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Development of a NASA Flight Surgeon Quick Reference Guide and Evaluation of the International Space Station Medical Kit: A Model for Resource-Limited Populations

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Development of a NASA Flight Surgeon Quick Reference Guide and Evaluation of the International Space Station Medical Kit: A Model for Resource-Limited Populations

by

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Dedication

To Mrs. Treosti:

For believing in me, even before I did…and still.

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This work fulfills graduate requirements, but also represents a culmination of effort towards a lifelong goal, none of which would have been possible without a number of people. From a technical standpoint, I would like to thank my capstone committee, as well as consultants David Alexander, Vickie Kloeris, Valerie Meyers, Tina Bayuse, Gary Beven, Pam Baskin, Sandra Whitmire, and Smith Johnston. From a personal and career standpoint, I would like to thank my parents, for letting me choose my own path; my family and friends, for unrelenting support; Douglas O'Handley, for the summer of a lifetime at NASA-Ames, which has led to my dream fellowship; Karen Buxbaum, for taking a chance on me that launched me into the world of operational spaceflight; "Uncle" Jack Kent Cooke and Don Pollock for their support through medical school; my Stanford Emergency Medicine Residency family for embracing the greater applications of this field; Julie Chittenden, for countless motivational study sessions; and to all those in my NASA Family: you know who you are—and I am forever grateful for you.

Development of a NASA Flight Surgeon Quick Reference Guide and Evaluation of the International Space Station Medical Kit: A Model for Resource-Limited Populations

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Abstract: The development of an operational Flight Surgeon Quick Reference Guide to complement on-orbit crewmember medical checklists aims to standardize medical care on the part of NASA's medical ground support for a unique patient population in an austere environment. Adapting terrestrial clinical guidelines for spaceflight requires not only reviewing both the current medical standard of care from various governing medical bodies, but also the pharmacologic and medical equipment armamentarium aboard the International Space Station. The product described herein reflects recommended medical management for various conditions and pharmacologic additions to the current ISS medical kit.

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List of Abbreviations

AAEM	American Academy of Emergency Medicine
CliFF	Clinical Findings Form
CMO	Crew Medical Officer
CO2	Carbon dioxide
CPR	Cardiopulmonary Resuscitation
DCS	Decompression Sickness
DUB	Dysfunctional Uterine Bleeding
EMCL	Exploration Medical Conditions List
EMRA	Emergency Medicine Resident Association
EVA	Extra-Vehicular Activity
GSBS	Graduate School of Biomedical Science
HMS	Health Maintenance System
HSRB	Human System Risk Board
IMM	Integrated Medical Model
ISS	International Space Station
JSC	Johnson Space Center
NASA	National Aeronautics and Space Administration
SAS	Space Adaptation Syndrome
SMS	Space Motion Sickness
TDC	Thesis and Dissertation Coordinator
UTI	Urinary Tract Infection
UTMB	University of Texas Medical Branch
VIIP	Visual Impairment and Intracranial Pressure

Chapter 1 Introduction & Purpose

Human spaceflight for long-duration NASA missions has traditionally followed a preventive medicine and public health approach by requiring the selection of healthy individuals to minimize overall risk. Therefore, astronaut health is based largely on disease prevention via screening and selection. As a result, NASA currently has no requirements for a physician to be onboard during International Space Station (ISS) missions, which are currently four months to one year in duration. However, when prevention is insufficient and occupational or acute health conditions arise, astronauts are expected to treat themselves and each other, with telemedicine support from ground specialists when possible.

This scenario is similar to that shared by a number of underserved or extreme environment populations on Earth: wilderness medicine and other providers supporting high-altitude mountaineering expeditions, polar studies, or military deployments;[1,2,3] US Peace Corps Volunteers issued personal medical kits for self-treatment in the field;[4] healthcare providers executing humanitarian missions in developing countries; disaster relief teams responding to populations affected by natural disasters;[5] and physicians and mid-level providers working in domestic but rural areas with limited resources, such as on Native American Indian reservations, or in rural hospitals caring for critically ill patients but lacking tertiary care specialists.[6]

When environments are extreme and resources already limited, the need to synthesize a quick reference guide that lists possible treatments using only the resources at hand can aid to improve, expedite, and standardize care for these populations.[7]

While this project was aimed specifically at improving the healthcare delivery of the NASA astronaut population in this manner, the process of developing the reference guide described herein can be applied to any of the aforementioned terrestrial populations, and aims to be a model from which caregivers working in myriad austere or underserved settings may benefit.

Historical Background on Identification of Medical Risks

An evidence-based process must be implemented to accurately determine the diseases for which a population is at risk, and to subsequently develop a relevant reference guide for healthcare providers that targets these specific diseases. What follows below is currently used at NASA; its implementation is fully adaptable to outside organizations and the terrestrial populations mentioned above.

To formally document, predict and mitigate the health risks to astronauts, NASA has developed an Exploration Medical Conditions List (EMCL),[8] a living document that will continue to expand with our ever-increasing aerospace medical knowledge, and the Integrated Medical Model (IMM),[9] a prediction tool that calculates the probabilities of the EMCL conditions occurring based on a particular mission profile. In this way, the IMM makes an evidence-based prioritization of conditions from the data above to most efficiently target mission resource allocation.

