# A 3D-Printed Portable Sterilizer to Be Used During Surgical Procedures in Spaceflight

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**INTRODUCTION:** During spaceflight, it is important to consider the mechanisms by which surgeries and medical procedures can be safely and efficiently conducted. Instruments used to carry out these processes need to be sterilized. Thus, we have designed and tested a three-dimensional-printed (3D-printed) portable sterilizer that implements far ultraviolet-C (Far UV-C) light radiation to disinfect bacteria and microorganisms from surgical instruments.

**METHODS:** The sterilizer was 3D-printed with polylactic acid filament. Effectiveness was assessed through three trials at differing times of sterilization and compared against a control group of no sterilization and against Clorox wipes. Cultures were incubated on agar dishes and counted with ImageJ.

**RESULTS:** Increasing time under Far UV-C light radiation increased the percentage of sterilization up to 100% at 10 min. The 3D-printed sterilizer was significantly better than Clorox wipes and control.

**DISCUSSION:** As sterilization will be necessary for surgical procedures in microgravity and upmass is a significant concern, we have successfully demonstrated a 3D-printable portable sterilizer for surgical instruments that achieves 100% success in using Far UV-C light to disinfect its surface of bacteria with a 10-min sterilizing time. Further research is necessary to test this design in microgravity and with differently sized and shaped instruments.

**KEYWORDS:** 3D-printing, sterilizer, medical, space.

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With increased numbers of people traveling further from Earth, the risk of medical events requiring procedures increases. During long-duration spaceflight, humans may experience trauma, infections, and medical emergencies, which can threaten the lives of crewmembers and result in loss of mission.[4] As a result of this, it is critical to consider the mechanisms by which individuals in space can undergo medical or surgical procedures as needed. Not only must qualified medical personnel be available to perform procedures,[8] but appropriate equipment and instruments must also be available. Thus, a medical infrastructure should be thoroughly developed to promote successful medical care during spaceflight.[3,10,18]

A variety of studies have demonstrated the feasibility of conducting surgical procedures in the simulated microgravity environment and in spaceflight, with most existing and future spacecrafts having sufficient volumes to allow providers to perform procedures.[3,9] Successful procedures in space will require sterile equipment. Although there has been research investigating the microbiome of space and spacecrafts,[1,2,6] this has not focused on in-flight sterilization of the equipment necessary for successful execution of invasive medical and surgical procedures.

The ability to sterilize instruments is crucial in preventing surgical site infections and other life-threatening surgical and postsurgical complications, such as microbial contamination and disease transmission.[12] This is likely to be just as true in space as it is on Earth.[16] Even storing instruments outside the habitat may not be sufficient since bacterial spores have been shown to survive in space.[5] Traditional autoclaves weigh up to

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454 kg and can be very large, some comparable to the size of a semitruck or airplane.[19] A medical grade autoclave can use up to 300 gal of water a day and up to 222 kW/day during high-usage periods.[17] Given the habitable volume limits of space vehicles and the energy requirements of lifting mass into space, mission planners must carefully ration the available mass, volume, and energy expenditures of the spacecraft. This is especially true in the packaging of additional contingency equipment (such as those used to treat unplanned health incidents) which should be small and light enough to not interfere with crucial mission objectives and equipment.

One solution is to hold high-mass equipment in digital stasis using weightless electronic files, which can be converted into physical instruments and equipment using three-dimensional (3D) printers. This allows a limited mass of material to be converted to a variety of purposes on demand. On missions with small crews, limited resources, and tight timelines, one must also consider the operating cost of the medical system for aspects of the mission itself.[13] The primary advantage of 3D-printing for space missions is localized manufacturing.[6] It appears to be a promising modality to provide surgical resources in space and other remote environments.[21] 3D-printing can be used to turn weightless electronic files into surgical and medical instruments that can be safely used during spaceflight. In addition, 3D-printer filament can be recycled and reused, allowing a limited supply of filament to be even more useful.[14] 3D-printed products are reusable and can be used on-demand. Their ability to be regenerated is cost-effective and provides an environmentally friendly edge, while their ability to be used on-demand increases accessibility and time-efficiency.

3D printers have been successfully used in space and are a promising technology to enable crews to "carry" contingency equipment, such as spare parts and medical instruments, without sacrificing critical mass and volume needed to support the primary mission objectives. This paper demonstrates that this technology can be applied to sterilization equipment and provides a digital template for such equipment. In 2014, from a collaboration between NASA and Zero-G technology, a 3D printer was used for the first time to successfully print an object aboard the microgravity environment of the International Space Station, using ground controllers to send and adjust printing files.[7] This groundbreaking event has opened the door to expand the use of 3D printers into space to create surgical instruments without affecting speed or performance of procedures.[20] Having a 3D-printing device that can function in the conditions of space and create its own maintenance parts, surgical equipment, and a machine that can sterilize those instruments will revolutionize medical treatment in space as it creates an endless reservoir of supplies. Many limitations of medical care in space, such as malfunctioning parts or contaminated fields/tools, would be eliminated, thus allowing for timely medical care and treatment. Its portability, ability to be controlled remotely, and localized and additive manufacturing gives 3D printers a primary advantage over other modes of engineering both for medical and nonmedical needs during spaceflight.

