

The National Antimicrobial Resistance Monitoring System

Manual of Laboratory Methods



**FOURTH EDITION
2020**

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Introduction

The National Antimicrobial Resistance Monitoring System – Enteric Bacteria (NARMS) was established in 1996 as a collaborative effort between the Food and Drug Administration's Center for Veterinary Medicine (FDA-CVM), U.S. Department of Agriculture Food Safety Inspection Service (USDA-FSIS), and the Centers for Disease Control and Prevention (CDC). The NARMS program monitors select enteric bacteria in humans, animals and retail meats for changes in resistance to various antimicrobial drugs of human and veterinary importance.

The primary objectives of NARMS are to:

1. Monitor trends in antimicrobial resistance among enteric bacteria from humans, retail meats, and animals
2. Disseminate timely information on antimicrobial resistance to stakeholders in the U.S. and abroad to promote interventions that reduce resistance among foodborne bacteria
3. Conduct research to better understand the emergence, persistence, and spread of antimicrobial resistance
4. Provide data that assist the FDA in making decisions related to the approval of safe and effective antimicrobial drugs for animals
5. Provides timely antimicrobial resistance data for outbreak investigations

Additionally, NARMS provides a national source of enteric bacterial isolates that are valuable for research such as diagnostic test development, discovering new genes and molecular mechanisms associated with resistance, studying mobile gene elements, and virulence and colonization studies.

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Equipment and Materials

1. Equipment and Supplies

Aerobic incubator, 36±1°C
AIM Auto-Inoculator (Trek¹)
Anaerobe jars (Mart Microbiology B.V.)
Anoxomat® automatic anaerobic system (Spiral Biotech)
ARIS with auto reader (Trek¹)
Bax® Q7 Instrument
Campylobacter MIC panels (CMVCAMPY) and perforated seals (Trek¹)
Cryovials
Densitcheck (bioMérieux)
Dosing Heads (Trek¹)
Dry Ice
Extended length pipette tips
Gram positive MIC panels and seals (CMV#AGP) (Trek¹)
Gram negative MIC panels and seals (CMV#AGNF) (Trek¹)
Light Cycler (Roche)
MALDI-TOF Biotyper Smart system
Microaerobic gas mixture (85% nitrogen, 10% carbon dioxide, 5% oxygen)
Microaerobic incubators 36±1°C and/or 42°C
Mirror viewing device
Re-sealable (Ziploc-type) bags
Sensititre AutoInoculator (Nephelometer & Dispenser) (Trek¹)
Sensitouch Manual plate reader with SWIN computer (Trek¹)
Sterile plate spreaders
Thermal Cycler
Vitek 2 Compact (V2C) (bioMérieux)
Vizion plate reader (Trek¹)
Vortex mixer

2. Media and Reagents

95% Ethanol
Acetonitrile²
Bactidrop ninhydrin (Remel)
Bax® System Real-time PCR Assay Kits (Dupont Nutrition and Health)
Biochemicals (arginine, arabinose, sucrose, MDGP, motility)
Bolton's *Campylobacter* Enrichment Broth (Oxoid)
Brain Heart Infusion (BHI) agar
Brain Heart Infusion broth
Brucella broth with 15-20% glycerol

