earth Asteroids (NEAs). This operational concepts document is being developed to guide the National Aeronautics and Space Administration (NASA) Human Research Program (HRP) and the National Space Biomedical Research Institute in determining telemedicine and telementoring gaps that currently exist for exploration missions. This will document the consensus of the NASA space medicine community about the direction they would like to go and serve as a roadmap for future research and technology development in the area of telemedicine.

1.2 Scope

An operational concepts document is a high-level narrative of the strategies and capabilities needed for a program. This document focuses on the telemedicine and telementoring operational concepts required for a mission to a NEA. The complete scope of telemedical operations is covered: training (crew and ground cadre), in-flight operations, ground operations, and data management.

This document does not provide the complete crew health operational concept for a NEA mission. It is understood that other medical procedures, exercise countermeasures, and habitability and environmental factors are critical to crew health for space flight missions. Assumptions are made about those operational concepts with regard to how they interface with the telemedicine system.

The vehicles and hardware discussed in this document were referenced at the time of the January 2011 Telemedicine Workshop. Note that the current names of the vehicles and hardware may be different than those discussed in this document.

1.3 Assumptions

1.3.1 General assumptions

This document presents the operational concepts for an end-to-end telemedicine system for an exploration class mission to a NEA, which will consist of a 6-month transit to the NEA, 1-month NEA proximity operations, and another 6-month transit back to Earth. Extravehicular activities (EVAs) will be performed at least three times per week by each crew member during NEA proximity operations.

Timely contingency return to Earth will not be possible following departure from low Earth orbit (LEO). Delays in communication with Earth will vary with distance but are expected to be 0 to 24 seconds in each direction. Depending on the communications infrastructure, periodic communication blackouts may occur. Thus, the crew will require autonomous medical capability, supported by the ground medical team acting as remote consultants via asynchronous telemedicine technologies.
The crew will consist of three crew members. A minimum of two crew members will be trained as crew medical officers (CMOs), who will assist each other and provide backup if one CMO becomes incapacitated. The primary CMO will provide medical care to the crew in coordination with the ground medical team and manage medical data on board. The deputy CMO will assist the primary CMO in fulfilling his or her responsibilities. Training to the level of a physician and/or mid-level provider (physician assistant, nurse practitioner, or equivalent) will be necessary for the CMOs, since they may have to respond to medical contingencies without real-time support from the ground.

The ground medical team will consist of flight surgeons and biomedical engineers (BMEs) serving as flight controllers in the Mission Control Center (MCC), the crew surgeon and deputy crew surgeon as the primary physicians for the assigned crew members, tertiary care consultants, behavioral health and performance (BHP) specialists, environmental system engineers, and strength and conditioning specialists. The term “Medical Mission Control” (MMC) used in this document refers to both the flight control room (FCR) and the supporting back room in the MCC where medical consultations will occur or be patched through. The flight surgeon on console will monitor crew health, respond to crew medical issues, coordinate medical consultations, and communicate the health status of the crew with the flight director. The BME on console will monitor the status of all health-related hardware and provide technical expertise to the flight surgeon.

1.3.2 Crew health assumptions

Crew selection criteria and preflight medical and psychological screening will be in place to minimize the range of medical contingencies that might occur during a NEA mission. Existing medical standards for International Space Station (ISS) crew members will likely be augmented by additional standards per the Aerospace Medical Board (AMB) based on the NEA mission’s objectives and duration. The AMB will also certify exploration crews for training and flight, with waivers granted on a case-by-case basis dependent on risk acceptance on a program level.

In addition to primary prevention strategies implemented by NASA’s Space Clinical and Operations Division before crew selection to a mission and engineering controls against known hazards, secondary and tertiary prevention will be employed in flight to prevent illness and injury, reduce the severity of illness and injury, and minimize complications of and disability from injury or illness. The medical system for a NEA mission will address the conditions of concern on the Exploration Medical Condition List (EMCL) (JSC-65722). This is not an all-inclusive list, but outlines the scope of the telemedicine and telementoring system that will be needed. The prioritization and mitigation of these medical risks will be weighed against mission and programmatic constraints.