The EMCL and IMM use an evidence-based data analysis to assess the health hazards most likely to occur and impact spaceflight operations during exploration-class missions: historically, they extrapolate data from the International Space Station (ISS) and Space Shuttle medical checklists, as well as the Lifetime Surveillance of Astronaut

Health (LSAH, an internal NASA repository of astronaut medical data) list of experienced in-flight medical conditions.[10]

When there is insufficient spaceflight data available but a condition is considered to have significant crew or mission impact (such as cardiac issues), age-matched terrestrial data from similar populations (e.g., military or occupational health studies)[11] is used to help predict the overall risk of a given medical condition occurring.

While a detailed explanation of the determination of a condition's overall risk is too extensive for the purposes of this document, the basic framework is as follows[9]: the condition's incidence obtained from the databases above is multiplied by the number of crewmembers likely to be affected (e.g., a factor 6 for a standard ISS crew), and by the length of the mission in days or duration of potential exposure to the condition if an external factor is involved. This calculated number of events is then assigned a relative risk score of 1-5 (very low to very high likelihood). Similar rankings are used to determine the relative risk score of the condition's consequence to the mission. The overall risk of a medical condition is the product of its incidence and the consequence to the mission, and is then plotted on a 5x5 risk scoreboard (see Appendix A). This helps NASA's Human System Risk Board (HSRB) prioritize certain conditions for mitigation research.[8] A condition's risk score can change when new data is acquired that supports of refutes its current ranking.

The current EMCL and IMM contain approximately 100 conditions relevant to manned space exploration. These are the conditions that the Flight Surgeon Quick Reference Guide was developed to address. By listing and predicting incidences, consequences and mitigation strategies for each condition, the EMCL and IMM serve to guide future health care planning for manned spaceflight. Many of the conditions identified to date are active areas of research to further understand best practices for prevention, mitigation, and/or treatment.

Scope of Medical Resource Limitations at NASA

Currently, each mission to the ISS consists of three to six astronaut crewmembers. Two astronauts per crew are designated as Crew Medical Officers (CMOs). If an astronaut happens to have prior training as a physician, he or she may by default be designated a CMO, but if no physician-astronaut is part of the crew, the CMOs do not necessarily have any prior medical training. In fact, the majority of astronauts are not physicians, but rather military pilots, engineers, or research scientists. CMOs therefore undergo approximately 40 hours of basic medical training in addition to their general mission training. This includes lessons on how to examine a patient, using medical equipment such as a stethoscope, learning to draw blood, and administering CPR.

Basic medical procedures that a CMO or other astronaut may need to perform in space are listed in the International Procedure Viewer (IPV), a document that contains all procedural checklists required for spaceflight operations aboard the ISS. Astronaut crewmembers refer to the IPV based on the condition at hand and are expected to undertake critical actions to stabilize the patient or condition on their own. As time and communication resources allow, the crewmembers are to discuss any further steps with supporting physicians on the ground, known as Flight Surgeons, in the Mission Control Center (MCC) located at NASA's Johnson Space Center in Houston, TX.

Role of the Flight Surgeon and Overview of Command Structure in Mission Control

It is important to note that the term "Flight Surgeon" is a misnomer: much like the term "Surgeon General," a Flight Surgeon is most often not an actual surgeon, but rather, typically an Emergency, Family Practice or Internal Medicine physician with specialized training in aerospace medicine. Although the name would further imply, they do not fly in space with the astronauts whom they support. On the contrary, operational Flight Surgeons work shifts in MCC and monitor crew health and safety from the ground, which limits the medical capabilities aboard ISS.

It is also important to note that the crew's IPV medical procedures do not contain guidelines on the management of more complex medical issues such as undifferentiated abdominal pain. For this, the expertise and clinical judgment of the Flight Surgeon are indicated.

However, unlike in terrestrial medicine, where physicians are the top of the decision-making hierarchy, Flight Surgeons in Mission Control play only one of many integral roles, and operational decision-making in MCC is shared. The decision process is comprised not only Flight Surgeon recommendations, but also input from biomedical engineers and other flight controllers responsible for ISS mechanical support systems such as environmental control, navigational control, communications, and power. When a situation arises that may have medical implications for crew, the Flight Director executes his or her final decisions based on the input and recommendations received from the Flight Surgeon and other flight controllers.

One example is decompression sickness. In the context of spaceflight, this implies that a leak or depressurization in either an EVA (Extra-Vehicular Activity, also known as a spacewalk) space suit, or in the ISS cabin, has occurred. Changes in the ambient environmental pressure requires not only medical management by the Flight Surgeon, but also the input from the engineers who manage the EVA and/or the Environmental and Thermal Operating Systems for ISS (a Mission Control position known as ETHOS). If the leak causing the depressurization is small, the astronaut may have very mild symptoms from a medical standpoint. However, any leak in spaceflight has the potential to be life- and mission-threatening and must be addressed from a non-medical standpoint by the other aforementioned parties. If the crew's medical symptoms are mild, then the Flight Director may allow the crew to continue to work in a slightly hypobaric environment to secure the ISS with the input of ETHOS and other flight controllers as governed by pre-designated mission rules.

SPECIFIC RESOURCE GAPS ADDRESSED/PROJECT RATIONALE

While the IPV serves to help astronauts with their own basic medical care, no physician equivalent of the IPV or current document on advanced management exists for the Flight Surgeons. Historically, any further steps in medical management were provided based on the Flight Surgeon's clinical experience, the medical standard of care (i.e., what any other reasonable physician in the same specialty would do in the same situation), and any consultant recommendations.

Given that Flight Surgeon background medical specialties and experiences vary within the field of medicine as described above, an effort should be made to standardize operational recommendations for space medicine. The development of a Flight Surgeon-specific handbook aims to address this by serving as a useful reference for healthcare delivery and telemedicine in the astronaut population by adapting terrestrial clinical practice guidelines based on available resources.

