

Journal of Visualized Experiments

Cefoperazone treated mouse model of clinically relevant Clostridium difficile strain R20291 --Manuscript Draft--

Manuscript Number:	JoVE54850R1
Full Title:	Cefoperazone treated mouse model of clinically relevant Clostridium difficile strain R20291
Article Type:	Invited Methods Article - JoVE Produced Video
Keywords:	Clostridium difficile; mouse model; antibiotic; colonization; cytotoxicity; histology; inflammation; Vero cells
Manuscript Classifications:	2.3.130: Bacteria, Anaerobic; 2.3.510.415.400: Gram-Positive Endospore-Forming Rods; 2.3.510.415.400.200: Clostridium; 3.1.252: Bacterial Infections; 3.6.405: Gastrointestinal Diseases
Corresponding Author:	Casey M. Theriot, PhD North Carolina State University Raleigh, NC UNITED STATES
Corresponding Author Secondary Information:	
Corresponding Author E-Mail:	cmtherio@ncsu.edu
Corresponding Author's Institution:	North Carolina State University
Corresponding Author's Secondary Institution:	
First Author:	Jenessa A. Winston, DVM, Dipl. ACVIM (Small Animal Internal Medicine)
First Author Secondary Information:	
Other Authors:	Jenessa A. Winston, DVM, Dipl. ACVIM (Small Animal Internal Medicine) Rajani Thanissery, DVM, PhD Stephanie A. Montgomery, PhD, DVM, Dipl. ACVP
Order of Authors Secondary Information:	
Abstract:	Clostridium difficile is an anaerobic, gram positive, spore forming enteric pathogen that is associated with increasing morbidity and mortality consequently posing an urgent threat to public health. Recurrence with C. difficile infection (CDI) after successful treatment with antibiotics is high, occurring in 20-30% of patients, thus necessitating discovery of novel therapeutics against this pathogen. Current animal models of CDI result in high mortality rates and thus do not approximate the chronic insidious disease manifestations seen in humans with CDI. To evaluate therapeutics against C. difficile a mouse model approximating human disease utilizing a clinically relevant strain is needed. This protocol outlines the cefoperazone mouse model of CDI using a clinically relevant and genetically tractable strain, R20291. Techniques for clinical disease monitoring, C. difficile bacterial enumeration, toxin cytotoxicity, and histopathologic changes throughout CDI in a mouse model are detailed in the protocol. Compared to other mouse models of CDI, this model is not uniformly lethal at the dose administered, allowing for observation of a prolonged clinical course of infection concordant with human disease. Therefore, this cefoperazone mouse model of CDI proves a valuable experimental platform to assess effects of novel therapeutics on amelioration of clinical disease and restoration of colonization resistance against C. difficile.
Author Comments:	We have several items that we would like to include for the reader at the end of the protocol. * Vero Cell Calculation Worksheet * Example Calculations * Media Recipes (TCCFA and 1X DMEM)

	There was not a section to upload these, so we loaded them as supplements. Please let us know if you have any questions.
Additional Information:	
Question	Response
If this article needs to be "in-press" by a certain date to satisfy grant requirements, please indicate the date below and explain in your cover letter.	



College of Veterinary Medicine
Department of Population Health and Pathobiology
<https://cvm.ncsu.edu/research/departments/dphp/>

Campus Box 8401
1060 William Moore Drive
Raleigh, NC 27607
P: 919.513.6240
F: 919.513.6464

July 8, 2016

Avital Braiman, PhD
Director of Editorial of *JoVE*
One Alewife Center, Suite 200
Cambridge, MA 02140

Dear Dr. Braiman,

Enclosed, please find our revised manuscript (JoVE54850) entitled "Cefoperazone treated mouse model of clinically relevant *Clostridium difficile* strain R20291" that we are submitting for consideration for publication in *JoVE*. We have addressed all the reviewers' comments in the attached "Rebuttal Comments" section.

Clostridium difficile is an anaerobic, gram positive, spore forming enteric pathogen that is associated with increasing morbidity and mortality consequently posing an urgent threat to public health. Recurrence with *C. difficile* infection (CDI) after successful treatment with antibiotics is high, occurring in 20-30% of patients, thus necessitating discovery of novel therapeutics against this pathogen. Current animal models of CDI result in high mortality rates and thus do not approximate the chronic insidious disease manifestations seen in humans with CDI. To evaluate therapeutics against *C. difficile* a mouse model approximating human disease utilizing a clinically relevant strain is needed. This protocol outlines the cefoperazone mouse model of CDI using a clinically relevant and genetically tractable strain, R20291. Techniques for clinical disease monitoring, *C. difficile* bacterial enumeration, toxin cytotoxicity, and histopathologic changes throughout CDI in a mouse model are detailed in the protocol.

Successful execution of a murine model of CDI is challenging. Researchers struggle with certain aspects of CDI the mouse model and *JoVE* provides an excellent format to clarify some of the challenges researchers can encounter. In particular, we are interested in highlighting the most challenging and critical steps of the mouse model using *JoVE*'s video production including: calculation of the inoculum of *C. difficile* spores administered to mice, sterile collection of mouse feces, feces and cecal content bacterial enumeration of *C. difficile*, and completion of the Vero cell cytotoxicity assay.

This manuscript would be the first that fully details all steps of the mouse model of CDI using a clinically relevant strain. Compared to other mouse models of CDI, this model is not uniformly lethal at the dose administered, allowing for observation of a prolonged clinical course of infection concordant with human disease. Therefore, this cefoperazone mouse model of CDI proves a valuable experimental platform to assess effects of novel therapeutics on amelioration of clinical disease and restoration of colonization resistance against CDI. We anticipate that researchers interested in *C. difficile* pathogenesis and the development of novel therapeutics against *C. difficile* would greatly benefit from the protocol outlined in this manuscript.

This manuscript is the product of the team and all authors made substantial contributions to the conceptualization, acquisition, and interpretation of the data presented in this protocol. In addition, all authors contributed to the preparation of this manuscript for submission.

Thank you again for your consideration and I look forward to your response.

Sincerely,

Casey M. Theriot, Ph.D.
Assistant Professor Infectious Disease
College of Veterinary Medicine
Department of Population Health and Pathobiology
North Carolina State University
cmtherio@ncsu.edu

Potential Peer Reviewers:

Vincent Young, MD/PhD
University of Michigan, Department of Internal Medicine/Infectious Disease
youngvi@umich.edu

Anna Seekatz, PhD
University of Michigan, Department of Internal Medicine/Infectious Disease
aseekatz@med.umich.edu

Xinhua Chen, PhD
Beth Israel Deaconess Medical Center Harvard Medical School
xchen1@bidmc.harvard.edu

Sarah Kuehne, PhD
The University of Nottingham
sarah.kuehne@nottingham.ac.uk

Xingmin Sun, PhD
University of South Florida, College of Medicine, Internal Medicine and Molecular Medicine
sun5@health.usf.edu

David Aronoff, MD, FIDSA
Vanderbilt University Medical Center
d.aronoff@vanderbilt.edu

TITLE:

Cefoperazone-treated mouse model of clinically-relevant *Clostridium difficile* strain R20291

AUTHORS:

Winston, Jenessa A.

Department of Population Health and Pathobiology
North Carolina State University College of Veterinary Medicine
Raleigh, NC USA
jenessa_winston@ncsu.edu

Thanissery, Rajani

Department of Population Health and Pathobiology
North Carolina State University College of Veterinary Medicine
Raleigh, NC USA
rthanis@ncsu.edu

Montgomery, Stephanie A.

Department of Pathology and Laboratory Medicine
Lineberger Comprehensive Cancer Center
University of North Carolina School of Medicine
Chapel Hill, NC USA
stephanie_montgomery@med.unc.edu

Theriot, Casey M.

Department of Population Health and Pathobiology
North Carolina State University College of Veterinary Medicine
Raleigh, NC USA
cmtherio@ncsu.edu

CORRESPONDING AUTHOR:

Theriot, Casey M.

KEYWORDS:

Clostridium difficile; mouse model; antibiotic; colonization; cytotoxicity; histology; inflammation; Vero cells

SHORT ABSTRACT:

This protocol outlines the cefoperazone mouse model of *Clostridium difficile* infection (CDI) using a clinically-relevant and genetically-tractable strain, R20291. Emphasis on clinical disease monitoring, *C. difficile* bacterial enumeration, toxin cytotoxicity, and histopathological changes throughout CDI in a mouse model are detailed in the protocol.

LONG ABSTRACT:

Clostridium difficile is an anaerobic, gram-positive, spore-forming enteric pathogen that is associated with increasing morbidity and mortality and consequently poses an urgent threat to public health. Recurrence of a *C. difficile* infection (CDI) after successful treatment with antibiotics is high, occurring in 20-30% of patients, thus necessitating the discovery of novel therapeutics against this pathogen. Current animal models of CDI result in high mortality rates and thus do not approximate the chronic, insidious disease manifestations seen in humans with CDI. To evaluate therapeutics against *C. difficile*, a mouse model approximating human disease utilizing a clinically-relevant strain is needed. This protocol outlines the cefoperazone mouse model of CDI using a clinically-relevant and genetically-tractable strain, R20291. Techniques for clinical disease monitoring, *C. difficile* bacterial enumeration, toxin cytotoxicity, and histopathological changes throughout CDI in a mouse model are detailed in the protocol. Compared to other mouse models of CDI, this model is not uniformly lethal at the dose administered, allowing for the observation of a prolonged clinical course of infection concordant with the human disease. Therefore, this cefoperazone mouse model of CDI proves a valuable experimental platform to assess the effects of novel therapeutics on the amelioration of clinical disease and on the restoration of colonization resistance against *C. difficile*.

INTRODUCTION:

Clostridium difficile is an anaerobic, gram-positive, spore-forming bacillus that causes life-threatening diarrhea¹. *C. difficile* infection (CDI) is associated with increased human morbidity and mortality and results in over \$4.8 billion in healthcare costs per year¹⁻⁴. In 2013, the Centers for Disease Control and Prevention categorized *C. difficile* as an urgent antibiotic resistance risk, indicating that it poses an urgent threat to public health¹. Currently, antibiotic treatment with vancomycin and metronidazole are considered the standard of care for CDI⁵. Unfortunately, recurrence of CDI after successful treatment with antibiotics is high, occurring in 20-30% of patients^{2,5-7}. Therefore, the discovery of novel therapeutics against this enteric pathogen is necessary. To evaluate therapeutics against *C. difficile*, an animal model approximating the human disease in a clinically-relevant strain is needed.

Initially, Koch's postulates were established for *C. difficile* in 1977 using a clindamycin-treated Syrian hamster model⁸. This model is still utilized today to investigate the effects of *C. difficile* toxins on pathogenesis^{9,10}. However, CDI in the hamster model results in high mortality rates and does not approximate the chronic insidious disease manifestations that can be seen in humans with CDI^{10,11}. Based on the accessibility and reagent availability of murine platforms in research, a mouse model of CDI is relevant.

In 2008, a robust mouse model of CDI was established by treating mice with an antibiotic cocktail in drinking water (kanamycin, gentamicin, colistin, metronidazole, and vancomycin) for 3 days followed by an intraperitoneal injection of clindamycin¹². This rendered mice susceptible to CDI and severe colitis. Depending on the inoculum dose administered, a range of clinical signs and lethality can be observed using this model. Since this time, various antibiotic regimens have been investigated that alter the murine gut microbiota, decreasing colonization resistance to the point where *C. difficile* can colonize the gastrointestinal tract (reviewed in Best *et al.* and

Lawley & Young)^{13,14}.

More recently, a broad spectrum cephalosporin, cefoperazone, given in the drinking water for 5 or 10 days reproducibly renders mice susceptible to CDI¹⁵. Since administration of third-generation cephalosporins are associated with an increased risk of CDI in humans, use of the cefoperazone model more accurately reflects naturally-occurring disease¹⁶. Cefoperazone-treated mice susceptible to *C. difficile* have been challenged with both *C. difficile* spores and vegetative cells of a variety of strains ranging in clinical relevance and virulence¹⁷. Despite some of the original studies utilizing *C. difficile* vegetative cells as the infectious form, *C. difficile* spores are considered the major mode of transmission¹⁸.

In the last decade, *C. difficile* R20291, a NAP1/BI/027 strain, has emerged, causing epidemics of CDI^{19,20}. We sought to determine the clinical course of disease when cefoperazone-treated mice were challenged with the clinically-relevant and genetically-tractable *C. difficile* strain, R20291. This protocol details the clinical course, including weight loss, bacterial colonization, toxin cytotoxicity, and histopathological changes in the gastrointestinal tract of mice challenged with *C. difficile* R20291 spores. Overall, this mouse model proves to be a valuable experimental platform for CDI approximating human disease. This characterized mouse model can thus be utilized to assess the effects of novel therapeutics on the amelioration of clinical disease and on the restoration of colonization resistance against *C. difficile*.

PROTOCOL:

Ethical Statement:

The Institutional Animal Care and Use Committee (IACUC) at North Carolina State University College of Veterinary Medicine (NCSU) approved this study. The NCSU Animal Care and Use policy applies standards and guidelines set forth in the Animal Welfare Act and Health Research Extension Act of 1985. Laboratory animal facilities at NCSU adhere to guidelines set forth in the *Guide for the Care and Use of Laboratory Animals*. The animals' health statuses were assessed daily, and moribund animals were humanely euthanized by CO₂ asphyxiation followed by secondary measures. Trained animal technicians or a veterinarian performed animal husbandry in an AAALAC-accredited facility during this study.