## METHODS

A portable sterilizer, shown in **Fig. 1**, was developed for use with far ultraviolet-C (Far UV-C) light-emitting diode (LED) lights during spaceflight with Autodesk Fusion 360 and printed with polylactic acid filament to provide stability and durability. The device includes a base, rear support post, and an overhang on which the Far UV-C LED lights are placed. These lights, when activated, illuminate the surface of the base, thus sterilizing any instrument that is placed on it. Objects required beyond polylactic acid filament (1 kg, 160 $in^3$) include the 3D printer itself (7.3 kg, 738 $in^3$), 15 Far UV-C LED lights, solder lead, wire, and a flux pen with soldering station. Following 3D-printing of the sterilizer, the Far UV-C LED lights will need to be assembled to the inside of the overhang using the solder lead, wire, and flux pen from the soldering station. If soldering is not feasible, Far UV-C LED lights with wire legs can be used in assembly with the wire. The total mass and volume required to store this equipment prior to assembling is approximately 19.8 kg and approximately 5.9 $ft^3$, respectively. Following assembly, the overall height of the sterilizer is 4.0 in. The overall length is 8.0 in. The overall width is 5.0 in. The height of the overhang is 1.0 in, and the height of the rear support post is 2.0 in. The height of the base is 1.0 in, and the width of its side is 0.5 in. The height of the sides of the base is 0.5 in.

The 3D-printed portable sterilizer was tested against Clorox Disinfecting Wipes, a leading commercial disinfectant brand, as shown in **Table I**. To assess the sterilizer for its effectiveness in killing bacteria, bacterial swabbing and culture growth on agar plates via incubation was performed.

The study was conducted in a series of three trials, each utilizing a different duration of Far UV-C LED light activation (3 min, 6 min, and 10 min). Each of the three trials was separated into three tests to ensure accuracy and realistic results. The study design included two controls, one of which was the number of

**Fig. 1.** Original sterilizer 3D-printed via the Autodesk Fusion 360 program.

**Table I.** Comparison Between Properties of 3D-Printed Sterilizer, a Traditional Autoclave, and Clorox Disinfecting Wipes.

| DEVICE | MASS (kg) | VOLUME ($ft^3$) | POWER REQUIRED (kw) | EFFICACY | LIFESPAN (yr) |
|---|---|---|---|---|---|
| 3D-Printed Portable Sterilizer | 0.32 (fully assembled) | 0.09 | ∼0.038 | Sterilization of bacteria up to 100% within 10 min | ∼36 |
| Traditional Autoclave | ∼500 | Up to 200 | ∼30 | Sterilization of microorganisms up to 100% within 6 min | 30+ |
| Clorox Disinfecting Wipes | ∼2.6 | 0.20 | None | Disinfection of viruses and bacteria up to 99.9% within 10 s | 1 |

bacterial colonies on the surface of the sterilizer base without having activated the Far UV-C LED lights. The second control was the percentage of bacterial colonies killed from the surface of the sterilizer base after applying Clorox Disinfecting Wipes. This percentage was obtained by initially swabbing the surface of the sterilizer base and incubating a petri dish with agar of the sample in an incubator at 37°C. Once incubated for 48 h, the colonies grown on the dish were counted using ImageJ and recorded. This process was repeated after Clorox Disinfecting Wipes were used to clean the surface of the sterilizer base, and the colonies grown on the dish were counted using ImageJ and recorded. These values, obtained before and after applying Clorox Disinfecting Wipes, were used to calculate a percentage of bacteria killed, thus determining the effectiveness of the Clorox Disinfecting Wipes for that trial.

The rest of the trials consisted of recording the number of bacterial colonies on each dish before and after activating the Far UV-C LED lights for a total of 3 min, 6 min, then 10 min. These numbers obtained were converted to percentages of change to best depict the effectiveness of the sterilizer at various durations of application.

## RESULTS

Our results in **Fig. 2** showed that Clorox wipes, when used as a sterilizing agent during three different trials, had a percentage change of 99.37%, 75.86%, and 100% when measuring residual bacterial growth, with an average kill percentage of 91.54%. When using Far UV-C LED lights as a sterilizing agent for a period of 3 min, it had a percentage change in bacterial growth of 97.37%, 100%, and 99.16% when measuring residual bacterial growth, with an average kill percentage of 98.84%. When using Far UV-C LED lights as a sterilizer for a period of 6 min, it had a percentage change of 100%, 100%, and 97.23%, with an average kill percentage of 99.08%. When Far UV-C LED was allowed to operate for 10 min, the percentage change was noted to be 100%, 100%, and 100%, with an average kill percentage of 100% [analysis of variance $P < 0.0001$, degrees of freedom 14 (between groups 4; within groups 10)].