Further, the IPV itself is not complete: many conditions listed in the EMCL and IMM are not addressed in the IPV. Additionally, the IPV is currently organized for the use of non-physicians in a simplified, two-section format as follows:

1. Emergent health conditions, including steps expected to be executed by crewmembers on their own, with additional steps to be clarified when they are able to contact Mission Control; and
2. Exams, procedures, treatment.

The development of a Flight Surgeon handbook is a response to the gaps that exist in advanced medical care for EMCL/IMM conditions, especially those not addressed by the IPV. Its development serves to address the problem of insufficient and unconsolidated medical references by providing a single-point manual where the majority of medical information necessary to treat a given condition can rapidly be found. It will also strive to organize the material in a format that is more clinically intuitive to the Flight Surgeon for rapid access when medically necessary. This aims to improve, expedite and standardize healthcare delivery for this unique patient population, and in doing so, can serve as a model applicable to many other resource-limited populations on Earth.

Chapter 2 Methods

CONDITION REORGANIZATION

At the time this project was initiated, 96 medical conditions existed in the EMCL and IMM, and these were determined, as extensively described above, over the past several years prior to the initiation of this project. This list of conditions was reviewed and first reorganized by anatomical organ system or major Emergency Medicine subject (e.g., toxicology, trauma, shock). The reorganization by organ system followed the Table of Contents organization of the Pocket Emergency Medicine handbook.[12]

Next, conditions within the same category that had logically similar management were consolidated into one condition heading. This was done by using the author's clinical judgment, which was gained through completing an Emergency Medicine residency, and verified by Dr. Jennifer Law, NASA Flight Surgeon, for concurrence. For example, sprains/strains of the hip, wrist and ankle are listed as separate conditions in the IMM, but are treated similarly. Therefore, they were grouped together in the Reference Guide as one condition.

If, later in the development process, the treatment for a particular condition seemed to match that of other conditions in a different category, it was reorganized accordingly. As clinical medicine is often a spectrum, this was a subjective process, and there is no truly correct or incorrect structure, but rather, what is most logical based on emulating the structure of the pocket handbook above and based on author knowledge of clinical practice. This process resulted in 49 total recommendation pages that required development.

Gap Identification

Next, existing IPV procedures were compared against the list of medical conditions. Conditions lacking IPV procedures were identified, tabulated, and targeted as priorities for Flight Surgeon reference page development.

Medical Kit Familiarization

An afternoon of hands-on familiarization with training versions of the onboard medical packs was arranged with a NASA Flight Surgeon. This facilitated understanding of the physical location of medications, storage conditions, and logistics required for retrieval by crewmembers. Examples of the various packs include "Emergency Medical Treatment" for acute conditions, "Convenience Medications" with commonly used medications for minor conditions such as indigestion, and "Medical Supplies" such as elastic and adhesive bandages.

Reference Page Development

49 reference pages were generated, which comprise the handbook of advanced medical care for these conditions. This was done for each condition systematically as follows:

a. Cross-reference and review any corresponding IPV procedure(s)
b. Determine the overarching medical specialty that would typically manage the condition terrestrially, and reference their specialty board publications regarding standard of care management of the condition. In most cases, the American Academy of Emergency Medicine's (AAEM) Focused Review of the Core Curriculum[13] textbook and Hamedani's Pocket

Emergency Medicine handbook were sufficient to address the majority of conditions. Other conditions required referencing orthopedic, critical care, otolaryngology or other specialty publications.[14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52] When it was possible to choose from multiple specialties, the default specialty was Emergency Medicine, due to its broad overlap from primary to critical care, which encompassed the vast majority of conditions, and in order to streamline and expedite Reference Guide development.

c. Using the specialty reference(s) mentioned above, critical actions in conducting the medical history, exam and treatment were outlined to create each reference guide page. The general format for each condition is as follows:

- Topic
- Scenario
- Crew and Surgeon actions required (typically 4-5 steps) and alternatives if medications/equipment not adequate
- Pharmacological dosing
- Helpful clinical decision tools/rules
- Required medical supplies
- Notifications to other Mission Control team members
- References

d. This approach was then cross-checked against the two most applicable aerospace medicine textbooks, Fundamentals of Aerospace Medicine[53] and Principles of Clinical Medicine for Spaceflight,[54] for additional recommendations and considerations specific to the spaceflight environment.

e. AAEM's Core Curriculum textbook, Hamedani's Pocket Emergency Medicine handbook, ePocrates[55] and the Emergency Medicine Resident Association (EMRA) Antibiotic Guide[56] were used for the most current recommended pharmacology.

MEDICAL SUPPLIES SPREADSHEET DEVELOPMENT

The creation of each reference page was the driving factor in reviewing and updating the list of required medical supplies. Once a reference page was developed, a corresponding spreadsheet was created and placed on the reverse side of the reference page to aid the Flight Surgeon in guiding the crew to required equipment and medications. Spreadsheets are based on the current Health Maintenance System (HMS) master inventory of available equipment and medications, which was filtered in Excel to generate a spreadsheet for each condition. Any required medical supplies are organized first by ISS locker location, then by individual medical pack (e.g., Emergency Treatment pack, Medical Diagnostics pack, Convenience Medications pack, etc.). See Figure 1.

QUALITY CONTROL

Once each reference page was complete, it was submitted to Dr. Law, NASA Flight Surgeon, for review.