1. Administration of the antibiotic cefoperazone in drinking water to achieve susceptibility to *C. difficile* colonization and disease

NOTES: 5- to 8-week-old C57BL/6 WT mice (females and males) were purchased and quarantined for 1 week prior to starting the antibiotic water administration. Following quarantine, the mice were housed with autoclaved food, bedding, and water. Cage changes were performed weekly by laboratory staff in a laminar flow hood.

1.1) Prepare cefoperazone (0.5 mg/mL) in sterile distilled water 7 days prior to the targeted day of challenge (Figure 1).

1.2) Fill autoclaved water bottles with cefoperazone water (0.5 mg/mL) and place them in each mouse cage.

NOTE: Freshly-prepared cefoperazone water should be made and changed out every 2 days during a 5-day period, as denoted in steps 1.1 and 1.2. Proper disposal of cefoperazone water following institutional environmental health and safety guidelines is recommended.

1.3) After 5 days on cefoperazone water, replace the bottles with autoclaved water bottles filled with sterile distilled water. Give mice this drinking water for the duration of the experiment.

2. Preparation of the *C. difficile* spore inoculum and the oral gavage of the mice

NOTE: Before beginning, ensure that the following items are placed in the anaerobic chamber for at least 24 h: 1X phosphate-buffered saline (PBS; see Materials), taurocholate cycloserine cefoxitine fructose agar (TCCFA) plates (see Materials and the supplemental file), and a sterile L-shaped spreader.

NOTE: Mice challenged with *C. difficile* spores should be housed in a Biosafety Level 2 animal facility.

2.1) Obtain a *C. difficile* spore stock of the desired strain (in this case, R20291) that was prepared earlier and stored at 4 °C in sterile water^{21,22}. Determine the enumeration of this spore stock prior to use.

2.2) Based on the known concentration (spores/mL) of the spore stock, calculate the desired dilution to obtain 10⁵ spores per 25 µL. Ensure the inoculum volume is adequate to inoculate all mice in the experiment (25 µL per mouse), to perform the enumeration of the inoculum (approximately 30 µL), and to account for pipetting error.

2.3) Vortex the original *C. difficile* spore stock. Then, resuspend the calculated volume (from step 2.2) of the original *C. difficile* spore stock in sterile water within a screw-capped microcentrifuge tube. Perform this aerobically in a laminar flow hood. Identify this diluted mixture as the “spore inoculum.”

2.4) Place the spore inoculum into a 65 °C water bath and heat it for 20 min.

NOTE: This step will ensure that only active *C. difficile* spores remain after the heat treatment.

2.5) Within the laminar flow hood, take 50 µL of heated spore inoculum, place it in a sterile microcentrifuge tube, and pass it into the anaerobic chamber²³. Use this sample for spore enumeration.

2.6) Within the laminar flow hood, load the remaining heated spore inoculum into a 1-mL syringe attached to a sterile bulb-tipped gastric gavage needle. Utilize a manual syringe stepper to ensure accurate and rapid repeat dosing between mice. Ensure that the gavage needle is filled with the heated spore inoculum prior to use.

NOTE: A new sterile gavage needle for each mouse is not required. However, if various doses of *C. difficile* spores are administered, a new gavage needle is recommended for each dose.

NOTE: *C. difficile* spores are highly resistant to traditional disinfectants. Therefore, the use of a sporicidal disinfectant, such as #62 Perisept Sporicidal Disinfectant, is necessary. The manufacturer recommends a 2-min contact time to destroy *C. difficile* spores.

2.7) Gavage each mouse with 25 µL of the spore inoculum. Restrain each mouse gently by grasping the animal by the loose skin of the neck and back in order to immobilize the head. Using the index finger further immobilize the animal's head and to elongate the esophagus. Ensure that the animal does not vocalize or show other signs of distress during restraint.

NOTE: The total volume given to mice by gavage should not exceed 10 mL/kg bodyweight (0.1 mL/10 g).

2.8) Maintain the mouse in an upright, vertical position and gently pass the gavage needle into the side of the mouth. Direct the gavage needle along the roof of the mouth and slowly advance the gavage needle into the esophagus.

NOTE: If any resistance is encountered, the gavage needle may be entering into the trachea and thus should NOT be advanced, but rather removed and repositioned immediately.

2.9) After the gavage needle is approximately halfway into the esophagus, inject 25 µL of the heated spore inoculum and gently withdraw the gavage needle from the esophagus.

NOTE: Forceful advancement of the gavage needle may lead to the rupture of the esophagus or stomach. Therefore, if resistance is encountered when advancing the gavage needle, it is best to immediately remove and reposition the gavage needle.

2.10) Return the animal to its cage and observe it for any coughing or signs of respiratory distress, as this may indicate inadvertent tracheal administration or aspiration of the heated spore inoculum.

NOTE: Mice are extremely susceptible to *C. difficile* following antibiotic treatment; therefore, precautions to prevent cross-contamination between cages is essential. This is especially important when managing antibiotic-treated but unchallenged mice as controls.

2.11) After inoculating all mice, place the remaining heated spore inoculum into a sterile microcentrifuge tube and pass it into the anaerobic chamber for spore enumeration.

2.12) For enumeration of the heated spore inoculum (from step 2.4) and the remaining gavaged heated spore inoculum, make 1:10 serial dilutions of each inoculum in 1X PBS. It is recommended to make and plate 4-5 dilutions (*i.e.*, 10^{-1} through 10^{-5}).

2.13) Using aseptic technique, transfer 100 µL of each serial dilution onto an individual TCCFA plate.

2.14) Using a sterile L-shaped spreader, evenly spread the dilution applied to the medium across the plate. Even spreading of the diluted inoculum is essential for the accurate enumeration of spores.

2.15) Incubate the plates anaerobically for 24 h at 37 °C. After 24 h, *C. difficile* colony-forming units (CFUs) can be enumerated to obtain the infective dose administered to mice in the 25 µL (0.025 mL) volume (see the supplemental file “Example Calculations”). *C. difficile* colonies are flat and pale yellow and have irregular edges and a ground glass appearance²⁴.

NOTE: The limit of detection for bacterial enumeration is 10² CFU.

3. Monitoring mouse weight loss and clinical signs of disease throughout *C. difficile* infection

3.1) Weigh animals before and after the 5-day cefoperazone antibiotic treatment, after the 2-day recovery off of antibiotics (day 0), and then for the duration of the experiment.

NOTE: Obtain weights at a consistent time each day. Weights obtained the day of challenge (day 0) should be used as the initial baseline weight for comparison throughout *C. difficile* infection.

3.2) Place a digital scale into a laminar flow hood. Place a sterile plastic beaker onto the scale and tare the weight of the plastic beaker. Then, gently pick up the mouse by the base of the tail and place it into the plastic beaker.

3.2.1) Place the beaker back on the scale. Hover a hand over the top of the beaker to ensure that the mouse does not escape. It may take 2-3 s to obtain a stable weight. Then, gently place the mouse back into its cage. Record this weight and repeat the process for each mouse in that cage.

NOTE: It is imperative that precautions are taken to prevent cross-contamination between cages when obtaining weights. Each cage of mice should have its own plastic beaker for weighing. The plastic beakers should be disinfected with a sporicidal agent between each use and covered with sterile aluminum foil.

3.3) Monitor the challenged animals twice daily (at a minimum) for signs of clinically-severe *C. difficile* infection, including lethargy, loss of appetite, diarrhea, and hunched posture.

3.4) Humanely euthanize animals that lose 20% of their initial baseline bodyweight and/or develop severe clinical signs of *C. difficile* infection (listed in step 3.3).

NOTE: Mice that display clinical signs of *C. difficile* infection should be weighed as needed during the experiment to ensure that they have not lost 20% of their initial baseline bodyweight. During early time points in the experiment, this might mean twice-daily measurements.

4. Bacterial enumeration of *C. difficile* from mouse feces and cecal content

NOTE: Before beginning, ensure that the following items are placed into the anaerobic chamber for at least 24 h: 1X PBS (see Materials), TCCFA plates (see Materials), a sterile L-shaped spreader, and sterile microcentrifuge tubes and/or PCR plates for dilutions.

4.1) Obtaining samples for *C. difficile* enumeration

NOTE: Prior to obtaining feces or cecal content, weigh sterile microcentrifuge tubes on an analytical scale. Record the tube weight on the side of the tube, rounding to four decimal places (e.g., 0.9864 g). Denote this weight as the “tube weight.” Each sample collected should be placed in a sterile, weighed microcentrifuge tube.

4.1.1) Sterile collection of mouse feces

4.1.1.1) Gently restrain each mouse by grasping the animal by the loose skin of the neck and back in order to immobilize the head. Use the pinky finger to gently restrain the animal’s tail, thus exposing the anus. Ensure that the animal does not vocalize or show other signs of distress during restraint.

4.1.1.2) Hold a sterile, weighed microcentrifuge tube directly under the animal’s anus. It is imperative that the tube does not come into direct contact with the mouse.

4.1.1.2.1) As the animal defecates, collect the fecal pellet into the tube. Keep the tube at room temperature until all fecal samples are collected. It can take several minutes for a mouse to defecate, thus necessitating repeat attempts to collect feces.

4.1.1.3) Weigh the tubes containing feces on the analytical scale. Record the tube weight, rounding to four decimal places (e.g., 1.0021 g). Denote the obtained weight as the “final tube weight.”

4.1.1.4) Pass the fecal samples into the anaerobic chamber for bacterial enumeration directly after stool collection.

4.1.2) Sterile collection of mouse cecal content at the time of necropsy

4.1.2.1) After humane euthanasia by CO₂ asphyxiation followed by secondary measures, perform a necropsy to obtain the cecum²⁵. The cecum is the large, comma-shaped section of the gastrointestinal tract.

4.1.2.2) Place the cecum onto a sterile plastic petri dish. Use a disposable, sterile no. 10 scalpel blade to cut the cecum open from the blind end of the pouch to expose the cecal contents.

4.1.2.2.1) Gently extract the cecal contents by applying light pressure with the scalpel blade and sweeping the contents toward the incised portion of the cecum.

NOTE: Care should be taken to not disrupt the cecal tissue, which will be submitted for histopathological examination.

4.1.2.3) Place the cecal contents into a sterile, weighed microcentrifuge tube immediately following collection. Only about 10 mg of cecal content is required for bacterial enumeration.

4.1.2.4) Weigh the tubes containing cecal content on the analytical scale. Record the tube weight, rounding to four decimal places (*e.g.*, 1.0021 g). Denote the obtained weight as the “final tube weight.”

4.1.2.5) Pass the cecal content samples into the anaerobic chamber for bacterial enumeration.

4.2) Bacterial enumeration of *C. difficile*

4.2.1) Calculate the final weight of the contents (feces or cecal) that will be enumerated for *C. difficile*. Performed this by subtracting the “final tube weight” from the “tube weight.”

4.2.2) Calculate a 1:10 dilution of the contents into 1X PBS and resuspend accordingly. For fecal pellets, use the tip of the pipette to gently disrupt the pellet into solution (see the supplemental file “Example Calculations”).

4.2.3) Anaerobically incubate these resuspended samples at room temperature for 30 min, allowing the contents to settle.

4.2.4) Make serial dilutions for each sample in 1X PBS for enumeration of the CFU per g of content (feces or cecal). Perform this anaerobically.

4.2.5) Using aseptic technique, transfer 100 µL of each serial dilution to TCCFA plates. Using a sterile L-shaped spreader, spread the dilution applied to the media to evenly spread it across the plate. Even spreading of the dilution is essential for accurate enumeration of colonies.

4.2.6) Incubate the plates anaerobically for 24 h at 37°C. At this time, enumerate *C. difficile* colonies to obtain the CFU per g of content (feces or cecal). *C. difficile* colonies are flat and pale yellow and have irregular edges and a ground glass appearance²⁴.

NOTE: This protocol can be used to enumerate *C. difficile* from other murine GI content, including ileal and colonic content. PCR plates can be used for making serial dilutions.

5. Vero cell cytotoxicity assay to quantify *C. difficile* toxin cytotoxicity

NOTE: It is recommended that this assay be performed after completion of the mouse model on samples collected at necropsy and stored at -80 °C. Aseptic cell culture techniques are essential for preventing contamination of Vero cells during this assay. This protocol takes 2 days

to perform. All feces and intestinal content utilized in this assay must be stored in a weighed, sterile microcentrifuge tube (denoted with the “tube weight,” see section above). The final tube weight (including the contents) is measured via an analytical scale to the nearest four decimal places (see section above). Use of a multi-channel pipette is recommended for this assay.

NOTE: Before beginning, ensure that the following items are available: Vero Cells, Dulbecco’s modification of Eagle medium (DMEM) 1X with 10% heat-inactivated fetal bovine serum (FBS) and 1% penicillin/streptomycin media (denoted as “DMEM 1X media;” see Materials and the supplemental file), 0.25% Trypsin-EDTA, 1X PBS, 0.4% Trypan Blue, a 96-well cell culture flat-bottom plate, a 96-well filter plate, *Clostridium difficile* Toxin A (aliquot in 3 µL at 1 µg/µL in Ultra-Pure water and store at -80 °C), *Clostridium difficile* Antitoxin, a worksheet (for calculations and plate maps; see supplemental files).

NOTE: Caution should be taken during this assay for personnel exposure to *C. difficile* and its toxin.

5.1) Splitting the Vero cells (day 1)

5.1.1) Preheat the DMEM 1X media, 0.25% Trypsin-EDTA, and 1X PBS in a 37 °C water bath.