1.3.3 Countermeasure assumptions

As a secondary prevention strategy, aerobic exercise and strength conditioning will be commenced as early as possible during a NEA mission and continued throughout transit, proximity operations, and return. Exercise equipment will be reliable, easy to maintain, and require minimal mass, volume, and power. Medical information collected during exercise will be recorded and input into the crew electronic medical records (EMRs) to be forwarded to the ground medical team.
2 DOCUMENTS

2.1 Applicable Documents

JSC 24834 Astronaut Medical Standard Selection and Annual Medical Certification
JSC 27384 Behavioral Health and Performance Program Plan: Definition and Implementation Guide
  Volume 1: Crew Health
  Volume 2: Human Factors, Habitability, and Environmental Health
To Be Determined Human Exploration Framework Team Document
(TBD)
JSC-65722 Exploration Medical Condition List

2.2 Reference Documents

NPD 8900.1 Medical Operations Responsibilities in Support of Human Space Flight Programs
NPD 8900.3 Astronaut Medical and Dental Observation Study and Care Program

3 MEDICAL/BEHAVIORAL HEALTH SELECTION AND CERTIFICATION

For current LEO missions, the selection and certification standards for crew members are outlined in the Astronaut Medical Standard Selection and Annual Medical Certification document (JSC 24834) and the Behavioral Health and Performance Program Plan: Definition and Implementation Guide (JSC 27384). Additional standards for NEA missions are TBD.

4 PREFLIGHT

4.1 Crew Health

Crew selection and retention standards exist to minimize the likelihood of medical or psychological conditions developing during or after a mission. For NEA missions, selection and retention standards and the procedures by which they are assessed may be more conservative than for ISS missions.

To maintain the psychological health of the crew, there will be a robust preflight behavioral training program for the crew and key ground personnel, in addition to comprehensive preflight support for the crew and families. Behavioral health specialists will work with the crew and family members to ensure their psychosocial needs are met and to conduct mission-related behavioral training in preparation for using in-flight resources.

4.1.1 Health stabilization program

A preflight health stabilization program will be in place to minimize the possibility of a health problem that would medically disqualify a crew member from flight or threaten mission
decrement after launch. Particularly important will be immunization and exposure protection against diseases that could become symptomatic during the mission.

4.1.2 Prophylactic medical procedures

In addition to rigorous crew selection/retention standards and procedures, there will be preflight prevention strategies to mitigate the risk of certain illnesses or injuries in flight, which will potentially reduce the requirements for medical training and in-flight medical hardware. For example, the possibility of a prophylactic laparoscopic appendectomy may be considered. However, the benefits and risks will need to be carefully evaluated.

4.2 Preflight Training

4.2.1 Medical familiarization

For a NEA mission, the likelihood of one or more medical events is high. Therefore, all crew members will be trained in first aid and basic life support as defined by the American Heart Association. Also, all crew members will have at least a rudimentary understanding of the medical equipment on board and be familiar with the telemedicine system, including private medical conference technology.

4.2.2 Crew medical officers

The NASA Space Flight Human Systems Standard, Volume 1: Crew Health (NASA-STD-3001) requires Level of Care Five for NEA missions greater than 210 days. As such, the primary CMO will be a physician astronaut, with training and experience in primary care, acute care, surgical skills, space medicine, and care in remote environments with limited medical resources (e.g., Antarctica). The deputy CMO will be an experienced mid-level provider.

To provide crew members, especially the CMOs, with the best skill set to manage medical contingencies including those identified in the EMCL, crew training will include familiarization with the health maintenance systems, environmental health systems, countermeasures, other medical systems as applicable, and BHP issues specific to each mission segment. The TBD training flow will allow for maintenance of existing clinical skills, scheduled updates in skills (for example, basic life support, advanced cardiac life support, advanced trauma life support), and familiarization with the on-demand medical refresher training that will be available in flight. The CMOs will receive extensive training in the telemedicine system and protocols used in flight and participate in simulations with flight surgeons and BMEs.

4.2.3 Flight surgeons

Flight surgeons will train alongside the crew members in the medical training flow. They will be given additional training including: medical operations, environmental health systems, console support, countermeasures, early identification of behavioral changes, and other topics as applicable. The flight surgeons will participate in team simulations and telemedicine protocol simulations, acting as the medical mission controller when coordinating responses to medical consultations or medical contingencies.
4.2.4 Biomedical engineers

BMEs will be trained in the medical training flow. Their training will include on-board medical hardware, telemedicine and consultation protocols, technical aspects of remote patient monitoring, and EVA monitoring. BMEs will also participate in team simulations and telemedicine protocol simulations.

4.2.5 Tertiary care consultants

Flight surgeons may consult with terrestrial medical specialists should the need arise during any mission phase. Based on the EMCL, the following medical specialties should be available for rapid consultation at the discretion of the flight surgeon: internal medicine; cardiology; gastroenterology; infectious disease; pulmonology; neurology; psychiatry; dermatology; critical care; emergency medicine; hypobaric and hyperbaric medicine; and space medicine. Consultants in the following surgical specialties will be needed: general surgery; gynecology; neurosurgery; ophthalmology; orthopedics; otolaryngology; plastic surgery; trauma surgery; urology; dentistry; and maxillofacial surgery.