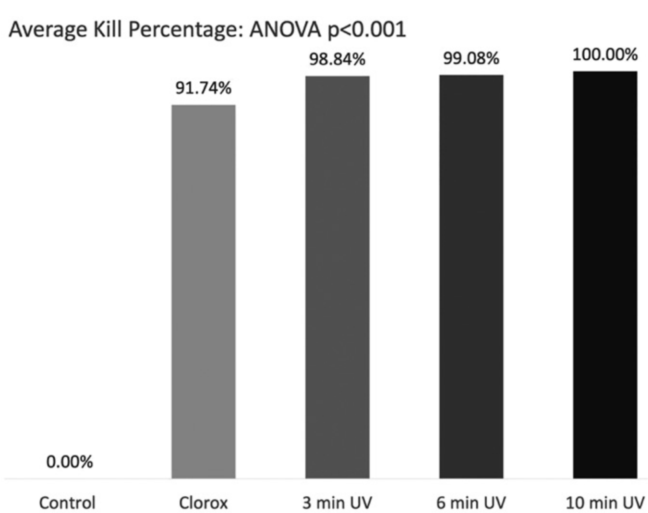


**Fig. 2.** Average kill percentage of controls and each UV duration.

## DISCUSSION

To address the need for a low-mass, low-volume, energy-effective, and accessible medical sterilization instrument in space, we have designed and tested the efficacy of a 3D-printed sterilizer in eliminating bacteria that could otherwise be harmful to spacecraft crew members. This sterilizer, in contrast with a traditional autoclave, only requires 0.038 kW of electricity to function. Its mass and volume are 0.032 kg and 0.09 $ft^3$, respectively. The minimal weight and size of the sterilizer allow for convenient application in spaceflight. Sterilization, as opposed to disinfection, completely eliminates all forms of microbial life, whereas disinfection eliminates vegetative forms of microorganisms with the exception of bacterial spores from inanimate objects.[15] Medical devices that enter sterile environments, such as surgical tools, need to be sterilized, rather than simply disinfected by means of disinfectant wipes/solutions. Additionally, this portable sterilizer proposes more value than sealed, presterilized equipment,[11] as it allows for repeated use in both a time- and resource-conservative fashion while still maintaining a high level of sterilization.

With the continued advancement in space technology, spaceflight missions are becoming longer and humans are traveling further from Earth. With this, the odds of running into a medical emergency that may warrant surgical intervention increase. Prior studies have shown both the spatial[8] and technical feasibility to perform surgery in space. We aimed to demonstrate that proper sterilization can also be adequately executed in a cost-efficient, timely manner using a 3D-printed device. Our sterilization device was able to kill 100% of bacteria after 10 min. The lifespan of the LEDs allows for approximately 52,560 sterilization cycles. Assuming the sterilizer is used to conduct 4 sterilizations per day, every day, its lifespan will last 36 yr. These results show the viability of a 3D-printed device and associated electrical components to help crewmembers eliminate potentially harmful bacteria from medical and surgical instruments for time-sensitive operations and procedures in space.

There are several limitations worth noting. First, the data collected was not bacteria-specific and did not test the effectiveness of the sterilizer on spores, fungus, or viral pathogens. Future studies with this device will need to investigate its effectiveness against spore-forming bacteria and other pathogens known to be a risk in spaceflight. Another practical consideration is that we did not test the sterilizer in microgravity. Related to this is the need to confirm that the device itself could be printed in microgravity since the absence of a constant directional force can interfere with the structural integrity of items being printed. Further, it is important to consider the number of UV LEDs in relation to efficiency. While this study was conducted using 21 LEDs and obtained 100% effectiveness within 10 min, additional testing could be done with increasing and decreasing the number of LEDs used to determine if there is a correlation between the number of LEDs and duration of time it takes to obtain a 100% disinfection rate and thus improve cost and efficiency. It is also unclear whether this sterilizer would be effectively able to sterilize instruments with crevasses or channels where the UV light would not effectively penetrate and is another area that could be further tested.

In conclusion, we have successfully demonstrated on a small scale the ability to create a device using 3D-printing and UV LEDs that can effectively sterilize surgical instruments. This device could easily be made in situ on a spacecraft with minimal upmass, allowing the performance of sterile surgical procedures to take place within a spacecraft environment. Future work will focus on addressing the limitations outlined above.

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