NASA's space medicine research group had previously created an IMM Clinical Findings Form (CliFF) for each medical condition in the IMM. The CliFF lists all the resources available in the ISS medical kit for condition treatment. Once each condition's medical supply spreadsheet for the Quick Reference Guide was finalized, it was compared to its corresponding CliFF resource table to ensure that both tables matched with regard to key supplies necessary to address each condition.

Developing Pharmacologic Recommendations

Based on review of terrestrial management of each condition as described above, certain medications are indicated. A spreadsheet of these recommended medications (including alternatives when more than one medication was acceptable) was generated, and those not already flown aboard ISS were submitted to Dr. Tina Bayuse, JSC Lead Pharmacist, for internal review. Any medications that had already been deemed in research studies to be unstable or otherwise unfeasible for spaceflight were removed to create the final recommendation list.

Chapter 3 Results

The specific aims of this project were to develop a NASA Flight Surgeon reference handbook to provide a single-point reference for advanced healthcare delivery to the astronaut population, and in doing so, evaluate the current International Space Station medical kit for any medications that could be potential be added to optimize care. The results of these efforts are as follows:

Consolidating the Conditions List

In developing the Reference Guide, redundancy was first mitigated by consolidating similar conditions that warrant identical overall clinical management. E.g., combining "wrist sprain/strain," "elbow sprain/strain," "ankle sprain/strain" and "hip sprain/strain" resulted in simplifying the 96 medical conditions list to 49 conditions. This reduces what would have been a significant amount of paperwork through which to sort during medical operations by approximately half. Tables 1 and 2 show the reorganization of the 96 conditions into 49 organ system-based conditions.

Table 1: The IMM Conditions List

	Medical Condition
1	Late Insomnia
2	Skin Abrasion
3	Skin Rash
4	Eye Abrasion
5	Late Headache
6	Space Motion Sickness (SAS)
7	Diarrhea
8	Nasal Congestion
9	Respiratory Infection
10	Back Injury
11	Barotrauma (Ear/Sinus Block)
12	Back Pain (SAS)
13	Insomnia (SAS)
14	Shoulder Sprain/Strain
15	CO_2 Headache
16	Headache (SAS)
17	Visual Impairment Increased Intracranial Pressure (VIIP)
18	Urinary Tract Infection
19	Skin Infection
20	Elbow Sprain/Strain
21	Ankle Sprain/Strain
22	Allergic Reaction
23	Pharyngitis
24	Constipation
25	Neck Injury
26	Mouth Ulcer
27	Dental Caries
28	Knee Sprain/Strain
29	Paresthesias [Extravehicular Activity (EVA)]
30	Indigestion
31	Eye Chemical Burn
32	Sinusitis
33	Hearing Loss
34	Wrist Sprain/Strain
35	Eye Infection

36	Hip Sprain/Strain
37	Gastroenteritis
38	Fingernail Delamination [Extravehicular Activity (EVA)]
39	Otitis Externa
40	Otitis Media
41	Hemorrhoids
42	Lower Extremity Stress Fracture
43	Urinary Retention
44	Skin Laceration
45	Influenza
46	Finger Dislocation
47	Shingles
48	Dental Abscess
49	**Smoke Inhalation***
50	Urinary Incontinence
51	Nosebleed
52	Dental Exposed Pulp
53	Vaginal Yeast Infection
54	Burns
55	Abnormal Uterine Bleeding
56	Hypertension
57	Dental Filling Replacement
58	Acute Prostatitis
59	Acute Diverticulitis
60	Acute Arthritis
61	Kidney Stone
62	Depression
63	Dental Avulsion
64	Anxiety
65	Wrist Fracture
66	Appendicitis
67	**Sepsis***
68	Acute Cholecystitis
69	Dental Crown Replacement
70	Angina/ Myocardial Infarction
71	Acute Pancreatitis
72	**Hypovolemic Shock***
73	**Medication Overdose***

74	Eye Corneal Ulcer
75	Hip Fracture
76	**Decompression Sickness***
77	**Stroke***
78	**Head Injury***
79	Lumbar Spine Fracture
80	**Choking/Obstructed Airway***
81	Compartment Syndrome
82	Abdominal Injury
83	**Chest Injury***
84	**Sudden Cardiac Arrest***
85	**Altitude Sickness***
86	Shoulder Dislocation
87	**Seizures***
88	Elbow Dislocation
89	Glaucoma
90	Behavioral Emergency
91	Eye Penetration
92	**Cardiogenic Shock***
93	**Radiation Syndrome***
94	**Neurogenic Shock***
95	**Toxic Exposure – Ammonia***
96	**Anaphylaxis***

* = medical conditions requiring oxygen or a ventilator

Summary

- Based on IMM outputs of 100,000 simulations of a six month ISS mission with six crew members and 3 EVAs
- None of the medical conditions requiring oxygen or a ventilator have a high likelihood or medium likelihood of occurrence
- Three of the medical conditions requiring oxygen or a ventilator have a low likelihood of occurrence (Smoke Inhalation, Sepsis, and Hypovolemic Shock)
- The remaining 13 medical conditions requiring oxygen or a ventilator have a very low likelihood of occurrence