Medical consultants will work in conjunction with ground-based flight surgeons. These flight surgeons will possess knowledge of the physiological changes associated with long-duration space flight, resources available in flight, medical equipment and procedures (especially those related to their field of expertise), the CMOs’ clinical backgrounds, and the telemedicine capabilities available. Consultants may receive training in remote guidance techniques and asynchronous telemedicine protocols. Consultants may participate in contingency simulations with crew members and flight surgeons when feasible.

5 LAUNCH

5.1 Medical Support

Launch will be supported by the assigned crew surgeon and deputy crew surgeon at the launch site. FCR support by a flight surgeon will be provided for the mission. BHP support will be available as needed. The flight surgeon and BME on console will monitor the crew members’ physiological data and ascent suit consumables, if provided to console.

Because of a moderate to high level of risk during launch, an emergency medical services system will be required at the launch and abort site(s), with Level of Care Three services or otherwise determined on a program level, based on risks specific to the crew, mission, and abort sites. Medical forces will have adequate medical resources and personnel – including sufficient advanced life support capability – to support the number of crew members being launched until they can be transferred to a definitive medical care facility (DMCF) or an intermediate medical care facility if a DMCF is not readily available.
6 NEAR EARTH ASTEROID TRANSIT/EARTH TRANSIT

6.1.1 Guiding principles
Telemedicine capabilities during NEA transit/Earth transit will be designed to allow the CMOs to diagnose, treat, and monitor the medical conditions listed in the EMCL. In addition, the telemedicine system will electronically capture and transmit data related to these conditions to the flight surgeon and consulting specialists via the MMC.

6.1.2 Communication latency
Lack of real-time communications will require planning for three distinct modalities based on communication latency: synchronous, store-and-forward, and just-in-time telemedicine. Synchronous telemedicine will occur in real time with essentially no latency. Store-and-forward telemedicine will involve assembling data at one point in time, storing the data, and transmitting the data at a later time. Just-in-time telemedicine will involve the use of real-time data transmissions but with a communication lag so that the receipt of the data and response from the recipient will be delayed.

The telemedicine system, from ground operations to the on-board system and crew, will be able to perform in all three modalities, and will be enabled by autonomous in-flight medical capabilities when ground communications are not available.

6.1.3 Vehicle medical capabilities

6.1.3.1 Vehicle Patient Area
The patient area of the vehicle will have sufficient volume to store and deploy the medical equipment needed to provide patient care, including restraints for the patient, CMO, and deputy CMO. Technologies will be designed to facilitate the CMOs’ clinical situational awareness – i.e., cognizance of the patient’s status to effect treatment and anticipate next steps. Capabilities will include high-resolution cameras that can be positioned to image any area of interest on the patient, a display monitor with the ability to provide split screen views, and videoconferencing with the ground medical team.

6.1.3.2 Telemedicine Consultation Protocols
Standardized telemedicine consultation protocols will be developed and utilized by the ground medical team and crew, with the general approaches trained preflight. For example, the ground team will incorporate anticipatory guidance into their communications with the crew so that the crew members will know what clinical changes to expect despite communication latencies. A framework for multimedia display of electronic medical checklists and procedures will be developed so that the CMOs can effectively receive consultation in each telemedicine modality (synchronous, store-and-forward, just-in-time) where applicable.

6.1.3.3 Telemedicine Hardware Requirements
Telemedicine hardware requirements will be defined in terms of function and constraints.
1. The specification of devices will be based on the needs identified in the EMCL.

2. Equipment will be robust and capable of operating reliably for the duration of a mission with little maintenance or repair requirements.

3. All devices that interface with the telemedicine system will be capable of acquiring data electronically for storage and transmission.

4. All telemedicine hardware will have networking capability and be integrated into the on-board crew EMR and intelligent integrative medical data processing unit (IIMDPU).

5. All medical and countermeasure data will be automatically downloaded to the EMR upon collection for downlink at predefined intervals.

6. Ideally, to minimize mass, volume, and power demands, medical devices will have multiple applications. For example, an ultrasound can be used for both diagnosis and treatment, a cardiac monitor can be used for both diagnosis and monitoring, and a fiber optic scope can be used for multiple anatomical sites.