¹ ThermoFisher Scientific/Trek Diagnostics

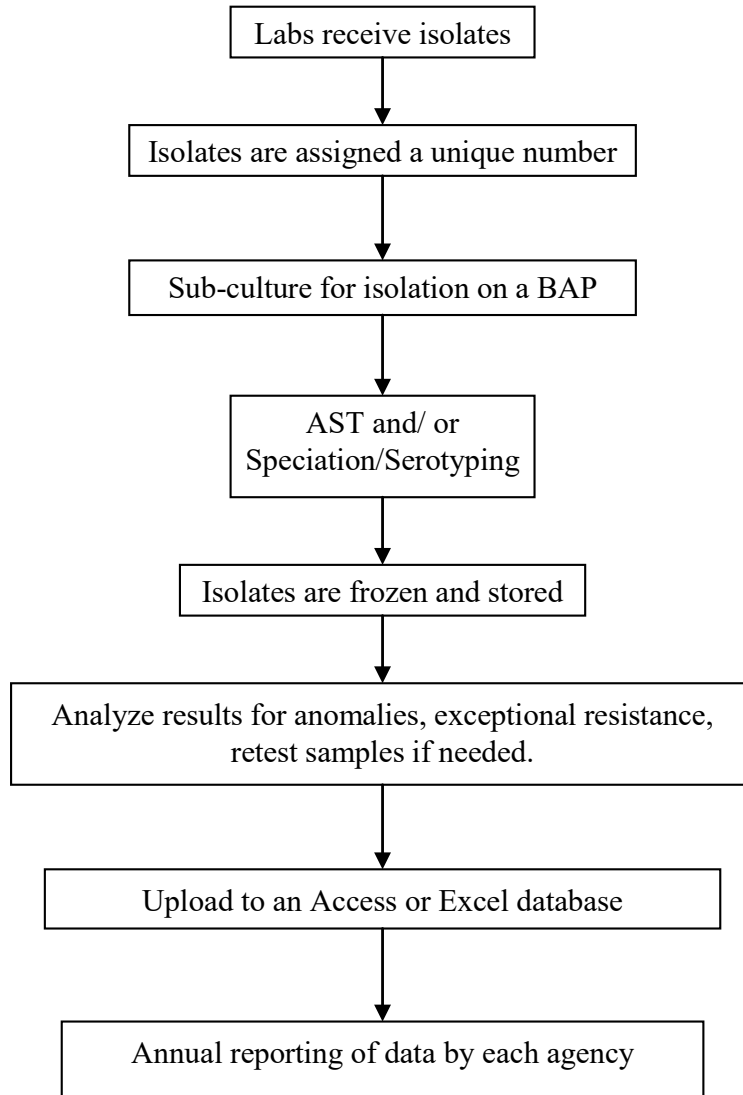
² For MALDI-TOF

Bruker Bacterial Test Standard (BTS)³
 Bruker Matrix HCCA master mix (portioned)³
 Bruker Standard Solvent³
 Campy-Cefex Agar (Hardy Diagnostics)
 Campy-CVA Agar (Remel)
 Cation-Adjusted Mueller-Hinton broth +TES, 5 ml (Trek⁴)
 Cation-Adjusted Mueller-Hinton broth + TES, 11 ml (Trek⁴)
 Chromagar ECC selective medium
 Enterococcosel Agar
 Eosin Methylene Blue (EMB) Agar
 Ethanol HPLC grade (200 proof)³
 Formic Acid HPLC grade³
 Defibrinated sheep blood
 Demineralized water , 5ml (Trek⁴)
 Guanidine hydrochloride³
 Hydrogen peroxide
 Indoxyl acetate (Remel)
 Luria Broth (LB) with 30% glycerol
 MacConkey Agar (MAC)
 Mueller-Hinton broth + TES + lysed horse blood, 11mL (Trek⁴)
 Nutrient Agar slants (NA)
 Oxidase identification sticks (Oxoid)
 Phosphate buffered saline or water
Salmonella antisera
 Sensititre 0.5 McFarland polymer turbidity standard (Trek⁴)
 Sodium Hippurate, 96% (Alfa Aesar)
 Trifluoroacetic acid³
 Trypticase Soy Agar (TSA) slants
 Trypticase Soy Agar (TSA) with 5% defibrinated sheep blood (blood agar plate, BAP) or (sheep blood agar, SBA)
 Trypticase Soy Broth with 15-20% Glycerol
 Wang's *Campylobacter* Freezing Media
 Water HPLC grade³

³ For MALDI-TOF

⁴ ThermoFisher Scientific/Trek Diagnostics

Figure 1. Overview of Isolate Processing



Salmonella & Escherichia coli (& Other Gram-negative Organisms)

A. Receipt of Isolates

Isolates are received from human, retail meats, and food animal sources. They are received either on agar slants or frozen in transport vials. Submission sheets and/or electronic files are included with shipments. Each agency works with *Salmonella* and *Escherichia coli* from different sources; therefore, the acquisition of isolates is different. For additional information please consult each agency's website.

CDC - Human *Salmonella* isolates are received from public health laboratories in all 50 states (<http://www.cdc.gov/narms>). In addition, CDC receives *Shigella* and non-cholerae *Vibrio* from the state labs and uses the method described below for antimicrobial susceptibility testing of those isolates.