Table 2: The Consolidated Conditions List

	AIRWAY:
1	Allergic reaction/anaphylaxis
2	Choking
	CARDIOVASCULAR:
3	Angina/Myocardial Infarction
4	Cardiac arrest
5	Hypertension
6	Stroke
	DENTAL:
7	Dental abscess/dental pulp exposed/avulsion
8	Dental caries/filling replacement/crown replacement
	DERMATOLOGY:
9	Skin rash/Skin infection/Shingles
	EAR/NOSE/THROAT/OTOLARYNGOLOGY:
10	Barotrauma/ear/sinus block/nasal congestion
11	Hearing loss
12	Sinusitis/respiratory tract infection/pharyngitis/influenza
13	Mouth ulcer
14	Nosebleed
15	Otitis media/otitis externa
	ENVIRONMENTAL/TOXICOLOGY:
16	Altitude sickness
17	DCS
18	Inhalation (ammonia, smoke)
19	Medication overdose
20	Radiation syndrome
	GASTROENTEROLOGY:
21	Abdominal pain: Appendicitis/cholecystitis/diverticulitis/pancreatitis/nephrolithiasis
22	Constipation/Hemorrhoids
23	Indigestion/Gastroenteritis/Diarrhea

	GENITOURINARY:
24	Urinary retention/incontinence
25	UTI/acute prostatitis
	GYNECOLOGY:
26	Yeast infection/DUB
	MUSCUOLOSKELETAL/ORTHOPEDICS:
27	Arthritis (gout, pseudogout, rheumatoid arthritis)
28	Back pain (SAS)/Back injury/Neck injury
29	Compartment syndrome
30	Fingernail delamination
31	Joint (finger, elbow, shoulder) dislocation
32	Joint sprain/strain
33	Lower extremity stress fracture
34	Wrist/hip/lumbar spine fracture
	NEUROLOGY:
35	Headache (SAS)/Late headache/CO2 headache
36	Paresthesias
37	Seizures
38	SMS (Space Motion Sickness)
39	VIIP (Visual Impairment-Intracranial Pressure)
	OPHTHALMOLOGY:
40	Eye abrasion/corneal ulcer/eye penetration
41	Eye chemical burn
42	Glaucoma
	PSYCHOLOGY:
43	Anxiety/behavioral emergency/depression
44	Insomnia (SAS)/Late insomnia
	SHOCK:
45	Septic
46	Hypovolemic, cardiogenic, neurogenic
	TRAUMA:
47	Burns
48	Head injury, chest injury, abdominal injury
49	Skin abrasion/laceration

Resource Gaps Filled by the Reference Guide

In total, 23 of the 49 conditions did not have corresponding IPV procedures, indicating a significant lack of overall medical resource documentation. Addressing these gaps by creating the reference guide therefore increases the amount of NASA medical procedure documentation by 88%.

The Flight Surgeon Quick Reference Guide

Due to the sensitive material contained within the ISS medical kit and the physical volume of the document (>100 pages), the Quick Reference Guide cannot be shown here in its entirety. Figure 1 is an example of a reference page, with the corresponding spreadsheet of required medications and equipment necessary to adequately manage the condition.

ABRASION/LACERATION

Scenario: Crewmember with skin trauma requiring wound care

CREW ACTIONS

2.13.301 SKIN PROCEDURE - SKIN LACERATION (abbreviated)

1. Have patient apply firm pressure directly on laceration to control bleeding.
2. Photo document the laceration [Digital Camera]. Refer to 3.480 D2XS MEDICAL IMAGING.
3. PREPARING THE LACERATION FOR CLOSURE
4. CHOOSING LACERATION CLOSURE TECHNIQUE

5. PLACING STAPLES or
6. PLACING SUTURES or
7. PLACING DERMABOND

8. PHOTO DOCUMENTING REPAIRED WOUND
9. DRESSING WOUND
10. CLEANING UP
11. DCT FOR PHOTO UPLOAD

SURGEON ACTIONS

IF ACTIVE BLEEDING:

- Have affected crewmember apply direct pressure.
- Advise CMO/caregiver to don nitrile gloves and goggles.

IF ABRASION:

- Clean wound with 4"x4" gauze soaked in potable water.
- Apply thin layer of Bacitracin to wound.
- Cover with appropriate sized gauze and medical tape or adhesive bandage.

IF LACERATION:

- Guide crew through laceration anesthesia, cleaning & repair as appropriate (refer to 2.13.301 SKIN PROCEDURE - LACERATION REPAIR).
- If hemostasis difficult, use hemostat and/or inject additional lidocaine with epinephrine in and around source of bleeding; apply proximal pressure while closing.
- If complicated laceration requiring specialist (e.g., crossing vermillion border of lip, eyelid margin, etc.), consider additional photographs and consult for guided closure.
- Apply layer of Bacitracin over stapled or sutured wound.
- Consider antibiotic prophylaxis for ENT or other complicated lacerations.
- Wound check in 24-48hrs and as needed thereafter prior to any suture or staple removal.

ACRONYMS

CONSTRAINTS/DOSAGES

Lidocaine w/ epinephrine:

- Max dose: 4mg/kg
- Lidocaine with epinephrine for injection into extremities has not been found to cause necrosis as previously believed.[1]

CRITERIA/CLINICAL DECISION TOOLS

GENERAL SUTURE DURATION GUIDELINES[2]:

Face: 4-5 days
Hand/Foot: 7-10 days
Scalp: 7 days
Joint: 10-14 days

ALSO USED TERRESTRIALLY

EQUIPMENT/MEDICATIONS

See back for HMS supplies.
Digital Camera
Goggles
Gray tape
SSC
Towels
Ziploc bag

NOTIFICATIONS

Crew Surgeons
Plastic Surgery or Ophtho consult PRN

REFERENCES

IPV 2.13.301, 3.480
[1]Waterbrook AL, Germann CA, Southall JC. "Is epinephrine harmful when used with anesthetics for digital nerve blocks?" Ann Emerg Med. 2007 Oct;50(4):472-5.
[2]Hamenadi, et al. Pocket Emergency Medicine. 2003.