Figure 1 depicts the interactions among diagnostic, treatment and monitoring devices, the EMR which stores the data as they are collected, and an IIMDPU.
The EMR system will provide a user interface to the telemedicine system and a repository for medical documentation containing patient history, physical examination findings, laboratory and imaging results, clinical impressions, treatment plans, medications, and progress notes. The full EMR will be available to authorized members of the ground medical team. However, to ensure crew medical confidentiality, the CMOs will see and maintain a “mission medical record” (MMR) that shows only the relevant medical data. For example, the MMR may display only the last 5 years of a crew member’s medical history, whereas the flight surgeons on the ground will be able to view both a mirrored version of the MMR and the full EMR.

The IIMDPU will analyze incoming diagnostic data (i.e., abnormal laboratory or imaging results) and recommend treatment options. It may also prompt the CMOs to adjust treatments based on ongoing treatment data (e.g., intravenous (IV) rates and antibiotic delivery) and patient monitoring data (e.g., vital signs, heart rhythm, and fluid balance). Such a system is not intended to replace the CMOs, but rather to enhance capability, suggest diagnostic and treatment options not considered, and ease the workload of the CMOs, especially in high acuity cases.

Collectively, the Intelligent Clinical Care System consisting of the EMR and IIMDPU will be linked with the MMC. New data added to a crew member’s EMR or any adjustments to patient parameters will be automatically downlinked to a mirror EMR and visible to the flight surgeons and consulting specialists in the MMC. Similarly, as shown in Figure 2, the MMC will be able to uplink patient care adjustments to the CMOs via the Intelligent Clinical Care System.

![Figure 2. Intelligent Clinical Care System and the Medical Mission Control.](image-url)
6.1.3.4 Medical Reporting/Updates

All ambulatory and routine medical data, including periodic health examinations and exercise countermeasure data, will be regularly downlinked to the MMC at predefined intervals. Medical data for acute events will be downlinked as needed, depending on their acuity. In addition, a medical status report will be submitted to the MMC on a regular, predefined basis.

6.1.3.5 Computer-Based Medical Proficiency Training for Crew Medical Officers

The CMOs will have access to a virtual reality training system, which will aid on-board training and skill proficiency maintenance for medical procedures. Instrumented gloves and sensors that can be attached to on-board medical tools will provide haptic input to the virtual reality system in order to enhance and maintain the cognitive and psychomotor skills needed to perform the wide range of complicated medical procedures defined by the EMCL. Just-in-time transmissions from the MMC will allow for uploading of additional medical procedures as required. To maintain medical proficiency, the CMOs will be required to complete a prescribed set of refresher skills at regular intervals.

6.1.3.6 Telemedicine Hardware and Imaging

Medical hardware can be categorized into diagnostic, treatment, and monitoring components. To the greatest extent possible, multifunctional hardware will be used due to mass, volume, and power limitations.

6.1.3.7 Diagnostic Hardware/Capabilities

Diagnostic imaging and data hardware to be included in the on-board medical system will meet the needs identified in the EMCL. Although not a comprehensive list, examples of the required diagnostic equipment are shown in Appendix B.

6.1.3.7.1 Treatment hardware/capabilities

Treatment hardware to be included in the on-board medical system will meet the needs identified in the EMCL. Although not a comprehensive list, examples of the required treatment equipment are shown in Appendix B.

6.1.3.7.2 Monitoring hardware/capabilities

Monitoring hardware to be included in the on-board medical system will meet the needs identified in the EMCL. Although not a comprehensive list, examples of the required monitoring equipment are shown in Appendix B.

6.2 Medical Intervention and Care

6.2.1 On-board medical encounter

The workup of any medical problem will follow standard clinical medical practice and consist of documentation of the history of the presenting problem, a focused physical examination, development of a differential diagnosis, imaging and laboratory testing to confirm or refute the differential diagnoses, and treatment of the medical condition. In addition, the CMOs may request consultation from the MMC.
6.2.1.1 History
When a crew member presents a medical problem, the chief complaint and the history related to it will be recorded using video and audio, and will be entered into the EMR. The MMR will display the patient’s relevant past medical history to the CMO.

6.2.1.2 Physical Examination and Imaging
Following the history, a focused physical examination will be performed. The physical examination (involving inspection, palpation, percussion, and auscultation) will be documented using audio and visual recording. Imaging data from any of the on-board diagnostic equipment will become part of the physical examination and will be entered into the crew member’s EMR.

6.2.1.3 Laboratory Analysis
An exploration medical laboratory will consist of one or more instruments that will analyze biological samples (i.e., blood, urine, saliva, sweat, and stool). Assays will include: measurement of dissolved gases, solutes, and biomolecules; identification of cells and cellular organisms in bodily fluids; and microscopic visualization of specimens.