5.1.2) Obtain a flask of Vero cells from the cell culture incubator (37 °C and 5% CO₂) and place it in the sterile cell culture laminar flow hood. Use 70% ethanol to wipe down the hood and equipment prior to use. Using a serologic pipette, aspirate the media from the tissue culture flask to remove it from the Vero cells and discard it into a waste container.

5.1.3) Rinse the Vero cells with 5 mL of 1X PBS (preheated) in the tissue culture flask. Aspirate the PBS and discard it into a waste container.

5.1.4) Add 5 mL of 0.25% Trypsin-EDTA to the tissue culture flask. Allow a contact time of 2-3 min. During this time, observe the cells begin to come off the flask surface. Gently rock the tissue culture flask side to side to loosen the Vero cells.

5.1.5) After contact time with Trypsin-EDTA, immediately add 5 mL of DMEM 1X media into the tissue culture flask. This will neutralize the Trypsin-EDTA. Use this solution to gently wash any unattached Vero cells off the back of the flask. Then, use a serological pipette to transfer this mixture into a 15-mL conical tube.

5.1.6) Centrifuge the Vero cells in the conical tube for 5 min at 180 x g and 25°C. Ensure that the centrifuge is properly balanced. After centrifuging, observe a visible pellet of Vero cells at the bottom of the conical tube. Be careful not to disrupt this pellet. Aspirate off the supernatant from the conical tube and discard it.

5.1.7) Resuspend the Vero cells in 3 mL of DMEM 1X media.

5.2) Counting the Vero cells

5.2.1) Add 100 μL of the Vero cell suspension (made in Step 5.1.7) to 100 μL of 0.4% Trypan Blue. Gently mix by pipetting the solution up and down.

5.2.2) Add 10 μL of this mixture to each chamber of a hemocytometer.

5.2.3) Count the number of viable cells within the four quadrants of the hemocytometer. Dead Vero cells will take up the Trypan Blue and thus will be stained blue (these cells should not be counted). Record these numbers in the "Vero Cell Worksheet," provided.

5.2.4) Sum the total number of viable Vero cells in all four quadrants and calculate the average. Multiply by the dilution factor, which is 2 since 100 μL of cells are in a total of 200 μL of liquid.

5.2.5) Multiply by the correction factor to give the "number of cells/mL." When using a hemocytometer, the correction factor is always 10^4 . Multiply by the total volume to give the "total number of cells."

5.3) Determining the number of wells required for each experiment

NOTE: A single sample (either feces or intestinal content) requires 24 separate wells to be performed in duplicate. A concentration of 10^5 Vero cells per well (total volume of 90 μL) is required.

NOTE: If one desires to incubate the Vero cell 96-well plates overnight at 37 °C, a concentration of 10^3 Vero cells per well is recommended to account for the extended incubation time. Calculations within the Vero Cell Worksheet would need to be adjusted to account for this change.

5.3.1) Determine the number of wells that can be utilized based on the amount of Vero cells available (from Step 5.2; use the Vero Cell Worksheet, provided).

5.3.2) Determine the volume of Vero cell suspension needed to fill the number of desired wells (based on the number of samples being tested). Ensure that any additional volume is added in to account for pipetting error (use the provided Vero Cell Worksheet).

5.3.3) Dilute the Vero cell suspension (obtained in Step 5.1.7) in DMEM 1X media to obtain the volume required for the experiment.

5.4) Seeding Vero cells into a 96-well cell culture plate

5.4.1) Using the Vero cell resuspension from Step 5.3.2, use a multi-channel pipette to add 90 μL of the Vero cell suspension to each well of a 96-well cell culture flat-bottom plate.

5.4.2) Incubate the plate with the Vero cells in a cell culture incubator at 37 °C and 5% CO_2 for a minimum of 4 h before adding toxin (samples) to the wells. This incubation time will allow the Vero cells to adhere to the bottom of each well.

5.5) Creating stock solutions from the samples (feces or intestinal content)

NOTE: All samples should have the “tube weight” and “final tube weight” measured via an analytical scale. Use Vero Cell Worksheet for calculations.

5.5.1) Calculate the weight of the contents. Convert g to mg, then mg to μL . Calculate the final total number of μL of solution needed to make a 1:10 dilution in 1X PBS. Calculate the total amount of 1X PBS to add to the sample.

5.5.2) Add the total volume of 1X PBS (calculated above) to the sample. Perform this aerobically, and using aseptic technique. For fecal pellets, use the tip of the pipette to gently disrupt the pellet into the solution.

5.5.3) Vortex the samples and then centrifuge them at $3,522 \times g$ for 5 min at room temperature. Ensure that the centrifuge is properly balanced. Be careful not to disrupt the pellet and resuspend the sample into solution.

NOTE: During Step 5.5.3, if only a few samples are being processed, contents can be sterilized by passing them through a single $0.22\text{-}\mu\text{m}$ filter instead of using a 96-well filter plate. Some samples may require multiple filters to sterilize the entire volume content using this technique.

5.5.4) Sterilize the sample/PBS mixture by taking $150 \mu\text{L}$ of supernatant and placing it into separate wells on a 96-well filter plate. Place the filter plate securely on top of a 96-well cell culture flat-bottom plate so that the contents will filter into this plate.

5.5.5) Centrifuge the filter plate/cell culture plate stack at $431 \times g$ for 5 min at room temperature. Ensure that the centrifuge is properly balanced and that the filter plate/cell culture plate stack are tightly aligned and will not shift during centrifugation.

NOTE: These filtered contents are the 10^{-1} stock that will be utilized in the dilution plates.

5.5.6) Place plate with filtered samples onto ice.

5.6) Creating Dilution Plate #1

NOTE: Dilution Plate #1 (DP#1) will require 6 wells per sample, including positive (*C. difficile* Toxin A) and negative (1X PBS) controls (see the DP#1 layout on the Vero Cell Worksheet).

5.6.1) To prepare the positive control (*C. difficile* Toxin A) for this assay, obtain $3\text{-}\mu\text{L}$ aliquots ($1 \mu\text{g}/\mu\text{L}$) from -80°C and add $297 \mu\text{L}$ of ultrapure water, yielding a final concentration of $0.01 \mu\text{g}/\mu\text{L}$. Place on ice.

5.6.2) Label the wells with their dilutions (10^{-1} to 10^{-6}) for each sample and indicate the positive and negative controls (see the DP#1 layout).

5.6.3) Add appropriate amounts of 1X PBS to each well. In the 10^{-1} wells, add **NO** PBS. For the

10^{-2} to 10^{-6} wells, add 90 μL of 1X PBS.

5.6.4) Add appropriate amounts of the samples to each well. In the 10^{-1} wells, add 100 μL of the 10^{-1} stock for each sample (see Step 5.5.7 from the filter plate). For the 10^{-2} to 10^{-6} wells, make serial dilutions; start by taking 10 μL from the 10^{-1} well and adding it to the 10^{-2} well. Continue the serial dilutions out to the 10^{-6} dilution.

5.6.5) Cover the DP#1 plate with a clear plastic adhesive seal and place it on ice.

5.7) Creating Dilution Plate #2

NOTE: Dilution Plate (DP#2) will require 2 lanes of 6 wells for each sample, including positive and negative controls (see the DP#2 layout on the Vero Cell Worksheet).

5.7.1) Label the wells with their dilutions (10^{-1} to 10^{-6}) for each sample and indicate the positive and negative controls (see the DP#2 layout). Label the wells with the sample name (denoted as “sample wells”) or the sample name with antitoxin (denoted as “antitoxin wells”).

5.7.2) Calculate the amount of antitoxin required for this assay. NOTE: The antitoxin is a 25X stock solution that needs to be diluted 1:25 in 1X PBS. Place the prepared antitoxin 1X solution on ice.

5.7.3) For “sample wells,” add 20 μL of 1X PBS to each well for all dilutions (10^{-1} to 10^{-6}) of that sample. For “antitoxin wells,” add 20 μL of 1X Antitoxin to each well for all dilutions (10^{-1} to 10^{-6}) of that sample.

5.7.4) Transfer 20 μL of the diluted sample in wells from DP#1 into the designated wells on DP#2 for rows 1-6 and rows 7-12 (see the DP#2 layout on the Vero Cell Worksheet). Mix the solution gently by pipetting up and down.

5.7.5) Cover DP#2 with a clear plastic adhesive seal and allow 40 min of incubation at room temperature. This incubation is to allow the antitoxin to bind and thus inactivate and neutralize the *C. difficile* toxin.

5.7.6) After the incubation, add 10 μL of mixture from DP#2 to the appropriate Vero cell wells (see the Vero Cell Plate layout on the Vero Cell Worksheet). Gently mix the solution by pipetting up and down, taking care to not disrupt the Vero cells that are adhered to the bottom surface of the wells.

5.7.7) Incubate the Vero cell plate overnight in a cell culture incubator at 37 °C and 5% CO_2 .

5.8) Assess Vero cells for rounding using a light microscope (day 2)

NOTE: Recall that the dilution factor changes by a factor of 10 when adding the sample mixtures to the Vero cell plate (e.g., 10^{-3} is now 10^{-4}). Wells that have antitoxin present should have little to no Vero cell rounding noted. Vero cell rounding (cytotoxicity) will be noted in

samples that contain *C. difficile* toxin. If the cytotoxic activity is neutralized in a dilution containing the sample and the antitoxin, the presence of *C. difficile* toxin resulting in Vero cell cytotoxicity is confirmed.

5.8.1) Examine for Vero cell rounding using a light microscope at 200X magnification. For sample wells (including the positive control), record the dilution of the well that is the *last* to have 80% Vero cell rounding noted.

5.8.2) Calculate the cytotoxic titer, which is defined as the reciprocal of the highest dilution that produced 80% Vero cell rounding per g of sample. For example, if the highest dilution is 10^{-5} , then the dilution factor would be 10^{-6} for this sample. Thus, the $\log[\text{final dilution factor}]/\text{g}$ of sample would be $\log[10^6]$, which yields a reciprocal titer of 6.

NOTE: Vero cells need to have undergone at least 3-4 passages and no more than 30 passages prior to their use in this assay²⁶.

REPRESENTATIVE RESULTS:

During a representative study, 5-week-old C57BL/6 WT mice were pretreated with cefoperazone in their drinking water (0.5 mg/mL) for 5 days and allowed a 2-day wash out with regular drinking water. Mice were challenged with 10^5 spores of *C. difficile* R20291 via oral gavage on day 0 (Figure 1A). Mice were monitored for weight loss and clinical signs (lethargy, inappetence, diarrhea, and hunched posture) of CDI for 14 days. The challenge of C57BL/6 WT mice with *C. difficile* R20291 spores resulted in diarrhea within 24 h and significant weight loss within 48 h post-challenge (Figure 1B). Although not observed in this experiment, mice challenged with a higher dose of *C. difficile* R20291 can become severely ill or have greater than 20% weight loss by 48-72 h post-challenge, thus necessitating humane euthanasia. Therefore, mice require a minimum of twice-daily monitoring after challenge with *C. difficile* spores.

In this representative study, a significant amount of weight loss and clinical signs of disease in mice were also observed on days 2-7 post-challenge (Figure 1B). At 7 days post-challenge, mice began to gain weight, and clinical signs of disease subsided. By the last week of the experiment, the mice appeared clinically normal, with no evidence of the clinical signs of CDI, including diarrhea.

Fecal pellets were collected prior to the challenge with *C. difficile* spores and every 48 h post-challenge (Figure 1C). Prior to the antibiotic treatment, mice were not colonized with *C. difficile*. Within 24 h post challenge with *C. difficile* spores, mice were colonized with 10^7 CFUs of *C. difficile* per g of feces (Figure 1C). Mice remained persistently colonized with *C. difficile* throughout the experiment, despite no evidence of weight loss or clinical signs of CDI for the last 7 days of the experiment.

[Place Figure 1A, 1B, and 1C here]

Four mice (2 males and 2 females) were humanely euthanized and prepared for necropsy on

day 0, prior to infection, to serve as uninfected controls. In addition, one mouse from each cage was humanely euthanized and prepared for necropsy on days 2, 4, 7, and 14 post-challenge (Figure 1A). Enumeration of *C. difficile* within the cecal content was performed at each necropsy. In concordance with fecal enumeration, no *C. difficile* was detected in the cecal content of mice prior to the challenge with *C. difficile*. At 48 h post-challenge, mice were colonized with approximately 10^8 CFUs of *C. difficile* per g of cecal content (Figure 2A). All mice remained persistently colonized throughout the experiment.

Cecal content was also assessed throughout the infection for the presence of *C. difficile* toxin using the Vero cell cytotoxicity assay. No evidence of *C. difficile* toxin cytotoxicity was detected in cecal contents prior to the challenge (Figure 2B). *C. difficile* cytotoxicity was detected 2 days after the challenge with *C. difficile* spores and persisted throughout the infection. Despite fairly uniform colonization with *C. difficile*, variation in the levels of *C. difficile* cytotoxic activity is evident in individual mice (Figure 2B).

