Disinfection of Medical Equipment for Exploration Missions: An Assessment of Necessity and Modalities

Aaron Harman
University of Massachusetts Medical School
Wyle Science Technology and Engineering Group Aerospace Medicine Clerkship

Anil Menon, M.D., M.S., M.P.H.
Element Scientist, Exploration Medical Capability
The University of Texas Medical Branch
NASA/Johnson Space Center Bioastronautics Contract

Sharmila Watkins, M.D., M.P.H.
Element Scientist, Exploration Medical Capability
The University of Texas Medical Branch
NASA/Johnson Space Center Bioastronautics Contract
Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA’s scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA’s institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA’s mission.

Specialized services that complement the STI Program Office’s diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

Access the NASA STI Program Home Page at http://www.sti.nasa.gov

E-mail your question via the Internet to help@sti.nasa.gov

Fax your question to the NASA STI Help Desk at (301) 621-0134

Telephone the NASA STI Help Desk at (301) 621-0390

Write to:
NASA STI Help Desk
NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Disinfection of Medical Equipment for Exploration Missions: An Assessment of Necessity and Modalities

Aaron Harman
University of Massachusetts Medical School
Wyle Science Technology and Engineering Group Aerospace Medicine Clerkship

Anil Menon, M.D., M.S., M.P.H.
Element Scientist, Exploration Medical Capability
The University of Texas Medical Branch
NASA/Johnson Space Center Bioastronautics Contract

Sharmila Watkins, M.D., M.P.H.
Element Scientist, Exploration Medical Capability
The University of Texas Medical Branch
NASA/Johnson Space Center Bioastronautics Contract

December 2012
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronyms and Abbreviations</td>
<td>ii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Relevant Medical Conditions</td>
<td>1</td>
</tr>
<tr>
<td>Summary of Evidence</td>
<td>3</td>
</tr>
<tr>
<td>Cleaning</td>
<td>4</td>
</tr>
<tr>
<td>Sterilization</td>
<td>4</td>
</tr>
<tr>
<td>High-Level Disinfection</td>
<td>6</td>
</tr>
<tr>
<td>Novel Technologies</td>
<td>8</td>
</tr>
<tr>
<td>Summary</td>
<td>8</td>
</tr>
<tr>
<td>References</td>
<td>9</td>
</tr>
</tbody>
</table>
**Acronyms and Abbreviations**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>@</td>
<td>at</td>
</tr>
<tr>
<td>C</td>
<td>Celsius</td>
</tr>
<tr>
<td>DNA</td>
<td>Deoxyribonucleic acid</td>
</tr>
<tr>
<td>ETO</td>
<td>Ethylene Oxide</td>
</tr>
<tr>
<td>FDA</td>
<td>Food and Drug Administration</td>
</tr>
<tr>
<td>FST</td>
<td>Forward Surgical Team</td>
</tr>
<tr>
<td>GA</td>
<td>Glutaraldehyde</td>
</tr>
<tr>
<td>HLD</td>
<td>High-level Disinfectant</td>
</tr>
<tr>
<td>HP</td>
<td>Hydrogen Peroxide</td>
</tr>
<tr>
<td>Hrs</td>
<td>Hours</td>
</tr>
<tr>
<td>ILD</td>
<td>Intermediate-level Disinfectant</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>LLD</td>
<td>Low-level Disinfectant</td>
</tr>
<tr>
<td>Min</td>
<td>Minute</td>
</tr>
<tr>
<td>Mon</td>
<td>Month</td>
</tr>
<tr>
<td>N/A</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>NM</td>
<td>Nanometer</td>
</tr>
<tr>
<td>OPA</td>
<td>Orthophthalaldehyde</td>
</tr>
<tr>
<td>PA</td>
<td>Paracetic Acid</td>
</tr>
<tr>
<td>SMEMCL</td>
<td>Space Medicine Exploration Condition List</td>
</tr>
<tr>
<td>Soln</td>
<td>Solution</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>Yrs</td>
<td>Years</td>
</tr>
</tbody>
</table>
Introduction