6.2.1.4 Treatment and Intervention
Treatment and intervention capability will be defined by the EMCL. Necessary medical equipment and consumables will be accessible from the patient area. A consumables and inventory tracking system in the EMR will record medication type, dose, amount, and date dispensed by the CMO.

6.2.2 Medical mission control and remote patient monitoring
Patient care will be coordinated by the flight surgeon in the MMC, and will involve experts such as BHP specialists, BMEs, strength and conditioning specialists, and tertiary care consultants. Multiple medical consultants may participate in a crew member’s care whether supervising procedures, responding to questions or emergencies, remotely monitoring the patient for early signs of clinical deterioration, promoting “best practice” care, or educating the CMO and deputy CMO. The level of involvement of the consultants will be dictated by the patient’s level of acuity and by the CMO’s or flight surgeon’s request for consultation. The CMO may opt to allow the remote consultants to intervene prior to direct communication only in an emergency or to act as needed by prior arrangement.

The remote medicine consultation process, while shown to have significant benefits to terrestrial intensive care unit patients and health care outcomes, is not designed as a replacement for bedside patient care. The CMO will remain essential given that many interventions cannot be delivered remotely, and that emergent procedures such as placement of an endotracheal tube may need to be performed by the CMO without synchronous guidance from MMC.

6.2.3 Patient consultations
The CMO may request a patient consultation to seek specialist guidance on a clinical case whenever the required care exceeds the clinical scope of the CMO as defined by their training
and the guidelines for on-board patient care as defined by NASA’s Space Clinical and Operations Division.

6.2.4 Ambulatory/routine care

Ambulatory medical care will constitute the vast majority of patient care during long-duration space flight, and will not require prolonged treatment and monitoring. Ambulatory care capabilities will be defined by the EMCL. Routine health monitoring and preventive care (including dental checks/cleaning, radiation monitoring, nutritional status, immune function assessment, and behavioral health screening) will be classified as ambulatory care.

6.2.4.1 Countermeasures Monitoring

Countermeasure monitoring will also fall under ambulatory care. It will be necessary to monitor countermeasure adherence and crew member progress to ensure that each crew member maintains functional status for mission and exploration activities. Routine assessment of muscular strength, aerobic capacity, bone density, psychological fitness, cognitive ability, and sensorimotor function may be required. In these cases, the results will become part of the crew member’s EMR.

The specific countermeasures to be employed on a NEA mission have not been defined and not all currently available countermeasures may be feasible for such a mission.

6.2.5 Acute care

Acute medical care will encompass all care delivered to immediately stabilize severe illness or injury that would typically require hospitalization to prevent loss of life or limb. Examples include burns, trauma, and cardiac arrest. Acute care capabilities will be defined by the EMCL. This will include advanced cardiac life support and limited advanced trauma life support. All required medical equipment and consumables for acute care should be located within the patient area.

For surgical conditions that cannot be managed medically, limited surgical capability guided by the EMCL will be available, with an emphasis on minimally invasive procedures to decrease the risk of complications and length of recovery. Appropriate anesthesia, possibly consisting of intravenous conscious sedation or locally infiltrated anesthetics, will be provided. An on-board medical procedures database and virtual reality simulation will be available for review of medical procedures and techniques.

7 NEAR EARTH ASTEROID PROXIMITY OPERATIONS

7.1 Overview

During NEA proximity operations, the three-person crew will reside in the Deep Space Habitat (DSH). Docked to the DSH will be the Multi-Mission Space Exploration Vehicle (MMSEV), which will transport two EVA crew members from the DSH to the NEA for EVAs up to 10 hours each. The third crew member will remain on-board the DSH and monitor the EVA crew. The contingency return time to the DSH via the MMSEV is expected to be two hours. The
MMSEV will have the capability for rudimentary physiological monitoring and stabilization of an ill or injured crew member until the patient can be transferred to the DSH.

7.2 Medical Intervention and Care

7.2.1 Routine care
Routine medical care during NEA proximity operations will mirror the capabilities during NEA transit/Earth transit. Additional examinations will be included to monitor crew members for EVA fitness and illnesses related to frequent EVAs, such as repetitive strain injury and other musculoskeletal injuries.

7.2.2 Acute care
Acute care capabilities during NEA proximity operations will mirror the capabilities during NEA transit/Earth transit. Additional diagnostic, treatment and monitoring capabilities will be employed to administer care in EVA-related medical events. This will include acute management of arterial gas embolism and decompression sickness using hyperbaric therapy.