PACKS: VERIFY LOCATION PRIOR TO DIRETING CREW TO ITEM

ABRASION/LACERATION	LAB1D4_D1						LAB1D4_D2					NOD2_Fwd Endcone or LAB1D4_K2
EQUIPMENT/MEDICATION	**Emergency Med Treatment**	**IV Supply**	**Minor Treatment**	**Topical & Inj Med**	**Physician Supply**	**N/A**	**Convenience Med**	**Med Diagnostic**	**Med Supply**	**Oral Med**	**N/A**	**N/A**
Bacitracin (Bacitracin)- Topical - 500 units/gm, 28 gm, tube							X					
Bandaid 2X3 -			X									
Gauze 4X4 - Packed within reclosable bag Gauze Pad Assy									X			
Iodine Swabstick - Packed within reclosable bag labeled Intraosseous Device Start Kit (-604)	X								X			
Lidocaine with Epinephrine (Lidocaine with Epinephrine) - 2% with 1:100,000 epi, 20 mL, multi dose vial				X								
Medical Tape 1" -									X			
Nitrile Gloves Medium -									X			
Nonstick Bandage -			X									
Syringe 10mL -									X			
Syringe 60mL -			X									

ADDITIONAL SUPPLIES AS NEEDED:

IF STAPLES:

Skin Stapler -			X									

IF SUTURES:

BZK Wipes - each									X			
Nylon Suture 5.0 -			X									
Sharps Container -			X									
Surgical Tools Kit -			X									

IF DERMABOND:

Dermabond (Dermabond)- Topical - 0.5 mL, swab				X								

Figure 1: Example Quick Reference Guide page and medical supplies spreadsheet

OTHER REVELATIONS DURING REFERENCE GUIDE DEVELOPMENT

While drafting the Reference Guide, a number of other findings were as below. Those findings listing sample size or percentage details of various clinical management scenarios should be specifically targeted as operational gaps:

1. Each page took approximately 4 hours to draft, although the process became more efficient as the project neared completion. This excluded instances when outside information, such as toxicology or JSC Food Lab (e.g., for fiber content information to treat constipation) queries, were required in order to complete the page, and excluded the time spent for Flight Surgeon review. Including editing time, the estimated total time for the Reference Guide alone was approximately 250 man-hours.
2. The organ systems or Emergency Medicine subjects with the most medical conditions of concern to the spaceflight population are musculoskeletal (n=8), otolaryngology (n=6), and environmental/toxicology (n=5).
3. The IMM lists 16 medical conditions that would potentially require oxygen or a respiratory ventilator. This distinction bore no weight on Reference Guide development-- i.e., the reference pages for these conditions were developed by the author independent of this knowledge. However, later realization of this fact revealed that there was 1:1 agreement between the IMM and the Reference Guide as to which conditions require supplemental oxygen. This demonstrates physician judgment agreement between the research and operations arms of the space medicine group.

4. 17 of the 49 conditions (34.7%) could potentially require evacuation and return to Earth as part of their medical management.
5. Due to pharmacology limitations and the very low likelihood of truly emergent conditions occurring in space (e.g., stroke, cardiac arrest), which is in turn due to selecting out for individuals at risk for these conditions, there appeared to be an inverse relationship between the severity of the condition and ability to treat it appropriately (although formal calculation of this relationship is beyond the timeframe and scope of this project). The best example of this is stroke: on Earth, stroke management includes the option of tPA (tissue plasminogen activator, a blood clot-dissolving agent). This is not carried aboard the ISS, making stroke management in space relatively simple: the patient would receive oxygen, aspirin if able to swallow, and likely be prepared for evacuation.
6. 35 of 49 conditions (71%) have management that suggests including the input of outside specialty consultants. The most common were Orthopedics (n=6), surgical specialties (General, Trauma, Plastics, n=5) and Ophthalmology/Optometry (n=4).
7. While medicine is a spectrum, and each condition can vary in severity, developing the reference pages revealed that all conditions would potentially require action on the part of the Flight Surgeon, further validating Reference Guide development.

RECOMMENDED PHARMACOLOGIC ADDITIONS TO THE ISS MEDICAL KIT

Based on the methods described above, a list of medications considered to be terrestrial standard of care for the conditions in question was submitted to the JSC Pharmacy for review of stability and feasibility in spaceflight.[57] Some of these medications had been previously researched and known to be unstable in spaceflight, at times reducing their potency. One example is Augmentin (amoxicillin + clavulanate),[58] which therefore cannot be flown. Amoxicillin is flown in lieu of Augmentin as a stand-alone drug for many related medical conditions, as are alternatives for those allergic to penicillin-class antibiotics. The subject matter of the full spreadsheet is considered Sensitive by NASA Medical Operations policy and cannot be displayed for external purposes. However, quantifiable results are permitted.

A total of 63 medications were submitted to Dr. Bayuse, JSC Lead Pharmacist, for review. After this review, 25 were considered to have mass or storage constraints for spaceflight (e.g., required refrigeration, narrow therapeutic index, short shelf life, or needs sterile water for injection) that precluded their addition to the ISS medical kit. This leaves 37 medications that could potentially be added to the kits. However, pharmacology research data is lacking on these medications, and given the above restrictions, it is likely that an additional proportion of these 37 medications may also be difficult to fly in space.

Chapter 4 Discussion

Healthcare delivery for remote populations and challenging occupational settings requires special support and considerations. This includes the ability to improvise and adapt common practices to environments when the typical medical resources may not be available. In such circumstances, a reference guide that synthesizes available treatments for the most common medical ailments expected for the population in question can be very useful in providing appropriate medical care.