Equipment sterilization is widely accepted as a critical component of any surgical procedure and is necessary for mitigating infection, morbidity, and mortality (Block, 1991). Since the advent of aseptic technique and modern sterilization, postoperative infections and complications of surgical procedures and other medical procedures have significantly declined. Hospitals are expected to utilize these concepts for procedures and tools as a standard of care (http://www.jointcommission.org). Of note, sterilization is the most stringent of a range of disinfection techniques. Depending on the intended use of the equipment, less stringent methods may be employed.

Spacecraft environments are not sterile environments and, like any terrestrial environment, may harbor pathogens; therefore, there is a need for disinfection if medical equipment is to be used more than once. In one study, the atmosphere particle count and colony-forming unit count in the spacecraft’s environment were a factor of 10 higher than in operating rooms on Earth (Campbell, 1992). The particles, which are larger than those found on Earth, are mostly made up of dead skin, and may contain fecal matter (Campbell, 1992). In planning for surgical procedures in space flight, it is important to consider tools and procedures in relation to their intended purpose, risk of pathogen transmission, and ideal level of disinfection to determine disinfection requirements. Currently, there are no reports of in-flight surgical emergencies requiring invasive surgical equipment for treatment—as defined by a de novo break of physiologic barrier of sterility such as the skin during an appendectomy. However, catheters, also considered to be invasive medical equipment, have been used in-flight to treat urinary retention (Stepaniak, 2007). Catheter use can potentially cause a urinary tract infection in the user by creating a pathway to the sterile bladder, and a catheter being used more than once would benefit from disinfection. Ultrasound use and dental emergencies have necessitated use of semi-invasive (i.e., entering a body cavity that isn’t already sterile, such as the mouth or esophagus) equipment on the International Space Station (ISS). Use of semi-invasive items is likely to increase during exploration missions, due to the longer duration and higher likelihood that an illness requiring treatment will appear. This will necessitate some form of disinfection/sterilization to safely reuse the medical equipment. Since there are many operational constraints on in-flight surgical procedures, it is not clear whether disinfection of invasive medical equipment will be necessary. This gap report explores various technologies that can facilitate disinfection of invasive medical equipment for use onboard spacecraft.

Relevant Medical Conditions

Many of the conditions on the Space Medicine Exploration Condition List (SMEMCL, 2012) will require a need for some type of disinfection. For example, any noninvasive monitoring will likely require low-level disinfection; many treatments, such as the delivery of oxygen via nasal canula, are recommended to receive high-level disinfection because of their contact with
mucosa; and some conditions will require sterilization of equipment for treatment such as a scalpel used for intra-abdominal surgery.

Since sterilization and high-level disinfection require dedicated and more complex processes than low-level disinfection and cleaning, those conditions needing more than low-level disinfection will be considered in this gap report.

Medical conditions that the onboard medical system must address, per the SMEMCL, and which may require sterilization or high-level disinfection for anticipated medical and procedural needs include:

- Anaphylaxis
- Burns
- Choking/obstructed airway
- Dental – caries
- Dental abscess
- Dental exposed pulp/pulpitis
- Dental crown replacement
- Dental filling replacement
- Dental avulsion/tooth loss
- Eye penetration (foreign body)
- Intra-abdominal infection (diverticulitis, appendicitis, other)
- Sepsis
- Skin laceration
- Smoke inhalation
- Surgical treatment
- Toxic exposure
- Urinary retention
- Urinary incontinence
- Visual impairment/intracranial hypertension

Per the SMEMCL, medical conditions that the onboard medical system should address if mass, volume, and power constraints allow, and which may require sterilization or high-grade disinfection of medical equipment, include:

- Abdominal injury
- Pneumothorax
- Decompression sickness
- Sudden cardiac arrest
Per the SMEMCL, there are medical conditions that the onboard medical system will not address because of a low likelihood of occurrence or an inability to treat due to mission constraints. Though these conditions are not intended to be specifically addressed, they may require sterilization or high-grade disinfection of medical equipment. These conditions include:

- Cardiogenic shock
- Compartment syndrome
- Head injury
- Hip/lower extremity fracture
- Hypovolemic shock
- Neurogenic shock

**Summary of Evidence**

The Spaulding classification, originally proposed in 1957, determines requirements for disinfection and sterilization of medical devices (McDonnell, 2011). The classification prioritizes sterilization requirements based on the intended use of the equipment and the respective risk of contamination for the patient. For example, instruments used for intra-abdominal surgery require a higher level of sterilization compared with instruments used intraorally. Based on the disease transmission risks associated with an instrument’s intended use, a varying level of disinfection (defined below) should be applied from medical equipment used in procedures that are high risk, moderate risk, or low risk for infectious complications. At each level of disinfection, the antimicrobial activity will vary in efficacy against microorganisms. Additional, important terminology is defined below (McDonnell, 2011). In regards to safety, standards of practice dictate that it is acceptable to reach a higher level of disinfection than recommended by the Spaulding classification.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning</td>
<td>Cleaning is a process that removes foreign material with enzymes or surfactant. Cleaning is an initial step in reprocessing tools.</td>
</tr>
<tr>
<td>Decontamination</td>
<td>Removal, inactivation, or destruction of pathogens on a tool that renders them incapable of transmitting infectious particles. Decontamination could comprise cleaning, disinfection, or sterilization.</td>
</tr>
<tr>
<td>Disinfection</td>
<td>A process of decontamination that can be chemical or physical.</td>
</tr>
<tr>
<td>Low-level Disinfectant (LLD)</td>
<td>An agent that destroys all vegetative bacteria, lipid viruses, some non-lipid viruses, some fungus, but not bacterial spores or tubercle bacilli.</td>
</tr>
<tr>
<td>Intermediate-level Disinfectant (ILD)</td>
<td>An agent that destroys all vegetative bacteria, lipid viruses, some non-lipid viruses, fungus spores, tubercle bacilli, but not bacterial spores.</td>
</tr>
<tr>
<td>High-level Disinfectant (HLD)</td>
<td>An agent that destroys all vegetative bacteria, fungi, lipid viruses, non-lipid viruses, and other microorganisms. It can also destroy bacterial spores but not in large quantities.</td>
</tr>
<tr>
<td>Sterilization</td>
<td>Destruction of all infectious agents including all spores.</td>
</tr>
</tbody>
</table>
Invasive medical equipment, such as surgical instruments used in an operating room, require sterilization whereas semi-invasive medical equipment, such as laryngoscope blades, need high-level disinfection. Though invasive equipment is used in a manner that confers a high risk of pathogen transmission, semi-invasive items have the highest rate of infection (Rutala, 2008). Hospital processes designed for invasive equipment are extremely stringent and may account for the lower rate of infection. Noninvasive equipment, such as blood pressure cuffs, rarely transmit disease and can be approached with low-level or intermediate-level disinfection (Weber, 1997).

Medical equipment expected to be included in a manifest for space flight can be categorized into three categories based on their individual decontamination requirements. For example, each item on the manifest can be classified as an invasive, semi-invasive, or noninvasive item. Invasive items will then necessitate sterilization. Some semi-invasive items might need sterilization while others might need high-level disinfection. A trade between medical capabilities, reuse, and decontamination requirements can then be more clearly made.

Cleaning
The first step in any disinfection process should include cleaning of the item. Debris removal is important before sterilization or disinfection because the presence of concentrated debris material can prevent disinfecting agents from reaching all of the surface area (Rutala, 2008). Friction and fluidics are the important components to cleaning. Friction can be applied through a brush or direct contact to remove debris; fluidics uses liquids to reach smaller spaces. Pressure enhances the ability of fluidics to remove debris. Much like standard cleaning of non-medical items, soaps, surfactants, and enzymatic solutions serve as helpful adjuncts to medical cleaning.