7.2.2.1 Intravehicular Activity Acute Care
Medical care during intravehicular activity (IVA) will be administered by the CMO and the deputy CMO. IVA medical care will occur in a manner consistent with acute care during NEA transit/Earth transit.

7.2.2.2 Extravehicular Activity Acute Care
During extravehicular activity (EVA), physiological monitoring of the EVA crew members will be conducted by the on-board CMO. Vital signs, heart rhythm, metabolic rate, oxygen consumption, and carbon dioxide (CO₂) production will be monitored to not only ensure that physiological limits are not exceeded, but also to detect early off-nominal events so that a proper response is executed, such as termination of the EVA. All physiological data collected during EVA will be entered into the crew members’ EMR.

A standard EVA medical kit will be deployed with the two-person EVA team so that basic care may be administered in the event of a medical emergency during an EVA. However, the standard operating procedure in such a scenario will be to abort the EVA and evacuate the crew member to the MMSEV/DSH immediately.

8 LANDING AND CREW RECOVERY
Landing loads, accelerations, and impacts will be specified to ensure that the crew will not be exposed to excessive forces. Some medical interventions will be immediately available to crew members while strapped in their seats: at a minimum, water and emesis containment/stowage.

After the vehicle recovery team ensures the vehicle is safe, the crew surgeon will check the medical status of the crew members. The extraction team will assist the crew from the landing vehicle after clearance from the crew surgeon first; if scene safety is a concern, then crew egress will take priority. BHP support will be available remotely or at the landing site if space is
available and allocated. A flight surgeon will support the MCC and provide a link to the EMR if access to a medical record is needed.

9 POST-LANDING

Immediate postflight recovery of the crew will nominally only require fluids and possibly some medications. Once the crew members have been extracted from the landing vehicle, they will undergo an initial postflight medical examination by the crew surgeon and deputy crew surgeon. Within approximately 24 hours, the crew members will return to the Johnson Space Center (JSC) or a designated postflight facility for a more thorough examination and family visitation. Postflight physicals, science data collection, and sample processing activities will also occur at this time.

Crew members will require reverse isolation and quarantine upon landing to meet international planetary protection requirements. At the same time, health assessment and biomedical sample collection will be performed. Medical samples that are returned to Earth will be analyzed, and the results will be provided to the crew surgeon and documented in the EMR.

10 DATA MANAGEMENT

To adequately support crew health and performance in flight, accurate, high-quality, and detailed environmental and physiological data will be collected. These data will be used by medical support personnel to recognize and treat illness and injury, and to evaluate and monitor the crew members’ health status and performance. In addition, these data may help answer research questions about human physiological changes in microgravity.

This section will address the operational concepts for a data management system as a part of the overall telemedicine system to access, store, and communicate crew health information. An overarching principle is that all required tasks will be designed to facilitate the efficient and effective use of crew time.

10.1 Data Acquisition

Nominally, the data management system will identify users without the need for user interaction or input. All acquired data will be synchronized to a common clock using a common vehicle time standard.

10.1.1 Medical devices

Data will be automatically collected from a variety of both commercial off-the-shelf and custom-developed medical devices. Data collected from all medical devices will be standardized, automatically associated with the source device and crew member for unambiguous identification, stored, reviewed, and communicated. Interfaces between the devices and the data management system will be wired or wireless.

10.1.2 Manual data entry

Using a standardized user interface, crew members will be able to manually upload data files and enter structured, dictated, and free text information into customized data entry forms.
10.2 Data Communication

Nominally, transmission of both medical data and system status data will occur automatically; however, manual data transmissions will also be possible during off-nominal operations. A standard set of data communications middleware services employing industry standard communications protocols and data formats will be utilized to enable all communications between devices and the data management system in a variety of settings.

10.2.1 Intravehicle

Within the vehicle, multidirectional communications among devices will be conducted electronically using a wired and/or wireless infrastructure.

10.2.2 Intervehicle

Data communication between vehicles will rely on the communications and avionics infrastructure between the vehicles. In the likelihood of limited bandwidth availability, prioritization of the data will be needed to ensure that the most critical data get transmitted first.

10.2.3 Vehicle to Earth

Due to communication latency, store-and-forward data communication will be the primary methodology used, with real-time communication as available. Communication bandwidth may be limited so data prioritization will be necessary.

10.2.4 Earth to vehicle

Earth-to-vehicle data will include system configuration updates and command and control parameters. During phases of the mission where the communication latency is practical for real-time communications, synchronous communications will be used; otherwise, store-and-forward will be used. Communication bandwidth may be limited so data prioritization will be necessary.