The process used to develop the NASA Flight Surgeon Quick Reference Guide can potentially be implemented in military, humanitarian aid, disaster relief, wilderness and expedition medicine settings to develop handbooks relevant to each particular situation. In fact, one such military publication already exists: the Air Force Flight Surgeon's Checklist.[59] It is hoped that other groups will reference this development process in determining their own population's medical risks and preventive and treatment measures. Overall, the guide affords a single-point reference that aims to improve, expedite, and standardize healthcare delivery.

Development of the NASA Flight Surgeon Quick Reference Guide resulted in two additional important changes: filling gaps in medical procedure documentation, and reducing the amount of excess or redundant clinical management documentation due to consolidation of similar conditions. Both these changes could potentially result in decreased medical errors, both on the part of the Flight Surgeon when instructing crew, and also on the part of crewmembers performing the procedure.

Challenges in Developing the Reference Guide

As described in the methods section, the consolidation process from 96 conditions to 49 reference pages was done using an organizational structure borrowed from an established Emergency Medicine handbook, as well as the clinical judgment and common sense of one Emergency Medicine physician. While referencing a published work provides some reliable support, exercising clinical judgment varies from individual to individual and depends on a number of factors, including the quality of medical education and residency training. Given these subjective factors, there is likely no objectively correct or incorrect way of organizing the conditions; had another physician undertaken this project, the organization would likely vary. It should be noted that the current organization of the Reference Guide is merely one way of many to present the information, and the author welcomes suggestions for improvement on future versions.

Development of the Reference Guide provided a comprehensive review of ISS medical capabilities and limitations. However, it required significant manual labor. No computer or automated process can reliably synthesize multiple medical resources and generate a product to replace clinical judgment, which was the ultimate tool in developing and organizing each recommendation page. There is no substitute for clinical judgment and a healthcare provider's clinical experience. However, in the context of extreme environments when a population is exposed to life-threatening situations, and as has been proven in the medical literature even in the context of a busy terrestrial hospital with nominal operations, the importance of a checklist, such as the steps provided in the Reference Guide, when under stress and time constraints cannot be underestimated.[60,61]

One particular limitation of this project is that the major aerospace medicine texts and any NASA clinical practice guidelines used in the development of the reference guide are becoming outdated, with new editions and revisions pending. Further, access to internal NASA clinical practice guidelines was limited during this project, and they typically cover non-emergent conditions such as hypercholesterolemia, which is not an acute medical condition that appears on the EMCL. Attempts were made to address this factor by using more current Emergency Medicine and consultant references whenever applicable.

The most noteworthy challenge in spreadsheet development was the inclusion of airway supplies. As noted in the results, there are currently 16 conditions that would require either supplemental oxygen or placement of a definitive airway. However, advanced airway placement during NASA missions at this time would require a physician-trained astronaut, who is not currently required to be aboard every mission. Including these extra supplies when they most often will not be used, due to no available physician and low risk of occurrence, proved cumbersome, and could potentially complicate and clutter what is meant to be a streamlined, rapid reference for the Flight Surgeon.

On the other hand, airway compromise is a true medical emergency, and in the event that a physician crewmember were aboard during this event, no specific procedure is documented. This highlighted the need to develop separate reference pages for physician-only procedures, such as intubation, which will be undertaken in the future as an extension to this project.

DIFFERENCES BETWEEN REFERENCE GUIDE AND THE IMM'S CLIFF RESOURCE TABLES

Comparison of the Reference Guide and the IMM's CliFF resource tables revealed discrepancies that reflect the different purposes for which each was developed. The CliFF aims to itemize the precise amount of resources used for a particular condition to predict the mass of essential medical items and to aid in mission planning. It therefore has a very focused approach, listing supplies down to individual units, including items such as IV caps. It references publications of in-depth research to determine the singular best treatment for a particular condition, e.g., septic arthritis. Additionally, the IMM is a computational prediction model with limitations as to clinical judgment. While it at times lists a single pharmacologic agent, e.g., penicillin, it does not account for the fact that a particular crew member who requires that medication may in fact have a penicillin allergy. It also does not predict the likelihood of complications from certain medical procedures, such as iatrogenic infection secondary to nasal packing for a severe nosebleed, and therefore does not list prophylactic antibiotics. These can be found in the Reference Guide page for epistaxis.

In contrast, the Quick Reference Guide assumes the Flight Surgeon will be presented with an undifferentiated patient whose diagnosis may initially be unclear, and is designed to aid the Flight Surgeon in working through a differential. The Reference Guide therefore adopts a broader approach, borrowing from more wide-ranging texts, and aims to consider alternate diagnoses, medication allergies, and consultant recommendations.

Given that the IMM's CliFF and Reference Guide have slightly different objectives, different medical publications were used to guide development. Attempting to reconcile every discrepancy would be a perpetual process, as antibiotic resistance and medical technologies advance, and is therefore beyond the timeframe and scope of this project. Keeping the overall purpose of the Reference Guide in mind, this was an effort to document a reasonably reliable handbook for quick access, with a handful of options for treatment, when appropriate, rather than determine the single best agent or method for treating a medical condition. It is also important to keep in mind the importance of models as well as practicality, and that "standard of care" in the practice of medicine has always been and will always be a spectrum.