The majority of mouse cecal content neutralized with *C. difficile* antitoxin during the Vero cell cytotoxicity assay and had no evidence of cytotoxicity (Vero cell rounding) in the dilutions performed. However, a few individual mice, despite retesting, had evidence of 50-100% cytotoxicity in the 10^{-1} dilution (dilution where the sample is most concentrated), with no evidence of Vero cell rounding in the other dilutions. The antitoxin utilized in this assay is a neutralizing polyclonal antibody to *C. difficile* toxin, prepared in goats²⁷. Therefore, this antitoxin may not neutralize the *C. difficile* binary toxin that is produced by strain R20291. However, the *C. difficile* binary toxin is not considered to be cytotoxic¹⁰. Excessive *C. difficile* toxin unable to be neutralized by the antitoxin or the presence of another cytotoxic agent other than *C. difficile* toxin could be contributing to this finding. This observation did not affect the determination of the cytotoxicity titer for these samples, since each sample's last dilution with the 80% Vero cell rounding had no evidence of cytotoxicity when combined with the antitoxin at the specified dilution.

[Place Figure 2A and B here]

It is recommended that histologic evaluation is conducted by a board-certified veterinary pathologist in a blinded manner. For tissue scoring, a 0-4 numerical scoring system should be employed to separately assess edema, inflammatory cell infiltration, and epithelial cell damage in the ileum, cecum, and colon based upon a previously-published scoring scheme¹⁷.

Upon blinded histopathologic examination of the murine ileum, cecum, and colon following challenge with *C. difficile* R20291, the most significant pathologic changes were noted in the cecum (Figure 3). The total cecal histologic scores were significantly different between day 0 and days 2 and 4 post-challenge. No significant lesions were noted in the ileum throughout infection (Figure 3). Milder lesions were noted in the colon. The total colonic histological scores were significantly different between day 0 and days 2 and 7 post challenge (Figure 3).

Representative H&E sections of the ileum, cecum, and colon throughout infection are available

in Figure 4. Each image has its respective total histological score and individual scores for epithelial damage, inflammation, and edema, as determined by a blinded board-certified veterinary pathologist (SAM).

[Place Figure 3 and Figure 4 here within a single panel]

FIGURE LEGENDS

Figure 1: Cefoperazone treated mice challenged with *C. difficile* R20291 exhibit weight loss and are colonized with *C. difficile*.

A. 5-week-old C57BL/6 WT JAX mice (n = 3M/3F per group) were pretreated with cefoperazone in their drinking water (0.5 mg/mL) for 5 days and allowed a 2-day wash out with regular drinking water. Mice were challenged with 10^5 spores of *C. difficile* R20291 via oral gavage on day 0. Mice were monitored for weight loss and clinical signs (lethargy, inappetence, diarrhea, and hunched posture) of CDI for 14 days. Feces was collected and used for bacterial enumeration prior to starting cefoperazone, immediately after finishing the antibiotic, and on days 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, and 14 throughout infection. Necropsy was performed on days 0, 2, 4, 7, and 14. B. The mice lost a significant amount of their baseline weight after challenge with *C. difficile* R20291. The average bodyweight of mice was measured daily from day 0. Significant weight loss was seen on days 2 through 7 when compared to day 0, the baseline weight. C. *C. difficile* R20291 bacterial load in the feces after the challenge. Within 24 h after the challenge with *C. difficile* spores, all mice were colonized with 10^7 CFUs (colony-forming units) per g of feces. No significant differences in these parameters were seen between females and males. Significance was determined by the non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest, (*, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$; ****, $p \leq 0.0001$). Error bars represent the standard deviations from the mean.

Figure 2: Colonization of the cecum and cytotoxicity during infection with *C. difficile* R20291.

A. Mice ceca remained persistently colonized with *C. difficile* throughout the experiment, despite resolution of clinical signs and observed weight gain. All mice were colonized with greater than 10^8 CFUs per g of cecal contents when assessed at 2 days post-challenge. B. Vero cell cytotoxicity assay from cecal content throughout infection with *C. difficile* R20291. Following the challenge with *C. difficile* spores, mice had significant levels of cytotoxicity, as measured in \log_{10} reciprocal dilution of toxin per g of cecal content on days 2, 4, and 7 post-challenge compared to day 0 (medians represented by the line). Significance was determined by the non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest, (*, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$; ****, $p \leq 0.0001$). Error bars represent the standard deviations from the mean.

Figure 3: Histological scoring of the murine ileum, cecum, and colon during infection with *C. difficile* R20291.

Total histological scores were calculated by adding all three scores from the parameters assessed: epithelial damage, inflammation, and edema. No significant histopathological changes were noted in the ileum throughout infection. Cecal tissue contained the most significant histological lesions during CDI. The total cecal histological scores were significantly

different from day 0 on days 2 and 4 post-challenge. Milder lesions were noted in the colon. The total colonic histological scores were significantly different from day 0 on days 2 and 7 post-challenge. Significance was determined by the non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest (*, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$; ****, $p \leq 0.0001$). Error bars represent the standard deviations from the mean.

Figure 4: Histopathology during infection with *C. difficile* R20291.

This panel contains representative H&E sections of ileum, cecum, and colon throughout infection with *C. difficile* R20291. The total histological scores are in parentheses () for the corresponding day and tissue listed: for the ileum day 0 (0), day 2 (1), day 4 (0), day 7 (0), and day 14 (0); for the cecum day 0 (0), day 2 (5), day 4 (4), day 7 (3), and day 14 (3); and for the colon day 0 (0), day 2 (4), day 4 (1), day 7 (4), and day 14 (2). Photomicrographs were obtained on a light microscope with a 5 megapixel digital camera and its accompanying software (the scale bar represents 200 μ m).

DISCUSSION:

This protocol characterizes the clinical course, including weight loss, bacterial colonization, toxin cytotoxicity, and histopathological changes in the gastrointestinal tract, of antibiotic-treated mice challenged with *C. difficile* R20291 spores. There are several critical steps within the protocol where attention to detail is essential. Accurate calculation of the *C. difficile* spore inoculum is critical. This calculation is based on the original *C. difficile* spore stock enumeration, which should be consistent over multiple spore enumerations prior to starting this protocol. If the inoculum calculation is erroneous, it will result in an inaccurate inoculation dose of the mice. On the same note, preparation and dilutions of *C. difficile* spores based on these calculations should be prepared with care. Any dilution errors will result in an inaccurate starting spore inoculum. Lastly, precautions should be taken to avoid contamination of antibiotic-treated control mice (not inoculated with *C. difficile* spores). Cefoperazone-treated mice are extremely susceptible to *C. difficile* colonization and thus should not be in direct contact with *C. difficile*-infected mice²⁸⁻³⁰. If the aforementioned critical steps are recognized, successful execution of the CDI mouse model is expected.

Modification of the dose or strain of *C. difficile* spores administered to the mice may alter the outcomes of this model. Increasing the spore inoculum administered to mice could increase the morbidity and mortality observed, depending on the strain of *C. difficile* administered. A dose response experiment, evaluating a range of several inoculum doses, is recommended if using other *C. difficile* strains in order to characterize the clinical course of CDI.

This protocol uses TCCFA medium for *C. difficile* enumeration of spores and vegetative cells collectively. However, if distinct phases (such as germination and outgrowth) of the *C. difficile* lifecycle are desired, differential plating is required. Non-heat-treated contents, as described in this protocol, will yield the CFU per g content of spores and vegetative cells together. If the same GI content is heat-treated (20 min at 65 °C) and then plated on TCCFA media, this will yield a CFU of spores only, since *C. difficile* vegetative cells are destroyed by heat. Comparison of *C. difficile* enumeration using these two plating techniques allows for more detailed

information about the *C. difficile* lifecycle *in vivo*.

One major limitation of this mouse model is that the results may not be reproducible in mice from different strains or vendors. Recall that disruption of the gut microbiota following cefoperazone treatment renders mice susceptible to CDI²⁸. Variations in the initial composition of the gut microbiota between different murine strains from different vendors could alter the mouse model of CDI³¹. Once researchers have successfully completed this model, it is recommended that the mouse strain and vendor from where the mice are acquired stay consistent for additional studies to limit variations in the gut microbiota composition, which could alter the outcomes of the model.

Another limitation of the protocol is that the Vero cell cytotoxicity assay does not quantitatively measure *C. difficile* toxin levels *in vivo*. Instead, epithelial (Vero) cell cytotoxicity represents a qualitative approach that measures relative cytotoxicity of *C. difficile* toxins present in samples. Other techniques such as qRT-PCR and immunoblotting would be helpful to determine the amount of toxin present in the samples.

Various models of CDI are currently being used, including the Syrian hamster model, *ex vivo* models, and human intestinal organoid models^{13,14,30,32}. However, the mouse model of CDI provides the increased availability of commercially-available murine reagents and assays to further examine the pathogenesis of *C. difficile*. Other mouse models of CDI have used different strains of *C. difficile*, such as VPI 10463, which results in substantial mortality and thus does not recapitulate human CDI^{12,17,29}. In this model, *C. difficile* R20291 was selected for its genetic tractability and clinical relevance as a recent 027 epidemic strain^{33,34}. Compared to other murine models of CDI, R20291 was not uniformly lethal at the dose administered, allowing for observation of a prolonged clinical course of infection concordant with human disease. Overall, this mouse model proves to be a valuable experimental platform of CDI. This fully-characterized *C. difficile* mouse model can be utilized to assess the effects of novel therapeutics on the amelioration of clinical disease and on the restoration of colonization resistance against *C. difficile*.

ACKNOWLEDGMENTS:

The authors would like to thank Trevor Lawley at the Wellcome Trust Sanger Institute for *C. difficile* R20291 spores and James S. Guy at the North Carolina State University College of Veterinary Medicine for Vero cells, both utilized in this manuscript. Animal histopathology was performed in the LCCC Animal Histopathology Core Facility at the University of North Carolina at Chapel Hill, with special assistance from Traci Raley and Amanda Brown. The LCCC Animal Histopathology Core is supported in part by an NCI Center Core Support Grant (2P30CA016086-40) to the UNC Lineberger Comprehensive Cancer Center. We would also like to thank Vincent Young, Anna Seekatz, Jhansi Leslie, and Cassie Schumacher for helpful discussions on the Vero cell cytotoxicity assay protocol. JAW is funded by the Ruth L. Kirschstein National Research Service Award Research Training grant T32OD011130 by NIH. CMT is funded by the career development award in metabolomics grant K01GM109236 by the NIGMS of the NIH.

DISCLOSURES:

The authors have nothing to disclose at this time.

REFERENCES:

- 1 Services., U. S. D. o. H. a. H. *Antibiotic Resistance Threats in the United States*, <<http://www.cdc.gov/drugresistance/pdf/ar-threats-2013-508.pdf>> (2013).
- 2 Lessa, F. C. *et al.* Burden of *Clostridium difficile* Infection in the United States. *New England Journal of Medicine* **372**, 825-834, doi:doi:10.1056/NEJMoa1408913 (2015).
- 3 Gerding, D. N. & Lessa, F. C. The epidemiology of *Clostridium difficile* infection inside and outside health care institutions. *Infect Dis Clin North Am* **29**, 37-50, doi:10.1016/j.idc.2014.11.004 (2015).
- 4 Dubberke, E. R. & Olsen, M. A. Burden of *Clostridium difficile* on the healthcare system. *Clin Infect Dis* **55 Suppl 2**, S88-92, doi:10.1093/cid/cis335 (2012).
- 5 Kociolek, L. K. & Gerding, D. N. Breakthroughs in the treatment and prevention of *Clostridium difficile* infection. *Nat Rev Gastroenterol Hepatol*, doi:10.1038/nrgastro.2015.220 (2016).
- 6 Kelly, C. P. & LaMont, J. T. *Clostridium difficile*--more difficult than ever. *N Engl J Med* **359**, 1932-1940, doi:10.1056/NEJMra0707500 (2008).
- 7 Louie, T. J. *et al.* Fidaxomicin versus vancomycin for *Clostridium difficile* infection. *N Engl J Med* **364**, 422-431, doi:10.1056/NEJMoa0910812 (2011).
- 8 Bartlett, J. G., Onderdonk, A. B., Cisneros, R. L. & Kasper, D. L. Clindamycin-associated colitis due to a toxin-producing species of *Clostridium* in hamsters. *The Journal of infectious diseases* **136**, 701-705 (1977).
- 9 Kelly, M. L. *et al.* Improving the reproducibility of the NAP1/B1/027 epidemic strain R20291 in the hamster model of infection. *Anaerobe*, doi:10.1016/j.anaerobe.2016.02.011 (2016).
- 10 Kuehne, S. A. *et al.* Importance of toxin A, toxin B, and CDT in virulence of an epidemic *Clostridium difficile* strain. *The Journal of infectious diseases* **209**, 83-86, doi:10.1093/infdis/jit426 (2014).
- 11 Bartlett, J. G., Onderdonk, A. B. & Cisneros, R. L. Clindamycin-associated colitis in hamsters: protection with vancomycin. *Gastroenterology* **73**, 772-776 (1977).
- 12 Chen, X. *et al.* A mouse model of *Clostridium difficile*-associated disease. *Gastroenterology* **135**, 1984-1992, doi:10.1053/j.gastro.2008.09.002 (2008).
- 13 Lawley, T. D. & Young, V. B. Murine models to study *Clostridium difficile* infection and transmission. *Anaerobe* **24**, 94-97, doi:10.1016/j.anaerobe.2013.09.008 (2013).
- 14 Best, E. L., Freeman, J. & Wilcox, M. H. Models for the study of *Clostridium difficile* infection. *Gut Microbes* **3**, 145-167, doi:10.4161/gmic.19526 (2012).
- 15 Reeves, A. E. *et al.* The interplay between microbiome dynamics and pathogen dynamics in a murine model of *Clostridium difficile* Infection. *Gut Microbes* **2**, 145-158, doi:10.4161/gmic.2.3.16333 (2014).
- 16 Owens, R. C., Jr., Donskey, C. J., Gaynes, R. P., Loo, V. G. & Muto, C. A. Antimicrobial-associated risk factors for *Clostridium difficile* infection. *Clin Infect Dis* **46 Suppl 1**, S19-31, doi:10.1086/521859 (2008).
- 17 Theriot, C. M. *et al.* Cefoperazone-treated mice as an experimental platform to assess