10.2.5 Ground segment

The ground medical team will require access to protected medical data acquired in flight to make decisions about crew health and performance. Industry standard data management systems will be used to support secure ground-based operations.

10.3 Data Archival and Retention

The data management system will have the capability to store and retrieve medical data for review and analysis. Alternatively, medical data may be securely transmitted to another system for archiving.

10.3.1 Devices

Data-generating devices will have data storage capability. The duration of storage will depend on the criticality of the data and the frequency that the data is transmitted and stored on secondary storage media.
10.3.2 Local vehicle
The local vehicle will have centralized data storage capability to archive all generated data, with backup capability to provide redundancy. The centralized location will enable data distribution to intra-vehicle, inter-vehicle, and terrestrial destinations.

10.3.3 Ground segment
Industry-standard data management systems used to support the ground medical team will be used to store all downlinked medical data.

10.4 Data Access and Display
Access of the data for review or analysis will be an important capability of the data management system. The data will be displayed to the crew and ground medical team in a relevant and user-friendly way.

10.4.1 Devices
Data-generating devices will have data access capability. Data may be displayed on the device or sent to different locations such as a secondary storage device with display capability.

10.4.2 Local vehicle
Centrally stored data will be accessible to connected devices or peripherals with appropriate security access. The data will be displayed to the crew members in a user-friendly manner.

10.4.3 Ground segment
Industry-standard data management systems used to support the ground medical team will be used to review all downlinked medical data.

10.5 Information Surety

10.5.1 Criticality
Medical data used to support mission-impact decision making will utilize a highly redundant, time-critical, and fault-tolerant system with information security mechanisms to guarantee data integrity and timely delivery.

10.5.2 Reliability, integrity, and availability
All data collected by the data management system will be available continuously throughout the mission. Data and system redundancy and backup mechanisms will be used to prevent data losses.

10.5.3 Confidentiality
All personally identifiable data and system resources and functions will be accessible by authorized users only. All medical data will be transmitted and stored in a manner that meets the requirements for medical privacy.

10.6 System Administration

10.6.1 Local/on board
All system administration functions will be available from a centralized control interface accessible to authorized users from any on-board workstation. User, system configuration and status, and data management functions will be available. During off-nominal operations, system configuration updates may be performed manually by on-board users.

10.6.2 Remote/ground
All functions required to perform administrative tasks will be available from a centralized remote control interface accessible only by authorized personnel. User, system configuration and status, and data management functions will be available to the ground medical team. During nominal support operations, system configuration updates may be performed automatically from the ground without the need for local user intervention.
## APPENDIX A. ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMB</td>
<td>Aerospace Medical Board</td>
</tr>
<tr>
<td>BHP</td>
<td>Behavioral Health and Performance</td>
</tr>
<tr>
<td>BME</td>
<td>Biomedical Engineer</td>
</tr>
<tr>
<td>CMO</td>
<td>Crew Medical Officer</td>
</tr>
<tr>
<td>DMCF</td>
<td>Definitive Medical Care Facility</td>
</tr>
<tr>
<td>DSH</td>
<td>Deep Space Habitat</td>
</tr>
<tr>
<td>EMR</td>
<td>Electronic Medical Record</td>
</tr>
<tr>
<td>EVA</td>
<td>Extravehicular Activity</td>
</tr>
<tr>
<td>FCR</td>
<td>Flight Control Room</td>
</tr>
<tr>
<td>HRP</td>
<td>Human Research Program</td>
</tr>
<tr>
<td>IIMDPU</td>
<td>Intelligent Integrative Medical Data Processing Unit</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>IV</td>
<td>Intravenous</td>
</tr>
<tr>
<td>IVA</td>
<td>Intravehicular Activity</td>
</tr>
<tr>
<td>JSC</td>
<td>Johnson Space Center</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>MCC</td>
<td>Mission Control Center</td>
</tr>
<tr>
<td>MMC</td>
<td>Medical Mission Control</td>
</tr>
<tr>
<td>MMR</td>
<td>Mission Medical Record</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>MMSEV</td>
<td>Multi-Mission Space Exploration Vehicle</td>
</tr>
<tr>
<td>NEA</td>
<td>Near Earth Asteroid</td>
</tr>
<tr>
<td>EMCL</td>
<td>Exploration Medical Condition List</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
</tbody>
</table>
APPENDIX B. EXAMPLES OF ON-BOARD MEDICAL SYSTEM HARDWARE