Sterilization
Sterilization aims to lower the probability of a spore surviving the process to 1 in 1 million. With this threshold, there have been only a few reported cases of pathogen transmission (Agalloco, 1998). This threshold can be reached by different modalities such as heat and chemical sterilization. An important operational consideration is the effect of sterilization on the function of the equipment where heat may damage some plastics. Also, all temperatures described below assume ambient temperature and pressure to be standard at 1 atmosphere and 15°C.

Steam Sterilization (Autoclave)
There are two types of steam sterilizers: the gravity displacement autoclave and the high-speed prevacuum sterilizer. The former relies on gravity for the steam to displace air out the bottom of the chamber through the drain vent and would therefore not be as effective in a microgravity environment. The latter has a vacuum pump to ensure air removal from the sterilizing chamber before the steam is introduced, improving the odds that it would function in microgravity. Another system is a steam-flush pressure-pulsing process, which removes air rapidly by using a
steam flush and a pressure pulse—it has the same advantage as the vacuum pump. There are also portable steam sterilizers that would work well within the volume constraints of spacecraft.

Steam at 132°C for 4 minutes under pressure is the most widely used and dependable terrestrial method of sterilization because of cost and availability. In addition, it is nontoxic, penetrates materials quickly, is compatible with many materials, and is effective.

**Dry-heat Sterilizers**

This method is only used for materials that could be damaged by moist heat or that are impenetrable to moist heat such as powders, petroleum products, and sharp instruments. Its advantages include being nontoxic, inexpensive, and able to penetrate materials, and is noncorrosive for metal and sharp instruments. Disadvantages include a slow rate of heat penetration and microbial killing. Also, the high temperatures of 160°C for 60 minutes could potentially damage some materials.

There are two types of dry-heat sterilizers: the static-air (gravity convection) type and the forced-air type. As the name implies, the gravity convection sterilizer relies on less dense air heated at the bottom to rise above cooler air, and might operate differently in microgravity, where no convection occurs. The forced-air type works faster and creates more uniform temperature control by actively moving hot air into the device.

**Glass Bead Sterilizer**

This technique is a quick method used commonly in dental offices. It uses small glass beads heated to high temperatures ranging from 217°C to 232°C for several minutes. It has been shown to be somewhat effective, but not as much as autoclave sterilization (Venkatasubramanian, 2010). The FDA has also not cleared this device because it is believed there is a risk of infection due to incomplete sterilization. In addition, this device relies upon gravity to keep the beads in the crucible, which would not be available in microgravity.

**Low Temperature Sterilization – Ethylene Oxide (ETO)**

ETO gas has been used since the 1950s for sterilization of instruments that are heat or moisture sensitive. Sterilization takes approximately 2.5 hours, also including 8 to 12 hours of aeration. Gas concentration, exposure time, temperature, and humidity all influence effectiveness (Association, 1999). ETO gas is unstable, can polymerize easily, and is flammable and explosive. In addition, acute human exposure can lead to irritation and depression of the central nervous system, and chronic exposure has been linked to various cancers (Rutala, 2008). Since ETO is absorbed by instruments, it must be aerated after sterilization to remove residual components. Due to the hazards involved with this technique, it is not suitable for utilization during space flight.
**Hydrogen Peroxide (HP) Gas Plasma**

HP plasma sterilization uses 1.8 milliliters of 58% HP that is vaporized in a sterilization chamber. Radio frequency energy is used to convert it into plasma that consists of highly charged particles and free radicals. Sterilization occurs at temperatures below 44°C over 75 minutes. Moisture inactivates the procedure. Unlike ETO, it does not produce toxic residues or emissions. It has other advantages over ETO, including less time and power required, lower carcinogenicity and safer use profile. Disadvantages include incompatibility with materials such as cellulose, linens, and liquids. Also, radio-frequency-based devices may negatively impact other electronics on the spacecraft.