FDA – Gram-negative organisms isolated from retail meat and seafood are received frozen by the FDA/CVM/NARMS laboratory from the retail meat surveillance sites. Each isolate is assigned a unique CVM/NARMS number prior to analysis. (<https://www.fda.gov/animal-veterinary/antimicrobial-resistance/national-antimicrobial-resistance-monitoring-system>).

FDA (Denver Laboratory) – *Salmonella* isolates are received from ORA laboratories. Isolates are from Domestic/Import food and feed samples.

USDA FSIS – *Salmonella* isolates from the Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) programs are isolated by FSIS Field Service Laboratories following [FSIS Microbiology Laboratory Guidebook](#) methods. *Salmonella* and *E. coli* isolates from post-mortem animal cecal contents of dairy cattle, beef cattle, swine, broilers and turkeys from federally inspected slaughter and processing plants (Cecal Sampling Program) are isolated and characterized by FSIS Eastern Laboratory.

B. Subculturing for Isolate Purity

Isolates are subcultured for purity on a BAP or MAC and incubated overnight at $36 \pm 1^\circ\text{C}$. If a culture appears contaminated or contains more than one strain type, additional selective media are used or additional isolation steps may be taken. If any isolate appears non-viable upon initial recovery, enrichment media may be used to promote the growth of the target organism. Once a pure culture is obtained, isolates are tested using the Vitek2 Compact (V2C), MALDI-TOF, serology, or other identification methods.

C. Isolate Storage

CDC - For long-term storage of *Salmonella* and *E. coli*, CDC prepares a suspension from a BAP in the appropriate medium and aliquots the suspended isolate into a cryovial for freezing.

FDA - Since FDA receives and stores all isolates frozen, the isolates are streaked for purity twice, tested and refrozen. All isolates are stored in a -70 to -80°C freezer.

USDA FSIS – *Salmonella* isolates from PR/HACCP are lyophilized and maintained for long-term storage at the FSIS Eastern Laboratory. *Salmonella* and *E. coli* isolates from the Cecal Sampling Program are frozen in LB broth with 20% glycerol and stored in a -70 to -80°C freezer.

D. Identification and Speciation of *Salmonella* and *E. coli*

CDC - *Salmonella* are identified at the primary site (state level) using standard biochemical methods, and serotyped according to the Kauffman-White scheme. Mixed or questionable isolates are confirmed by a CDC reference laboratory.

FDA - *Salmonella* speciation is performed using Whole Genome Sequencing (WGS) and SeqSero version 1 and 2 for *Salmonella* serotype determination from raw sequencing reads or genome assemblies. If there is a discrepancy between the two, SiSTR and NCBI are used to help assign a final consensus serotype. *Escherichia coli* isolates are confirmed on the V2C or MALDI-TOF.

USDA FSIS - *Salmonella* serotype is inferred from WGS raw sequencing reads or genome assemblies using SeqSero2. If serotype cannot be determined isolates are sent to the National Veterinary Service Laboratory (NVSL, Ames, IA) for serotyping. *Escherichia coli* from the Cecal Sampling Program are confirmed with real-time PCR targeting the *gadE* gene.

E. Antimicrobial Susceptibility Testing of *Salmonella* and *E. coli*

1. Gently invert a Sensititre 0.5 McFarland Polymer Turbidity Standard several times and place it in the nephelometer.
2. Press CALIBRATE on the keypad. This action will standardize the nephelometer to the center green LED light on the nephelometer.
3. Prepare a gram negative Sensititre™ panel (CMV#AGNF) for each isolate according to the manufacturers instructions. Ensure that the desiccant inside the package is orange. If the desiccant is green, discard the panel. Label each panel with appropriate identifying information. Place the panel in the AIM.

Steps 4 through 10 should be completed within 15 minutes.

4. Prepare the inoculum by selecting a few colonies from the BAP and suspend in a pre-labeled tube of 5 ml demineralized water. Vortex well.