Table B-1. On-board Medical System Diagnostic Hardware

<table>
<thead>
<tr>
<th>Enabling Technologies – Diagnostic</th>
<th>Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otoscope</td>
<td>Imaging</td>
</tr>
<tr>
<td>Ophthalmoscope</td>
<td>Imaging</td>
</tr>
<tr>
<td>Fundoscope with Camera</td>
<td>Imaging</td>
</tr>
<tr>
<td>Laryngoscope</td>
<td>Imaging</td>
</tr>
<tr>
<td>Anoscope</td>
<td>Imaging</td>
</tr>
<tr>
<td>Slit Lamp</td>
<td>Imaging</td>
</tr>
<tr>
<td>Digital Microscope</td>
<td>Pathology imaging</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Imaging</td>
</tr>
<tr>
<td>Dental X-Ray</td>
<td>Imaging</td>
</tr>
<tr>
<td>Physical Examination Camera</td>
<td>Imaging</td>
</tr>
<tr>
<td><strong>Physiologic</strong></td>
<td></td>
</tr>
<tr>
<td>Spirometer</td>
<td>Pulmonary function testing</td>
</tr>
<tr>
<td>Electronic Stethoscope</td>
<td>Auscultation</td>
</tr>
<tr>
<td>Tonometer</td>
<td>Intraocular pressure</td>
</tr>
<tr>
<td>Blood Analyzer:</td>
<td>Rheological properties</td>
</tr>
<tr>
<td>Complete Blood Count</td>
<td></td>
</tr>
<tr>
<td>Liver Function Tests</td>
<td></td>
</tr>
<tr>
<td>Renal Function Tests</td>
<td></td>
</tr>
<tr>
<td>Electrolytes</td>
<td></td>
</tr>
<tr>
<td>Cardiac Enzymes</td>
<td></td>
</tr>
<tr>
<td>Urinalysis:</td>
<td>Metabolic properties</td>
</tr>
<tr>
<td>Red Blood Cells</td>
<td></td>
</tr>
<tr>
<td>White Blood Cells</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td></td>
</tr>
<tr>
<td>Nitrites</td>
<td></td>
</tr>
<tr>
<td>Bilirubin</td>
<td></td>
</tr>
<tr>
<td>Urobilinogen</td>
<td></td>
</tr>
<tr>
<td>Ketones</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td></td>
</tr>
</tbody>
</table>
### Table B-2. On-board Medical System Treatment Hardware

<table>
<thead>
<tr>
<th>Enabling Technologies - Treatment</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound</td>
<td>Imaging/procedural guidance</td>
</tr>
<tr>
<td>Intravenous (IV) Pump/Pressure Infuser</td>
<td>Fluid/medication delivery</td>
</tr>
<tr>
<td>Laryngoscope</td>
<td>Imaging/procedural</td>
</tr>
<tr>
<td>Ventilator Carbon Dioxide Monitoring</td>
<td>Respiratory support</td>
</tr>
<tr>
<td>Oxygen Concentrator</td>
<td>Oxygen delivery</td>
</tr>
<tr>
<td>Hyperbaric Therapy</td>
<td>Decompression therapy</td>
</tr>
</tbody>
</table>

### Table B-3. On-board Medical System Monitoring Hardware

<table>
<thead>
<tr>
<th>Enabling Technologies – Patient Monitoring</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital Signs Monitor:</td>
<td>Vital signs</td>
</tr>
<tr>
<td>Pulse Oximetry</td>
<td></td>
</tr>
<tr>
<td>Blood Pressure</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
<td></td>
</tr>
<tr>
<td>Cardiac Monitor:</td>
<td>Rhythm and hemodynamic properties</td>
</tr>
<tr>
<td>12 Lead Electrocardiogram</td>
<td></td>
</tr>
<tr>
<td>Invasive Blood Pressure</td>
<td></td>
</tr>
<tr>
<td>Radiation Dose Analyzer</td>
<td>Quantify radiation exposure</td>
</tr>
</tbody>
</table>
The purpose of this document is to present the operational concepts for the telemedicine system needed to support human exploration missions to Near Earth Asteroids (NEAs). This operational concepts document is being developed to guide the National Aeronautics and Space Administration (NASA) Human Research Program (HRP) and the National Space Biomedical Research Institute in determining telemedicine and telementoring gaps that currently exist for exploration missions. This will document the consensus of the NASA space medicine community about the direction they would like to go and serve as a roadmap for future research and technology development in the area of telemedicine. This document focuses on the telemedicine and telementoring operational concepts required for a mission to a NEA.