- differential virulence of *Clostridium difficile* strains. *Gut Microbes* **2**, 326-334, doi:10.4161/gmic.19142 (2011).
- 18 Martin, J. S., Monaghan, T. M. & Wilcox, M. H. *Clostridium difficile* infection: epidemiology, diagnosis and understanding transmission. *Nat Rev Gastroenterol Hepatol*, doi:10.1038/nrgastro.2016.25 (2016).
 - 19 O'Connor, J. R., Johnson, S. & Gerding, D. N. *Clostridium difficile* infection caused by the epidemic BI/NAP1/027 strain. *Gastroenterology* **136**, 1913-1924, doi:10.1053/j.gastro.2009.02.073 (2009).
 - 20 He, M. *et al.* Emergence and global spread of epidemic healthcare-associated *Clostridium difficile*. *Nat Genet* **45**, 109-113, doi:10.1038/ng.2478 (2013).
 - 21 Perez, J., Springthorpe, V. S. & Sattar, S. A. Clospore: a liquid medium for producing high titers of semi-purified spores of *Clostridium difficile*. *Journal of AOAC International* **94**, 618-626 (2011).
 - 22 Sorg, J. A. & Dineen, S. S. Laboratory maintenance of *Clostridium difficile*. *Curr Protoc Microbiol* **Chapter 9**, Unit9A.1, doi:10.1002/9780471729259.mc09a01s12 (2009).
 - 23 Edwards, A. N., Suarez, J. M. & McBride, S. M. Culturing and maintaining *Clostridium difficile* in an anaerobic environment. *Journal of visualized experiments : JoVE*, e50787, doi:10.3791/50787 (2013).
 - 24 George, W. L., Sutter, V. L., Citron, D. & Finegold, S. M. Selective and differential medium for isolation of *Clostridium difficile*. *J Clin Microbiol* **9**, 214-219 (1979).
 - 25 Knoblaugh, S., Randolph-Habecker, J. & Rath, S. in *Comparative Anatomy and Histology* (ed Suzanne M. Dintzis) 15-40 (Academic Press, 2012).
 - 26 Ammerman, N. C., Beier-Sexton, M. & Azad, A. F. Growth and maintenance of Vero cell lines. *Curr Protoc Microbiol* **Appendix 4**, Appendix 4E, doi:10.1002/9780471729259.mca04es11 (2008).
 - 27 TECHLAB. *Clostridium difficile* Toxin/Antitoxin Kit Cat No. T5000, <http://www.techlab.com/wp-content/uploads/2013/06/t5000insert_rev_0307.pdf> (2007).
 - 28 Theriot, C. M. *et al.* Antibiotic-induced shifts in the mouse gut microbiome and metabolome increase susceptibility to *Clostridium difficile* infection. *Nat Commun* **5**, 3114, doi:10.1038/ncomms4114 (2014).
 - 29 Koenigsnecht, M. J. *et al.* Dynamics and establishment of *Clostridium difficile* infection in the murine gastrointestinal tract. *Infect Immun* **83**, 934-941, doi:10.1128/iai.02768-14 (2015).
 - 30 Theriot, C., Bowman, A. & Young, V. Antibiotic-Induced Alterations of the Gut Microbiota Alter Secondary Bile Acid Production and Allow for *Clostridium difficile* Spore Germination and Outgrowth in the Large Intestine. *mSphere* **1**, 00045-00015 (2016).
 - 31 Xiao, L. *et al.* A catalog of the mouse gut metagenome. *Nature biotechnology* **33**, 1103-1108, doi:10.1038/nbt.3353 (2015).
 - 32 Leslie, J. L. *et al.* Persistence and toxin production by *Clostridium difficile* within human intestinal organoids result in disruption of epithelial paracellular barrier function. *Infect Immun* **83**, 138-145, doi:10.1128/iai.02561-14 (2015).
 - 33 Stabler, R. A. *et al.* Comparative genome and phenotypic analysis of *Clostridium difficile* 027 strains provides insight into the evolution of a hypervirulent bacterium. *Genome*

- Biol* **10**, R102, doi:10.1186/gb-2009-10-9-r102 (2009).
- 34 Valiente, E., Dawson, L. F., Cairns, M. D., Stabler, R. A. & Wren, B. W. Emergence of new PCR ribotypes from the hypervirulent *Clostridium difficile* 027 lineage. *J Med Microbiol* **61**, 49-56, doi:10.1099/jmm.0.036194-0 (2012).

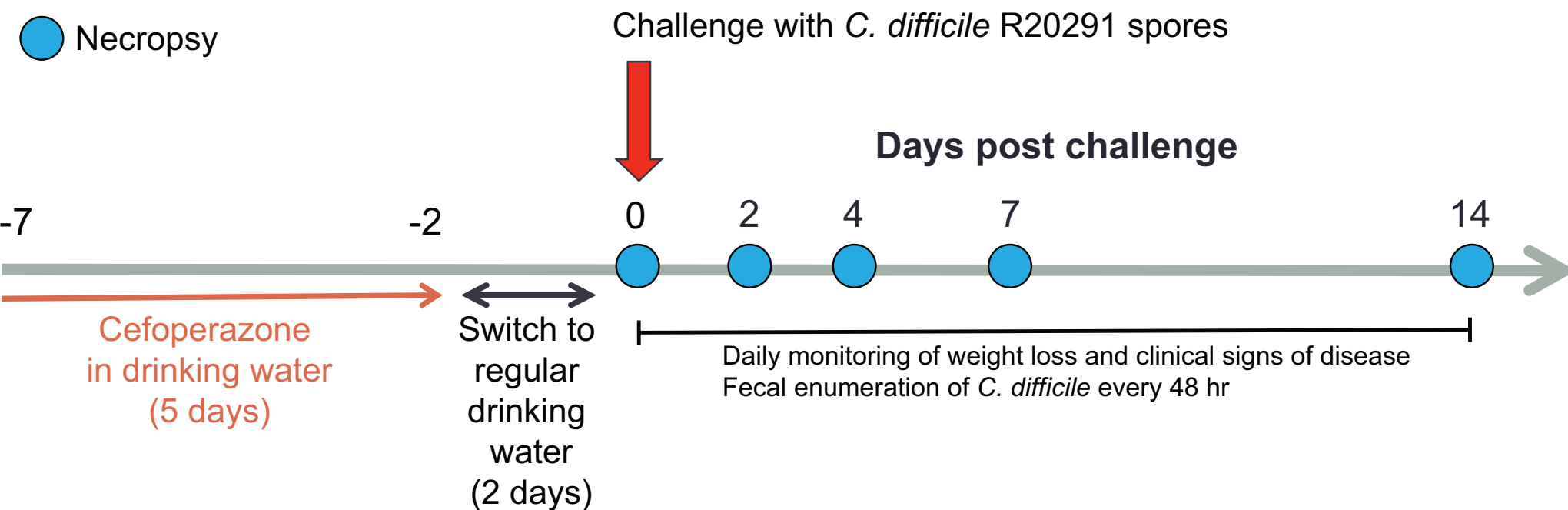
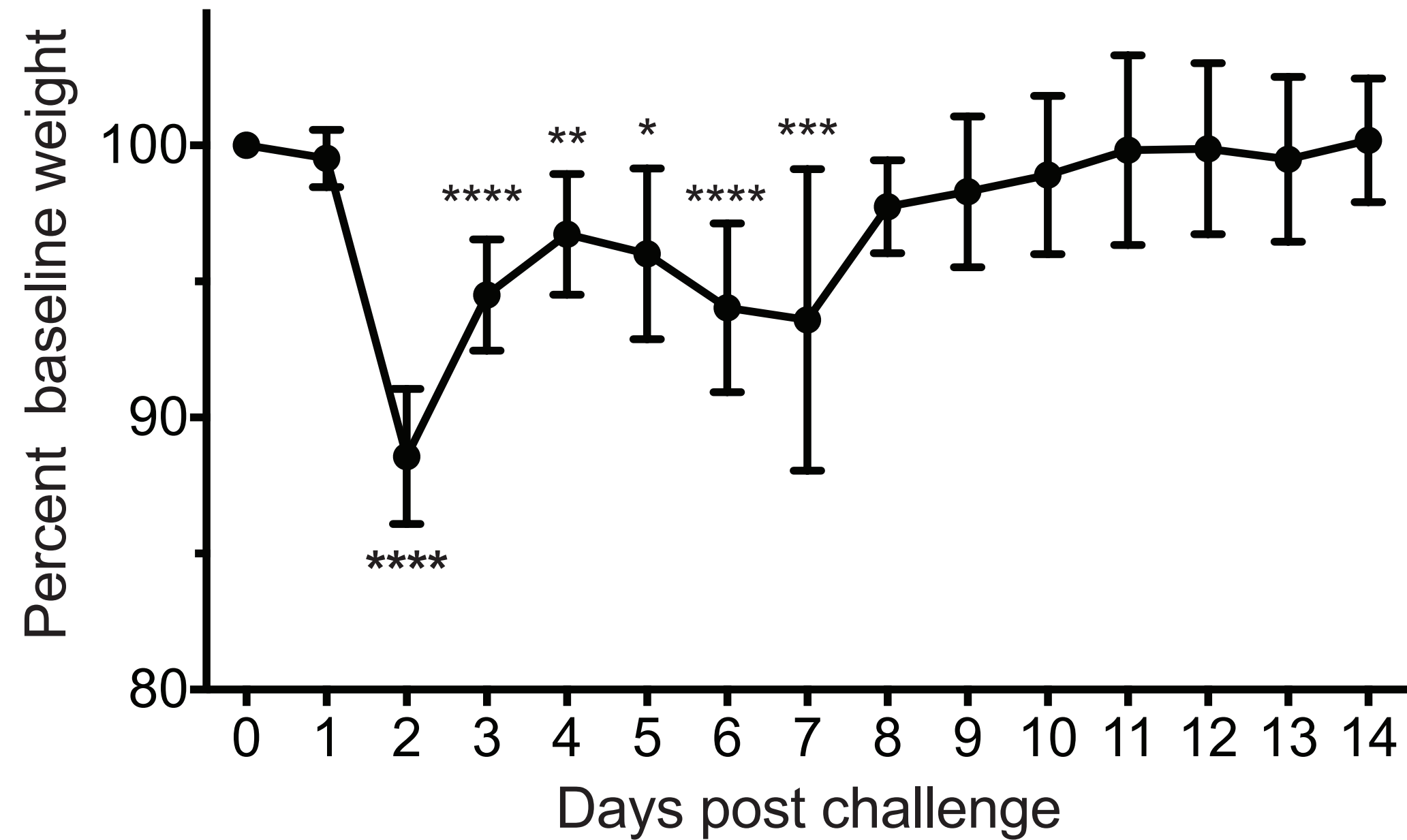
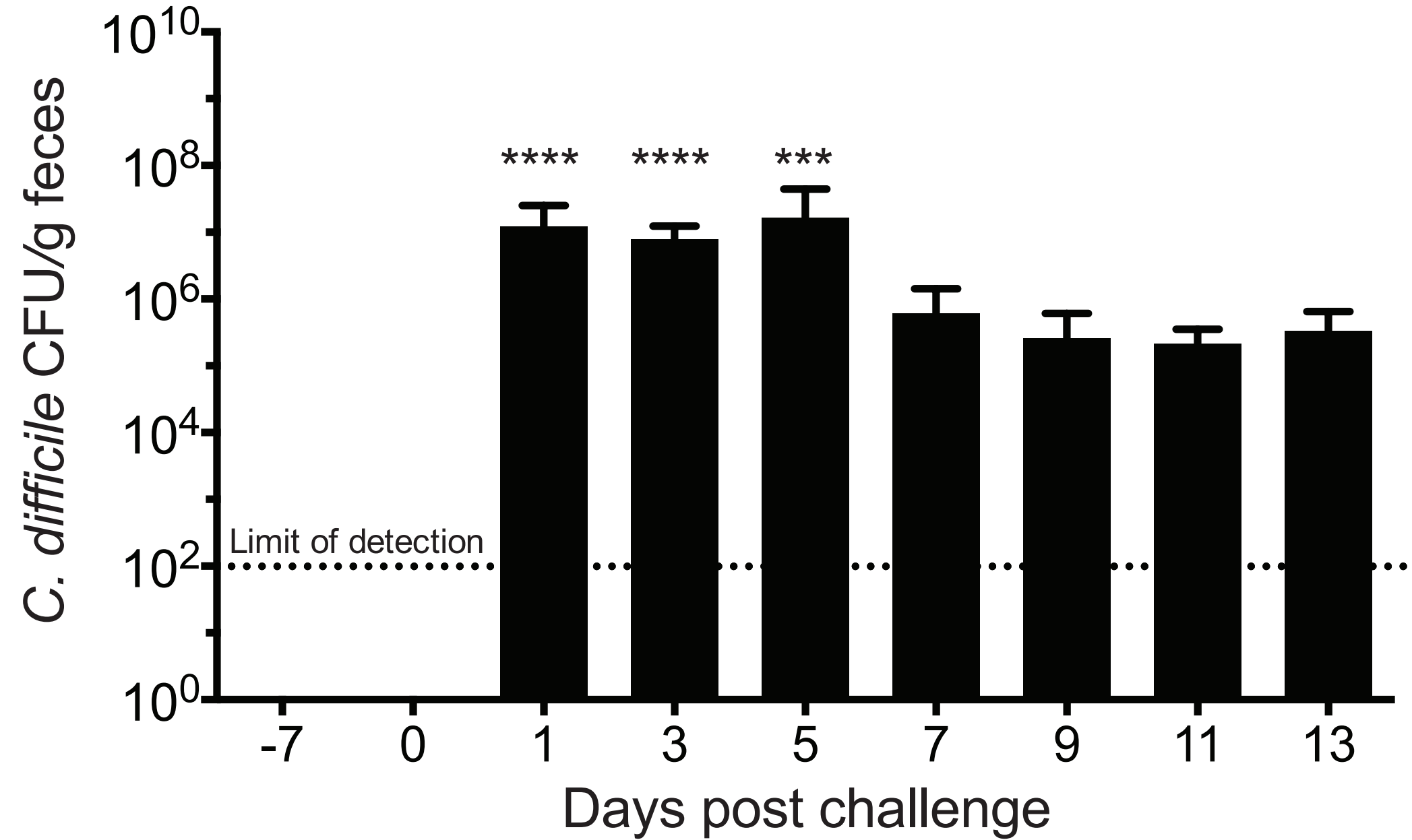