5. Adjust the suspension to a 0.5 McFarland equivalent by using the AIM nephelometer.
6. Transfer 10 µl of the suspension (20µl for non-cholerae *Vibrio*; CDC only) to a sterile 11 ml tube of Sensititre Cation-Adjusted Mueller-Hinton Broth with TES. This transfer is performed with a sterile, extra long pipette tip. Vortex well.
7. Aseptically replace the MHB tube cap with a disposable dosing head.
8. Open the dosing head clamp, invert the inoculated MHB tube and insert it in the clamp.
9. Select the full panel dosing pattern on the LCD touchscreen display of the AIM. Select 50 µl as the required dispensing volume for the panel. Once the panel and dispensing volume are selected, press the center green image on the LCD of the AIM to begin dispensing into each well of the panel.
10. Once the MIC panel is inoculated, remove the panel from the AIM and cover it with the provided clear plastic adhesive seal. Ensure that all wells are covered.
11. Repeat steps 4 through 10 for the remaining the test isolates and controls. ***Note: The testing panel should be inoculated and placed in the incubator within 15 minutes of preparing the cell suspension.***
12. At least weekly, perform colony counts from the panel's positive control well (see [Colony Counts](#), p.20).
13. Incubate panels in the ARIS with the auto-reader or an aerobic incubator (stack no more than 4 high) at 35 ±1°C for 18 hours.
14. Panels should be read by the ARIS auto reader or visually, using the Vizion or mirrored viewing device at 18-20 hours. ARIS procedures are provided in the ARIS manual from Thermo Fisher Scientific/Trek Diagnostics.
15. In a timely manner, review the minimum inhibitory concentration (MIC) results for abnormalities as outlined in the section [Criteria for Retesting of Isolates](#). For antimicrobials where no MIC is detected by the ARIS, the panels should be visually inspected. MIC's for the folate pathway inhibitors should be confirmed manually using a mirrored viewing device.

F. Interpretive Criteria

For categorizing susceptibility, breakpoints were adopted from the most recent version of the CLSI document M100 or based on NARMS data when needed (e.g., streptomycin). Refer to the NARMS Integrated Report Data Tables for a reference table showing *Salmonella* and *E. coli* breakpoints.

G. Quality Control (QC) for testing *Salmonella* and *E. coli*

1. Antimicrobial susceptibility testing
 - a. **Control strains:** *E. coli* ATCC 25922, *Enterococcus faecalis* ATCC 29212, *Staphylococcus aureus* ATCC 29213, and *Pseudomonas aeruginosa* ATCC 27853.
 - b. **Frequency:** The QC strains are tested either daily or weekly and whenever a new lot of sterile water, MHB, or panels are used.
 - c. **Control strain storage:** Maintain stock cultures at -20°C or below for prolonged storage. Store subcultured isolates at 2 to 8°C as appropriate for the organism type. The control strain is plated from the freezer onto a BAP at least monthly and then is subcultured once prior to testing.
 - d. **Media:** For each new lot number of panel, uninoculated MHB is dispensed into the panel and the panel is then incubated for a sterility test.
 - e. **Criteria for repeat testing:** If more than 1 out of 20 or 3 out of 30 MICs for each antimicrobial agent/QC organism combination is outside of acceptable MIC limits, it is repeated for 5 consecutive test runs. CLSI guidelines (M07-ED11) are followed in the event of further QC failures.
2. Quality Assurance
 - a. Each agency has the option to participate in the WHO External Quality Assurance System (EQAS) annually to test samples for identification, antimicrobial susceptibility and serotyping. The results are recorded and posted on the WHO EQAS website.
 - b. *Inter-Agency:* AST and identification methods are exchanged bi-annually among agencies for comparability of results.
3. All final data are audited internally within each individual agency to ensure the accurate reporting of results.

Campylobacter

A. Receipt of Isolates

Isolates are received from human, retail meats, and food animal sources. They may be received on agar slants, frozen in transport vials or by primary isolation from chicken carcass rinses and turkey sponges collected by the Food Safety and Inspection Service (FSIS). Submission sheets and/or electronic files are included with the isolate shipments. Each agency works with *Campylobacter* from different sources; therefore, the acquisition of isolates is different for each group. A brief summary is given below. A more detailed description can be found at each agency's website.