**Paracetic Acid (PA)**

PA is used to sterilize endoscopes at a concentration of 0.2% at 50°C, and for 30 minutes of exposure (Cheung, 1999). However, the efficacy may not be as high as the previously described techniques at killing bacteria and spores. Sterilization depends on surface contact and is not as effective in small lumen devices. In addition, the solution must be prepared with sterile water, which might be difficult to recycle in-flight.

**Orthophthalaldehyde (OPA)**

OPA is used in current ISS operations to prevent the buildup of biofilms in cooling loops. It has also been used as a high-level disinfectant, particularly for cleaning endoscopes (Rutala, 2008). A 20% solution applied for 5 to 12 minutes is most commonly used for this purpose. Advantages include a high compatibility with other materials, low potential for inhalation injury, and effective reduction in bacterial loads. Disadvantages include skin and eye irritation, potential for anaphylactic reactions, and a requirement for rinsing away residual disinfectant after application for sterilization.

**High-Level Disinfection**

High-level disinfection can be achieved by boiling water, by moist heat at 80°C, and by chemical agents. Boiling data assume 100°C at 1 atmosphere for 10 minutes of immersion (Rutala, 2008). Operational challenges include boiling water in a microgravity environment, getting the water to reach these desired temperatures, and damage to instruments that are submerged in the boiling water. In addition, boiling does not kill sufficient bacteria to satisfy the requirements for sterilization.

Moist heat or hot water washing at 80°C provides disinfection between a high-level and a low-level (http://www.ific.narod.ru/Manual/Clean.htm). It is useful for equipment such as glass
beakers, respiratory equipment, and other semi-invasive items that are not damaged by heat and do not need sterilization.

Chemical Agents

High-level disinfection can be achieved with a number of chemical agents such as alcohol, chlorine, formaldehyde, glutaraldehyde (GA), HP, iodine, PA, phenolics, and ammonia (Rutala, 2008). However, many of these chemicals must be available in ample quantities, cannot be recycled, and are toxic to humans.

Liquid chemicals, such as HP and PA, are currently used in austere environments such as forward operating positions in the military (Doona, 2006). The Forward Surgical Teams (FSTs) of the United States Army provide emergent surgical care to injured troops who would otherwise not survive transportation to a hospital. An FST can set up a functional operating room in just 1 hour and be ready to relocate within 2 hours. Despite equipment limitations, FSTs provide a useful paradigm for sterilization techniques that function in austere environments. FSTs use autoclaves to sterilize surgical instruments prior to deployment and chemical sterilization, such as GA, for sterilization of equipment in the field. Liquid chemicals are relatively inexpensive, do not require power, and can be used to sterilize many materials. However, unlike space flight, FSTs do not face the same long-term water constraints, a need to recycle materials, and limited disposal ability.

In addition to toxicity, there are several drawbacks with liquid sterilization. While heat can penetrate through materials on the surface of the instruments, such as tissue, liquids cannot and therefore require direct contact to kill pathogens. Also, some liquids must be rinsed off with water after sterilization, a process that potentially reintroduces microorganisms. Certain chemicals, such as GA, have vapor that causes respiratory irritation if inhaled, and in an environment with relatively poor ventilation, such as the ISS, could be dangerous to crewmembers. Additionally, in microgravity, special methods would have to be developed to contain the fluid and secure it to prevent unintended exposure.