FORWARD WORK

Since the initiation of this project, six additional conditions have been added to the EMCL and IMM. It is expected that more will follow in the future. Some conditions can be consolidated into already existing and related conditions' reference pages, but the development of new pages will need to be evaluated by continuing to monitor the EMCL and IMM at regular intervals, such as a quarterly review, and maintaining communication with the research arm of the space medicine group. Further, as mentioned above, physician-specific procedures such as intubation will also be outlined.

Now that the development methods for the Reference Guide have been established and the process expedited by word-processing technology and the filter function in Excel in order to create spreadsheets, future versions should be relatively feasible to update. It is hoped that both a hard copy and an electronic version of the Quick Reference Guide will be made available at the SURGEON console in MCC.

With regards to determining the effectiveness of the Reference Guide once it is implemented, potential specific metrics that could be measured include changes in morbidity, mortality, length of time taken to administer of medical care, and patient satisfaction scores.

The metrics displayed in the results section regarding most commonly affected organ systems, percentage of conditions requiring evacuation or specialty consultant, and the number of potential medication additions all imply one overall challenge: that there remains significant room for improvement in healthcare delivery in resource-limited populations. As pertains to missions to asteroids or Mars, the metrics described above should, ideally, be specifically targeted for improvement. A crew to Mars must be completely autonomous, which implies that a physician must be aboard the crew, and the medications and skillsets currently available must be improved and expanded.

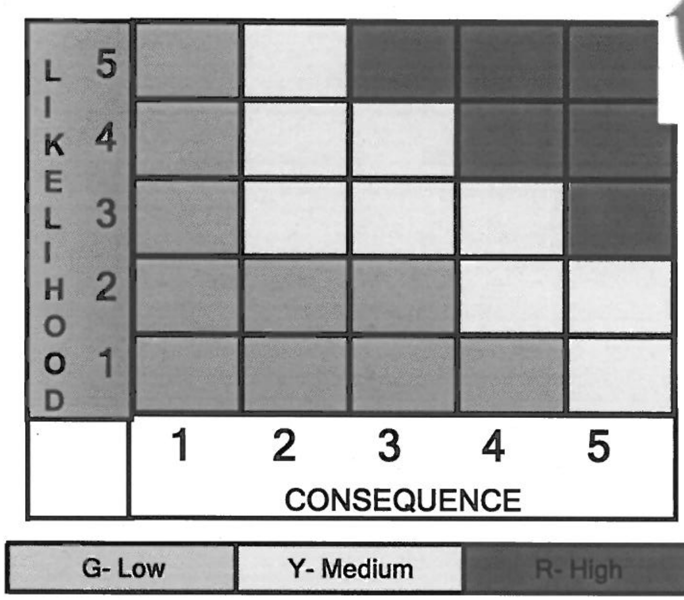
Mercurial political climates and continual changes in funding priorities on a global scale currently preclude a focused and concerted effort towards true exploration class missions to destinations such as Mars. However, this Reference Guide hopes to be applicable as building block for next step in management of remote populations, and to set an example for the medical support required for the endeavor of such missions, in conjunction with future iterations of the ECML and IMM. Missions to Mars must address communication delays due to their long distance from Earth, which further limits the availability of a Flight Surgeon. Sources have suggested that exploration missions should thus require the presence of a physician among the crew,[62,63] which would slightly alter the Reference Guide but still serve as a single-point master handbook for crew health.

In conclusion, the goal of the Quick Reference Guide is to serve as a model for other resource-limited populations by providing operational Flight Surgeons with a single-point resource from which they may draw the most amount of information needed in order to mitigate medical contingencies in real time. Like the EMCL, it is a living document that can be updated and modified to reflect changes and new knowledge in the field of space medicine. It is hoped that this will be used during future missions, with feedback provided to the author to improve subsequent editions.

Appendix A The Human Systems Risk Scorecard[64]

HSRB Risk Scorecard

Likelihood of Occurrence	
5 -Highly Likely	Nearly certain to occur. Controls have little or no effect. ≥ **0.5 events**
4 -Likely	Highly likely to occur. Controls have significant uncertainties. **0.1-0.5 events**
3 -Possible	May occur. Controls exist with some uncertainties **0.01-0.1 events**
2 -Unlikely	Not likely to occur. Controls have minor limitations/uncertainties **0.001-0.01 events**
1 -Highly Unlikely	Very unlikely to occur. Strong controls in place **<0.001 events**



Consequence Criteria				
1	2	3	4	5
Very Low	**Low**	**Moderate**	**High**	**Very High**
PH: Injury not requiring treatment **OP:** Negligible performance decrement that reduces efficiency, but doesn't impact mission objectives **LTH**: Disability is short term	**PH:** Acute health event or injury requiring treatment available in Med Kit **OP:** Performance decrement that impacts nominal operations, but workarounds are available **LTH**: Can be corrected with terrestrial advances in treatment and/or surgery to approximate pre-flight condition	**PH**: Injury, Illness or incapacitation that may affect personal safety or health **OP:** Performance decrement that moderately impacts mission operations, workarounds are available **LTH:** Will result in a disability or occupational illness, partially correctable, requires compensation	**PH:** Injury, illness or incapacitation that could become serious enough for evacuation **OP:** Performance decrement resulting in failure to meet major mission objective **LTH:** Results in a disability or occupational illness, incomplete correction, incomplete compensation	**PH:** Death (LOC) or permanent disabling injury **OP:** Contingency abort (LOM) **LTH:** Permanent disability or occupational illness, unable to correct or compensate; premature death

PH: Personal Health; OP: Operational impact; LTH: Long-Term Health; LOC: Loss of Crew; LOM: Loss of Mission

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Vita

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