Figure 1b





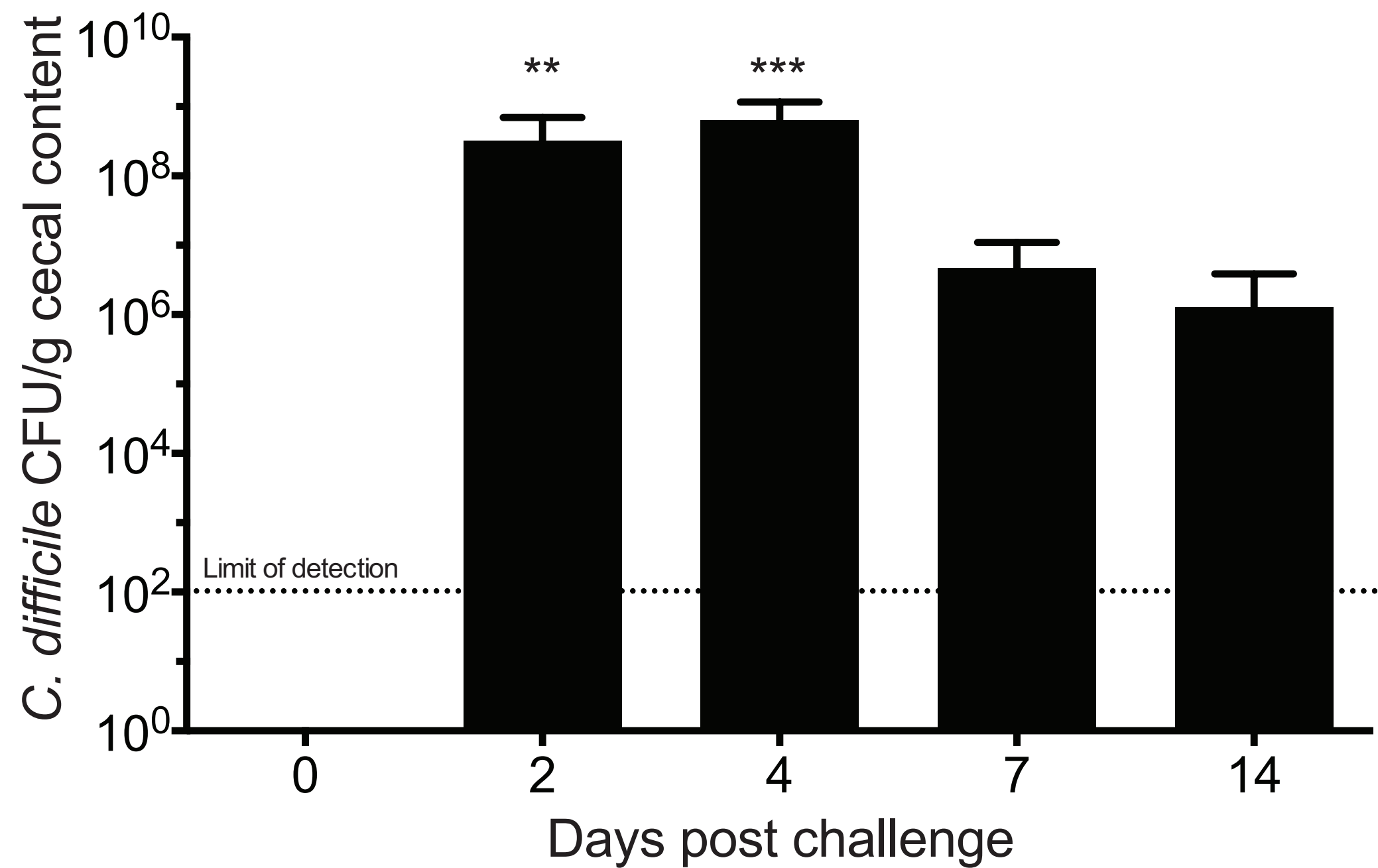


Figure 2b

\log_{10} (reciprocal dilution
toxin per gram cecal contents)

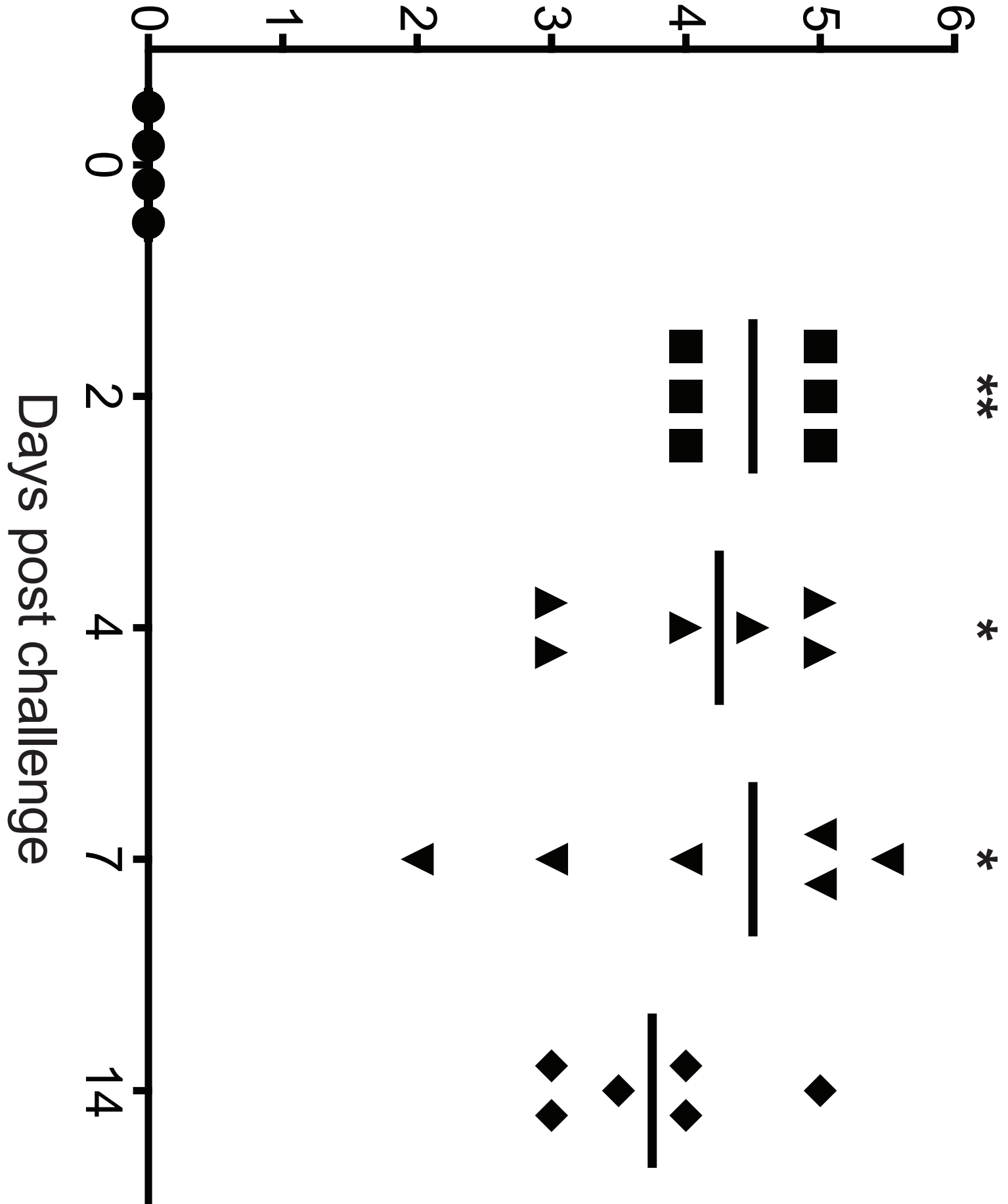
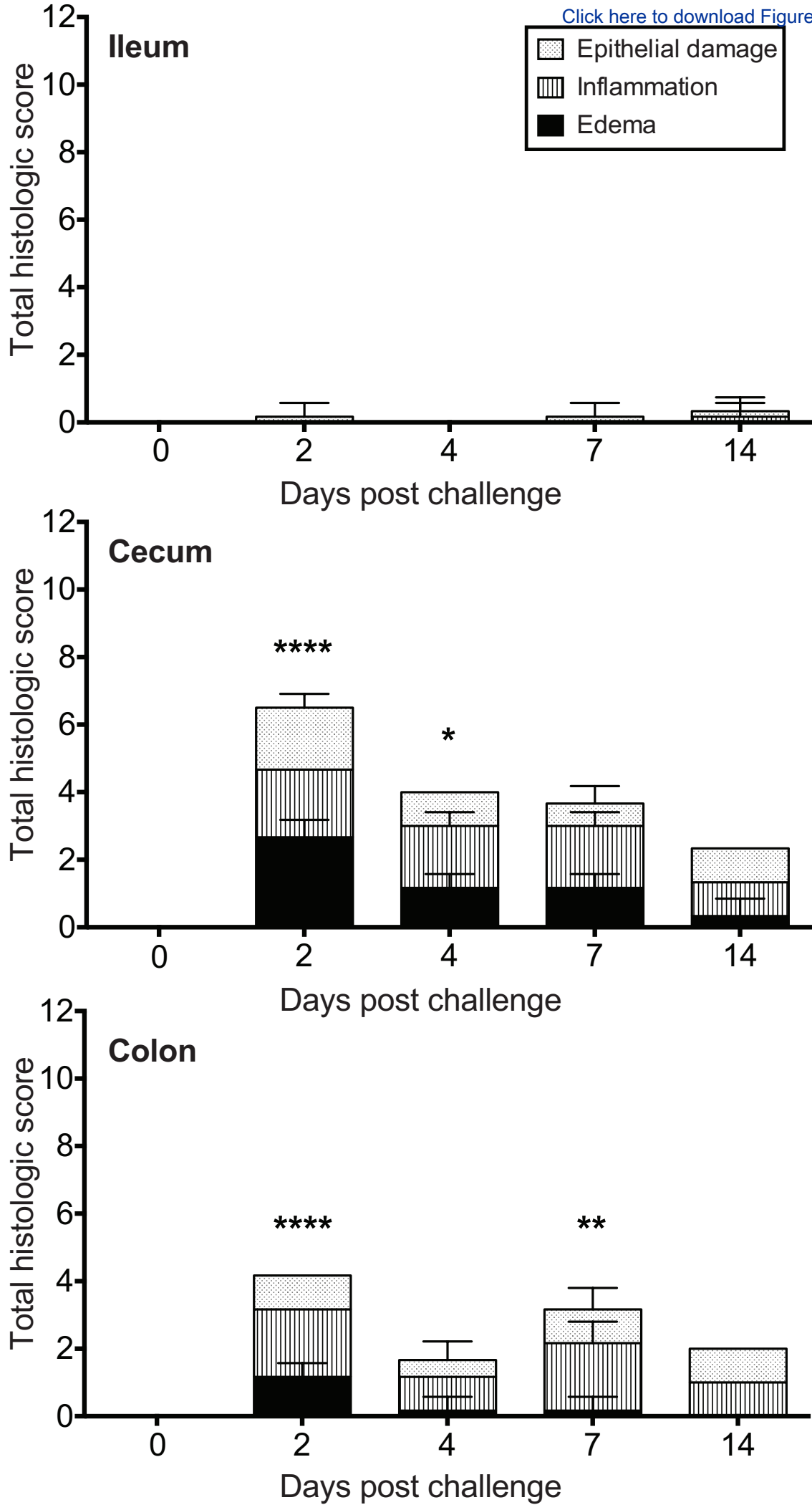
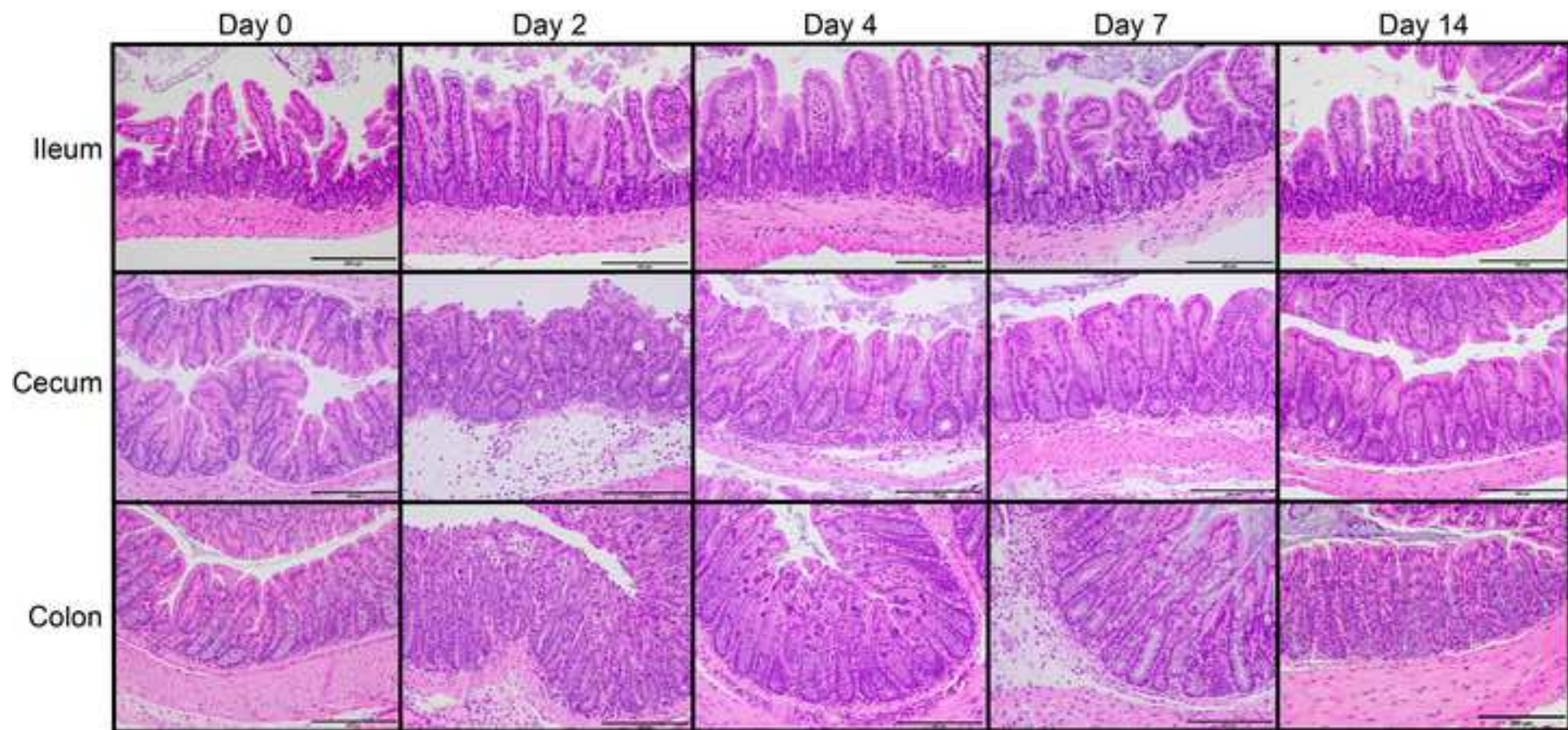