CDC - Human *Campylobacter* isolates are received from ten state health departments that participate in the Foodborne Diseases Active Surveillance Network (FoodNet). Each isolate is assigned a unique CDC/NARMS number prior to analysis.
(<http://www.cdc.gov/narms>)

FDA - Retail meat *Campylobacter* isolates are received frozen by the FDA/CVM/NARMS laboratory from the retail meat surveillance sites. Each isolate is assigned a unique CVM/NARMS number prior to analysis.
(<https://www.fda.gov/animal-veterinary/antimicrobial-resistance/national-antimicrobial-resistance-monitoring-system>)

USDA FSIS - *Campylobacter* isolates from the Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) programs are isolated by FSIS Field Service Laboratories following [FSIS Microbiology Laboratory Guidebook](#) methods. *Campylobacter* isolates from post-mortem animal cecal contents of dairy cattle, beef cattle, swine, broilers and turkeys from federally inspected slaughter and processing plants (Cecal Sampling Program) are isolated and characterized by FSIS Eastern Laboratory.

B. Subculturing for Isolate Purity

1. Sub-culture isolate onto a BAP and streak for isolation. Incubate plate under microaerophilic conditions (85% N₂, 10% CO₂, 5% O₂) for 24 hours at 42°C. Alternatively, plates can be incubated at 36±1°C for 36-48 hours.
2. If there is typical *Campylobacter* growth, select a single, well-isolated colony and streak for isolation on another BAP and incubate as above.
3. If there is sufficient growth of a pure culture, the isolate is processed for identification, susceptibility testing, and freezing. Additional plates may be inoculated if more growth is needed.
4. For contaminated or mixed cultures, sub-culture on Campy-Cefex agar or a selective *Campylobacter* agar until a pure isolate is obtained.

5. Cultures remain viable up to one week on plates stored at 4°C in a microaerophilic atmosphere.

C. Recovery of Isolates Showing No Growth

1. Prepare Bolton broth with 5% lysed horse blood (no selective supplement) and aseptically dispense 2 ml into sterile 15 ml disposable centrifuge tubes (or dispense 20-25 ml into 50 ml tubes).
2. For frozen stock, thaw the entire culture vial and add it to the prepared tube of broth. For plated stock, use a sterile cotton swab to remove all growth from a plate and suspend it in broth.
3. With the screw cap loose, incubate the inoculated broth tube at 36±1°C in a microaerophilic environment for 18-24 hours.
4. After incubation, use a swab (or dispense 75 µl) to transfer the broth to a BAP. Use a loop to streak the remainder of the plate for isolation. Incubate the plate as above.
5. Re-incubate the Bolton broth at 42°C for an additional 1-2 days and streak again onto a BAP in case the initial plate fails to produce growth.
6. If one of the plates above shows typical *Campylobacter* colonies, proceed with bacterial subculturing as previously described.
7. If there is no growth or the growth is obviously atypical, record as a non-viable sample and, if possible, request the site to re-submit the original isolate.

D. Isolate Storage

For long term storage of a *Campylobacter* isolates, use a fresh (≤ 48 h/ 36±1°C or ≤ 24 h/42°C) culture on a BAP to prepare a heavy homogeneous suspension in a cryoprotective medium and store at -80°C. Two isolate storage options are recommended:

1. Prepare cell suspension in defibrinated sheep blood. Flash-freeze tubes in an ethanol/dry ice bath before transferring to -80°C.
2. Prepare cell suspension in Brucella broth, LB with 15-20% glycerol or Wang's storage medium (Brucella broth, 10% sheep blood, 15% glycerol). Transition tubes at 4°C for approximately 30 min before transferring to -80°C.

E. Identification and Speciation of *Campylobacter*

Currently, each agency uses different methods for final isolate identification and speciation. To ensure comparability, each laboratory participates in several quality assurance programs (see [Quality Assurance](#) section below). A brief description of each agency's protocol is as follows.

CDC

Campylobacter speciation is performed using WGS.

FDA

Campylobacter speciation is performed using WGS. GyrA sequence information is used for speciation.

USDA FSIS

Campylobacter speciation is performed using WGS. In house scripts based on analyses of *hipO*, *glyA*, and *bipA* genes are used with Basic Local Alignment Search Tool (BLAST).