Table 1: A Comparison of Chemical Disinfection Agents

<table>
<thead>
<tr>
<th></th>
<th>HP (10% soln)</th>
<th>GA (2% soln)</th>
<th>PA (40% soln)</th>
<th>Iodine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sterilization</strong></td>
<td>30 min @ 20°C</td>
<td>20 min @ 30°C</td>
<td>5 min @ 40°C</td>
<td>5 min @ 30°C</td>
</tr>
<tr>
<td><strong>Shelf life</strong></td>
<td>6 hrs @ 20°C</td>
<td>10 hrs @ 30°C</td>
<td>10 min @ 40°C</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Reuse life</strong></td>
<td>2 yrs</td>
<td>2 yrs</td>
<td>6 mon</td>
<td>1 yr</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>Eye irritant</td>
<td>Respiratory irritant</td>
<td>Significant eye and skin irritant</td>
<td>Relatively safe as povidone form</td>
</tr>
</tbody>
</table>
Novel Technologies

Ultraviolet (UV) Radiation

UV radiation consists of wavelengths from 328 nanometers (nm) to 210 nm, with greatest bactericidal effect in the 240 nm to 280 nm range. It causes thymine molecules in DNA to dimerize, thereby rendering bacteria unable to replicate. This method has been used in the disinfection of air, and has been shown to quickly (within 15 minutes) and substantially reduce the amounts of several dangerous pathogens on surfaces of hospital rooms (Rutala, 2010). Other advantages include its relatively low cost, low energy expenditure, and small size. One drawback is that bacteria in small cracks of surgical equipment can be shaded from the UV rays. Also, several health risks are associated with excessive UV exposure, including cutaneous malignancies and eye diseases (Gallagher, 2006).

Ozone

Current ozone sterilization processes use oxygen and water to create ozone radicals inside a chamber and kill pathogens at 30°C after an exposure of 4.5 hours (Rutala, 2011). Ozone can achieve sterilization-level decontamination. It operates at low temperatures and the current devices using it reduce the ozone molecules after use, rendering them innocuous. Penetration through tissue on medical instruments is still an unsolved issue, and there is limited scientific data supporting ozone effectiveness.

Exposure

Given the extreme heat and cold and UV radiation present outside of spacecraft, it would be possible to sterilize materials through exposure. Spacesuits are sometimes positioned in sun exposed areas to “bake” and clean the suit. Similarly, extremes of heat and cold could be accessed if there was no potential damage to the materials. However, areas of shade in the process or device can reduce the effectiveness of exposure.

Summary

Disinfection can be applied to medical equipment and tools and reduce the risk of infection from contamination by infectious agents. The necessary level of disinfection is determined by risk tolerance and the intended use of the medical equipment. Sterilization can be achieved with steam and maybe a potential asset for exploration missions where medical equipment is reused. However, this effective ground-based sterilization technique needs to be validated in microgravity. Other modalities of disinfection do exist and similarly need to be considered from an engineering feasibility standpoint in conjunction with medical operations given the tradeoffs in effectiveness described above.
References


## Disinfection of Medical Equipment for Exploration Missions: An Assessment of Necessity and Modalities

**AUTHOR(S):**
Aaron Harman, Anil Menon, Sharmila Watkins

**PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES):**
Lyndon B. Johnson Space Center
Houston, Texas  77058

**SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES):**
National Aeronautics and Space Administration
Washington, DC  20546-0001

**ABSTRACT**
Equipment sterilization is widely accepted as a critical component of any surgical procedure and is necessary for mitigating infection, morbidity, and mortality. Spacecraft environments are not sterile environments and may harbor pathogens; therefore, there is a need for disinfection if medical equipment is to be used more than once. In planning for surgical procedures in space flight, it is important to consider tools and procedures in relation to their intended purpose, risk of pathogen transmission, and ideal level of disinfection to determine disinfection requirements. Currently, there are no reports of in-flight surgical emergencies requiring invasive surgical equipment for treatment—as defined by a de novo break of physiologic barrier of sterility. However, catheters have been used in-flight to treat urinary retention. Catheter use can potentially cause a urinary tract infection, and a catheter being used more than once would benefit from disinfection. Ultrasound use and dental emergencies have necessitated use of semi-invasive equipment on the International Space Station. This gap report explores various technologies that can facilitate disinfection of invasive medical equipment for use onboard spacecraft.