Figure 3





Name of Material/ Equipment	Company	Catalog Number
#62 Perisept Sporidicial Disinfectant Cleane	SSS Navigator	48027
0.22 µm filter	Fisherbrand	09-720-3
0.25% Trypsin-EDTA	Gibco	25200-056
0.4% Trypan Blue	Gibco	15250-061
1% Penicillin/Streptomycin	Gibco	15070-063
10% heat inactivated FBS	Gibco	16140-071
1ml plastic syringe	BD Medical Supplies	309628
1X PBS	Gibco	10010-023
2 ml Micro Centrifuge Screw Cap	Corning	430917
96 well cell culture flat bottom plate	Costar Corning	CL3595
96 well filter plate	Millipore	MSGVS2210
Adhesive Seal	ThermoScientific	AB-0558
Bacto Agar	Becton Dickinson	214010
Bacto Proteose Peptone	Becton Dickinson	211684
Cefoperazone	MP Bioworks	199695
Cefoxitine	Sigma	C47856
Clostridium difficile Antitoxin Kit	Tech Labs	T5000
Clostridium difficile Toxin A	List Biological Labs	152C
D-cycloserine	Sigma	C6880
Distilled Water	Gibco	15230
DMEM 1X Media	Gibco	11965-092
Fructose	Fisher	L95500
Hemocytometer	Bright-Line, Sigma	Z359629
KH ₂ PO ₄	Fisher	P285-500
MgSO ₄ (anhydrous)	Sigma	M2643
Millex-GS 0.22 µm filter	Millex-GS	SLGS033SS
Na ₂ HPO ₄	Sigma	S-0876
NaCl	Fisher	S640-3
Number 10 disposable scalpel blade	Miltex, Inc	4-410
PCR Plates	Fisherbrand	14230244

Plastic petri dish	Kord-Valmark Brand	2900	
Sterile plastic L-shaped cell spreader	Fisherbrand	14-665-230	
Syringe Stepper	Dymax Corporation	T15469	
Taurocholate	Sigma	T4009	
Ultrapure distilled water	Invitrogen	10977-015	
C57BL/6J Mice	The Jackson Laboratory		664
Olympus BX43F light microscope	Olympus Life Science		
DP27 camera	Olympus Life Science		
cellSens Dimension software	Olympus Life Science		

Comments/Description

This product will require dilution as recommended by the manufacturer
Alternative to filter plate for individual samples tested in the Vero Cell Assay
Needs to be heated in water bath at 37C prior to use

Needs to be heated in water bath at 37C prior to use

Part of TCCFA plates (see below)
Part of TCCFA plates (see below)

Part of TCCFA plates (see below)
Used as control for Vero Cell Assay
Positive control for Vero Cell Assay
Part of TCCFA plates (see below)

Needs to be heated in water bath at 37C prior to use
Part of TCCFA plates (see below)

Part of TCCFA plates (see below)
Part of TCCFA plates (see below)
Filter for TCCFA plates
Part of TCCFA plates (see below)
Part of TCCFA plates (see below)

Part of TCCFA plates (see below)

Mice should be 5-8 weeks of age



1 Alewife Center #200
Cambridge, MA 02140
tel. 617.945.9051
www.jove.com

ARTICLE AND VIDEO LICENSE AGREEMENT

Title of Article: Cefoperazone treated mouse model of C. difficile strain 1220291 :
 Author(s): JA Winston, R. Thanissery, SA Montgomery, CM Theriot A clinically relevant platform for testing therapeutics

Item 1 (check one box): The Author elects to have the Materials be made available (as described at <http://www.jove.com/publish>) via: ☒ Standard Access ☐ Open Access

Item 2 (check one box):

- ☐ The Author is NOT a United States government employee.
- ☒ The Author is a United States government employee and the Materials were prepared in the course of his or her duties as a United States government employee.
- ☐ The Author is a United States government employee but the Materials were NOT prepared in the course of his or her duties as a United States government employee.

ARTICLE AND VIDEO LICENSE AGREEMENT

1. **Defined Terms.** As used in this Article and Video License Agreement, the following terms shall have the following meanings: "**Agreement**" means this Article and Video License Agreement; "**Article**" means the article specified on the last page of this Agreement, including any associated materials such as texts, figures, tables, artwork, abstracts, or summaries contained therein; "**Author**" means the author who is a signatory to this Agreement; "**Collective Work**" means a work, such as a periodical issue, anthology or encyclopedia, in which the Materials in their entirety in unmodified form, along with a number of other contributions, constituting separate and independent works in themselves, are assembled into a collective whole; "**CRC License**" means the Creative Commons Attribution-Non Commercial-No Derivs 3.0 Unported Agreement, the terms and conditions of which can be found at: <http://creativecommons.org/licenses/by-nc-nd/3.0/legalcode>; "**Derivative Work**" means a work based upon the Materials or upon the Materials and other pre-existing works, such as a translation, musical arrangement, dramatization, fictionalization, motion picture version, sound recording, art reproduction, abridgment, condensation, or any other form in which the Materials may be recast, transformed, or adapted; "**Institution**" means the institution, listed on the last page of this Agreement, by which the Author was employed at the time of the creation of the Materials; "**JoVE**" means MyJoVE Corporation, a Massachusetts corporation and the publisher of *The Journal of Visualized Experiments*; "**Materials**" means the Article and / or the Video; "**Parties**" means the Author and JoVE; "**Video**" means any video(s) made by the Author, alone or in conjunction with any other parties, or by JoVE or its affiliates or agents, individually or in collaboration with the Author or any other parties, incorporating all or any portion of the Article, and in which the Author may or may not appear.

2. **Background.** The Author, who is the author of the Article, in order to ensure the dissemination and protection of the Article, desires to have the JoVE publish the Article and create and transmit videos based on the Article. In furtherance of such goals, the Parties desire to memorialize in this Agreement the respective rights of each Party in and to the Article and the Video.

3. **Grant of Rights in Article.** In consideration of JoVE agreeing to publish the Article, the Author hereby grants to JoVE, subject to **Sections 4 and 7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Article in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Article into other languages, create adaptations, summaries or extracts of the Article or other Derivative Works (including, without limitation, the Video) or Collective Works based on all or any portion of the Article and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. If the "Open Access" box has been checked in **Item 1** above, JoVE and the Author hereby grant to the public all such rights in the Article as provided in, but subject to all limitations and requirements set forth in, the CRC License.

ARTICLE AND VIDEO LICENSE AGREEMENT

4. **Retention of Rights in Article.** Notwithstanding the exclusive license granted to JoVE in **Section 3** above, the Author shall, with respect to the Article, retain the non-exclusive right to use all or part of the Article for the non-commercial purpose of giving lectures, presentations or teaching classes, and to post a copy of the Article on the Institution's website or the Author's personal website, in each case provided that a link to the Article on the JoVE website is provided and notice of JoVE's copyright in the Article is included. All non-copyright intellectual property rights in and to the Article, such as patent rights, shall remain with the Author.

5. **Grant of Rights in Video – Standard Access.** This **Section 5** applies if the "Standard Access" box has been checked in **Item 1** above or if no box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby acknowledges and agrees that, Subject to **Section 7** below, JoVE is and shall be the sole and exclusive owner of all rights of any nature, including, without limitation, all copyrights, in and to the Video. To the extent that, by law, the Author is deemed, now or at any time in the future, to have any rights of any nature in or to the Video, the Author hereby disclaims all such rights and transfers all such rights to JoVE.

6. **Grant of Rights in Video – Open Access.** This **Section 6** applies only if the "Open Access" box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby grants to JoVE, subject to **Section 7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Video in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Video into other languages, create adaptations, summaries or extracts of the Video or other Derivative Works or Collective Works based on all or any portion of the Video and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. For any Video to which this Section 6 is applicable, JoVE and the Author hereby grant to the public all such rights in the Video as provided in, but subject to all limitations and requirements set forth in, the CRC License.

7. **Government Employees.** If the Author is a United States government employee and the Article was prepared in the course of his or her duties as a United States government employee, as indicated in **Item 2** above, and any of the licenses or grants granted by the Author hereunder exceed the scope of the 17 U.S.C. 403, then the rights granted hereunder shall be limited to the maximum rights permitted under such

statute. In such case, all provisions contained herein that are not in conflict with such statute shall remain in full force and effect, and all provisions contained herein that do so conflict shall be deemed to be amended so as to provide to JoVE the maximum rights permissible within such statute.

8. **Likeness, Privacy, Personality.** The Author hereby grants JoVE the right to use the Author's name, voice, likeness, picture, photograph, image, biography and performance in any way, commercial or otherwise, in connection with the Materials and the sale, promotion and distribution thereof. The Author hereby waives any and all rights he or she may have, relating to his or her appearance in the Video or otherwise relating to the Materials, under all applicable privacy, likeness, personality or similar laws.

9. **Author Warranties.** The Author represents and warrants that the Article is original, that it has not been published, that the copyright interest is owned by the Author (or, if more than one author is listed at the beginning of this Agreement, by such authors collectively) and has not been assigned, licensed, or otherwise transferred to any other party. The Author represents and warrants that the author(s) listed at the top of this Agreement are the only authors of the Materials. If more than one author is listed at the top of this Agreement and if any such author has not entered into a separate Article and Video License Agreement with JoVE relating to the Materials, the Author represents and warrants that the Author has been authorized by each of the other such authors to execute this Agreement on his or her behalf and to bind him or her with respect to the terms of this Agreement as if each of them had been a party hereto as an Author. The Author warrants that the use, reproduction, distribution, public or private performance or display, and/or modification of all or any portion of the Materials does not and will not violate, infringe and/or misappropriate the patent, trademark, intellectual property or other rights of any third party. The Author represents and warrants that it has and will continue to comply with all government, institutional and other regulations, including, without limitation all institutional, laboratory, hospital, ethical, human and animal treatment, privacy, and all other rules, regulations, laws, procedures or guidelines, applicable to the Materials, and that all research involving human and animal subjects has been approved by the Author's relevant institutional review board.

10. **JoVE Discretion.** If the Author requests the assistance of JoVE in producing the Video in the Author's facility, the Author shall ensure that the presence of JoVE employees, agents or independent contractors is in accordance with the relevant regulations of the Author's institution. If more than one author is listed at the beginning of this Agreement, JoVE may, in its sole discretion, elect not take any action with respect to the Article until such time as it has received complete, executed Article and Video License Agreements from each such author. JoVE reserves the right, in its absolute and sole discretion and without giving any reason therefore, to accept or decline any work submitted to JoVE. JoVE and its employees, agents and independent contractors shall have

ARTICLE AND VIDEO LICENSE AGREEMENT

full, unfettered access to the facilities of the Author or of the Author's institution as necessary to make the Video, whether actually published or not. JoVE has sole discretion as to the method of making and publishing the Materials, including, without limitation, to all decisions regarding editing, lighting, filming, timing of publication, if any, length, quality, content and the like.

11. **Indemnification.** The Author agrees to indemnify JoVE and/or its successors and assigns from and against any and all claims, costs, and expenses, including attorney's fees, arising out of any breach of any warranty or other representations contained herein. The Author further agrees to indemnify and hold harmless JoVE from and against any and all claims, costs, and expenses, including attorney's fees, resulting from the breach by the Author of any representation or warranty contained herein or from allegations or instances of violation of intellectual property rights, damage to the Author's or the Author's institution's facilities, fraud, libel, defamation, research, equipment, experiments, property damage, personal injury, violations of institutional, laboratory, hospital, ethical, human and animal treatment, privacy or other rules, regulations, laws, procedures or guidelines, liabilities and other losses or damages related in any way to the submission of work to JoVE, making of videos by JoVE, or publication in JoVE or elsewhere by JoVE. The Author shall be responsible for, and shall hold JoVE harmless from, damages caused by lack of sterilization, lack of cleanliness or by contamination due to the making of a video by JoVE its employees, agents or independent contractors. All sterilization, cleanliness or decontamination procedures shall be solely the responsibility of the Author and shall be undertaken at the Author's

expense. All indemnifications provided herein shall include JoVE's attorney's fees and costs related to said losses or damages. Such indemnification and holding harmless shall include such losses or damages incurred by, or in connection with, acts or omissions of JoVE, its employees, agents or independent contractors.

12. **Fees.** To cover the cost incurred for publication, JoVE must receive payment before production and publication the Materials. Payment is due in 21 days of invoice. Should the Materials not be published due to an editorial or production decision, these funds will be returned to the Author. Withdrawal by the Author of any submitted Materials after final peer review approval will result in a US\$1,200 fee to cover pre-production expenses incurred by JoVE. If payment is not received by the completion of filming, production and publication of the Materials will be suspended until payment is received.

13. **Transfer, Governing Law.** This Agreement may be assigned by JoVE and shall inure to the benefits of any of JoVE's successors and assignees. This Agreement shall be governed and construed by the internal laws of the Commonwealth of Massachusetts without giving effect to any conflict of law provision thereunder. This Agreement may be executed in counterparts, each of which shall be deemed an original, but all of which together shall be deemed to be one and the same agreement. A signed copy of this Agreement delivered by facsimile, e-mail or other means of electronic transmission shall be deemed to have the same legal effect as delivery of an original signed copy of this Agreement.

A signed copy of this document must be sent with all new submissions. Only one Agreement required per submission.

CORRESPONDING AUTHOR:

Name:

Casey M. Theriot

Department:

PHP

Institution:

NCSU CVM

Article Title:

Cefoperazone treated mouse model of C. difficile strain R20291.

Signature:

Casey Theriot

Date:

3/30/16

Please submit a signed and dated copy of this license by one of the following three methods:

- 1) Upload a scanned copy of the document as a pdf on the JoVE submission site;
- 2) Fax the document to +1.866.381.2236;
- 3) Mail the document to JoVE / Attn: JoVE Editorial / 1 Alewife Center #200 / Cambridge, MA 02139

For questions, please email submissions@jove.com or call +1.617.945.9051

Author's response to reviews: We appreciate the time and effort of the reviewers to provide constructive feedback on our manuscript. We have revised the manuscript in response to the reviewers' comments. We are happy to resubmit our revised manuscript for consideration in JoVE.

Specific responses to reviewer's comments (non-bolded) are below.
Italicized sections indicate text that was added to the final revised manuscript.

Editorial comments:

•Formatting:

-Please include the state in the affiliation address.

The author's have made the requested change to the text on lines 8, 14, 21, and 27.

-Please define all abbreviations at first occurrence (ie TCCFA).

All abbreviations have been defined.

-Please number steps consecutively. For instance, 4.2.6 is missing.

All numbers has been confirmed.

-Please remove the word "you" from all documents, including supporting documents.

Supporting documents have been modified to remove the word "you".

-References – Please abbreviate all journal titles.

We are using EndNote and have formatted the bibliography based on JoVE settings.

•Grammar:

-Please copyedit the manuscript for grammatical errors, which is required prior to acceptance. Some example errors are listed below.

We have corrected the grammatical errors in the manuscript.

-4.1.2.1 – This should be reworded so that the mice are "undergoing a necropsy."

The text has been edited as follows: "*After humane euthanasia by CO2 asphyxiation followed by secondary measures, mice should undergo a necropsy to obtain the cecum.*" See lines 309-310.

-4.2.7 – "At this time enumerated"

The text has been edited as follows: "*4.2.6) Incubate the plates anaerobically for 24 hr at 37°C. At this time enumerate C. difficile colonies to obtain CFU per gram content (feces or cecal content).*" See lines 352-353.

-Section 5 note – "for personnel expose"

The text has been edited as follows: "*NOTE: Caution should be taken during this assay for personnel exposure to C. difficile and its toxin.*" See lines 378-379.

-Line 557 – "Feces was"

The text has been edited as follows: "*Fecal pellets were collected prior to challenge with C. difficile spores and every 48 hours post challenge (Figure 1C).*" See lines 582-583.

•Visualization: Protocol is discontinuous. The filmed portion should focus on the creation of the mouse model, including antibiotic treatment and gavage if possible. Alternatively, the title should be changed to reflect what will actually be filmed. In addition, a cohesive story should be highlighted rather than the few steps scattered throughout each section. For instance, the highlighting in section 2 would only require that some CFU counts are performed, which leaves out the bulk of the protocol.

The authors have modified the highlighting to create a more synchronous visual presentation to reflect the main purpose of the protocol.

•Additional detail is required:

-4.1.2.1 – Please provide a citation for the dissection or describe in more detail.

The authors have modified the text as follows: “*After humane euthanasia by CO2 asphyxiation followed by secondary measures, mice should undergo a necropsy to obtain the cecum. The cecum is the large, comma shaped section of the gastrointestinal tract.*” See lines 309-311.

-5.1.3 – Is the flask centrifuged?

The authors have modified the text as follows: “*Wash Vero cells with 5 ml of 1X PBS (preheated) in the tissue culture flask. Aspirate PBS and discard into waste container.*” See lines 389-390. Centrifugation is described in steps 5.1.4 to 5.1.6.

-5.6.4 – There is no step 5.5.7.

All step numbering has been confirmed.

•Branding:

-Please removing branding from supporting documents (like Milli-Q).

The authors have removed Milli-Q and other branding from the supplemental materials.

-Results – Jackson Laboratories; mice should appear in the materials table.

The authors have added this to the materials excel spreadsheet.

-Figure 4 legend - Olympus BX43F, cellSens Dimension, DP27 – all of these items should appear in the materials table.

The authors have added these items to the materials excel spreadsheet.

•If your figures and tables are original and not published previously, please ignore this comment. For figures and tables that have been published before, please include phrases such as “Re-print with permission from (reference#)” or “Modified from..” etc. And please send a copy of the re-print permission for JoVE’s record keeping purposes.

The figures in the manuscript are original.

•JoVE reference format requires that DOIs are included, when available, for all references listed in the article. This is helpful for readers to locate the included references and obtain more information. Please note that often DOIs are not listed with PubMed abstracts and as such, may not be properly included when citing directly from PubMed. In these cases, please manually include DOIs in reference information.

All references have DOIs when available.

•IMP: Please copyedit the entire manuscript for any grammatical errors you may find. The text should be in American-English only. This editing should be performed by a native English speaker (or professional copyediting services) and is essential for clarity of the protocol and the manuscript. Please thoroughly review the language and grammar prior to resubmission. Your JoVE editor will not copy-edit your manuscript and any errors in your submitted revision may be present in the published version.

•NOTE: Please include a line-by-line response letter to the editorial and reviewer comments along with the resubmission.

Reviewer comments:

Reviewer #1

Manuscript Summary:

N/A

Major Concerns:

Fig 1c, no significant difference in C diff CFU in feces collected on postinfection days of 7, 9, 11, 13 when compared to day of infection.

This is correct. There is no statistical significance noted in fecal CFU over the last week of the experiment. We used a more conservative statistical test (non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest), which did not find this statistical significant.

Fig 2a 2b, postinfection days 7 and 14 significant difference? It looks to me yes.

Again, based on the conservative statistical test performed (non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest) there is no statistical significance noted at these time points.

Minor Concerns:

The use of cefoperazone to develop a mouse model of CDI should be further scientifically justified. Mice pretreated with antibiotic mixture (Chen et al.,) can also develop no-severe diseases depending on C diff challenging doses.

The authors agree with the reviewer that depending on the inoculum dose administered that non-lethal illness can be observed. We have added the following sentence to the manuscript to address this comment:

"Depending on the inoculum dose administered, a range of clinical signs and lethality can be observed using this model." See lines 86-87.

Additional justification for the use of the cefoperazone model to study CDI were added into the introduction section as follows: *"Since administration of third generation cephalosporins are associated with increased risk of CDI in humans, use of the cefoperazone model more accurately reflects naturally occurring disease¹⁶."* See lines 93-95.

Additional Comments to Authors:

N/A

Reviewer #2**Manuscript Summary:**

The authors presented a mouse model of CDI with modified antibiotic regimen and a clinical relevant C difficile strain based on previous published models. Although the absolute advantage of this model version is debatable, the protocol is clearly written with great details, which will be helpful for CDI investigators. A few comments and suggestions are attached below; hopefully useful enough to make the protocol even better serve the CDI community.

1) The article used the term "antitoxin" multiple times based on a commercial kit. A brief description of the antitoxin or a reference would be helpful for readers to understand the principle. Is it an anti-toxin antibody derived from animals? (Polyclonal or monoclonal) Or is it *Clostridium sordellii* antitoxin?

Based on this comment the authors have added the following text to the protocol: *"The antitoxin utilized in this assay is a neutralizing polyclonal antibody prepared in goats to C. difficile toxin²⁶."* See lines 614-15.

2) Since the title of this article is "A clinically relevant platform for testing therapeutics". Therefore, an experimental example to test a therapeutic drug using this model would help validate the platform. Any data or previously published paper using this model to test a therapeutic drug would be supportive.

The authors agree with the reviewer that based on the current title that it implies that a therapeutic has been administered in the protocol. Based on this feedback we have modified the title as follows:

“Cefoperazone treated mouse model of clinically relevant Clostridium difficile strain R20291”

3) The mice were listed as male or female at 5-8 weeks old. The exact age used in the experiments of this article needs to be specified, since there are big variations in terms of size, weight and gut length in mice between 5 and 8 weeks old.

The author's have specified the exact age (5 weeks old) of the mice used in this protocol (see line 539).

4) Either a reference or a brief description of the histology scoring system would be helpful for the readers to adopt the system.

The authors included a brief description and reference for histologic scoring in the original submission. Please see text in lines 625-628 (including reference 17).

5) Recurrent CDI model is often used by investigators to examine their drug candidates. Have the authors tried that in this model setting?

The authors intend to use this model and another model that approximates recurrent CDI to evaluate drug candidates against this clinically relevant *C. difficile* R20291 strain. However, this is outside of the scope of the current protocol, which is to show researchers how to run the CDI mouse model.

6) In Figure 1b, the animal weights appear to recover after day 2, and drop a second time on day 6 and 7. Is that a repeatable phenomenon in this model?

Yes, this fluctuation in weight loss over the first week of the experiment is repeatable across multiple experiments.

7) In Figure 1c, what control value did the authors compare and reach the significant P values for day 1, 3, 5?

The authors compared all days to day 0 in the non-parametric Kruskal-Wallis one-way ANOVA test followed by Dunn's posttest.

Major Concerns:

N/A

Minor Concerns:

N/A

Additional Comments to Authors:

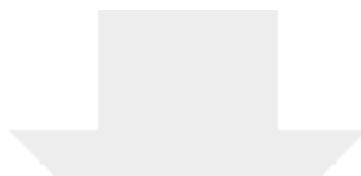
N/A



[Click here to access/download](#)

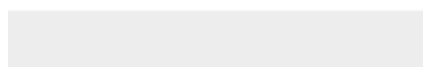
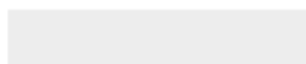
Supplemental File (as requested by JoVE)
JOVE R20291 Example Calculations.docx





[Click here to access/download](#)

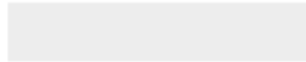
Supplemental File (as requested by JoVE)
JOVE Materials_TCCFA_Final.docx

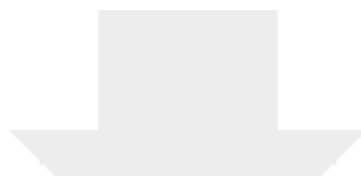




[Click here to access/download](#)

Supplemental File (as requested by JoVE)
JOVE Materials_DMEDM.docx





[Click here to access/download](#)

Supplemental File (as requested by JoVE)
JOVE Vero Cell Calculation Worksheet.docx