F. Antimicrobial Susceptibility Testing of *Campylobacter*

1. Set up a rack with one 5 ml Mueller-Hinton broth tube and one 11 ml Mueller-Hinton broth containing lysed horse blood for each isolate to be tested.
2. Prepare Sensititre™ CMVCAMPY panels by removing the foil wrapper and labeling with the isolate number. Make sure the desiccant inside the wrapper is orange. Do not use the panel if desiccant is green. Place the panel in the AIM.
3. Calibrate nephelometer using the 0.5 McFarland turbidity standard. When using the Sensititre™ AIM nephelometer, calibration is complete when the center green nephelometer LED is lit.

Steps 4 through 10 should be completed within 30 minutes.

4. Use a sterile swab to pick several colonies from a BAP incubated for 48 h/36±1°C or 24 h/42°C. Suspend colonies into 5 ml Mueller-Hinton broth, vortex, and adjust to a 0.5 McFarland standard.
5. Transfer 100 µl of the 0.5 McFarland Mueller-Hinton suspension above (see [Colony Counts](#), p.20) into 11 ml Mueller-Hinton with lysed horse blood using an extra long tip, then vortex.
6. Open the dosing head clamp, invert the inoculated Mueller-Hinton broth with lysed horse blood and set inside the clamp.
7. Select the full panel dosing pattern on the LCD touchscreen display of the AIM. Select 100 µl as the required dispensing volume for the panel. Once the panel and dispensing volume are selected, press the center green image on the LCD of the AIM to begin dispensing into each well of the panel.
8. Remove the panel once the dispensing has completed and cover the panel with the provided perforated seal making sure a perforated hole is situated above each well.
9. Incubate panels in a microaerophilic atmosphere (85% N₂, 10% CO₂, 5% O₂) at 36±1°C for 48 h or at 42°C for 24 h. Do not stack panels more than four high.
10. Perform colony counts from the panel's positive control well on at least a weekly basis as described above.

11. After incubation, read the panels by visual inspection with ample light preferably using a magnifying plate reader. Growth appears as a deposit of cells at the bottom of a well or as turbid growth. The minimum inhibitory concentration (MIC) is recorded as the lowest concentration of antimicrobial that inhibits growth. Occasionally, a precipitate or amorphous “speck” may be seen in a well and should not be considered as bacterial growth when determining the MIC.
12. After results are read, check the QC strain to make sure the QC ranges are within acceptable limits. If they are not, follow corrective procedures recommended by the Clinical and Laboratory Standards Institute (CLSI Document M07-ED11).
13. In a timely, manner, review the minimum inhibitory concentration (MIC) results for abnormalities as outlined in the section [Criteria for Retesting of Isolates](#).

G. Interpretive Criteria

For categorizing susceptibility, breakpoints were adopted by epidemiological cut-off values. Refer to the NARMS Integrated Report Data Tables for a reference table of interpretive criteria used for *Campylobacter*.

H. Quality Control (QC) for testing *Campylobacter*

1. Antimicrobial susceptibility testing
 - a. **Control strain:** *C. jejuni* ATCC 33560
 - b. **Frequency:** The control strain is included with every batch of testing
 - c. **Control strain storage:** The control strain is plated from the freezer onto a BAP at least weekly and then is subcultured at least once prior to testing.
 - d. **Media:** For each new lot number of panel, uninoculated MHB with blood is dispensed into the panel and the panel is then incubated for a sterility test.
2. Quality Assurance
 - a. Each agency has the option to participate annually in the World Health Organization (WHO) External Quality Assurance System (EQAS) to test samples for identification and antimicrobial susceptibility. The results are recorded and posted on the WHO EQAS website.
 - b. Each agency has the option to participate in the National *Campylobacter* and *Helicobacter* Reference Laboratory Quality Assurance Program for *Campylobacter* spp. Identification sponsored by the CDC.
 - c. *Inter-Agency:* AST and identification methods are exchanged bi-annually among agencies for comparability of results.
3. Auditing
 - a. All final data are audited internally within each individual agency to ensure the accurate reporting of results.

Enterococcus (& Other Gram-positive Organisms)

A. Receipt of Isolates

Isolates are received from retail meats, and food animal sources. They are received either frozen in transport vials; or they are recovered by culturing cecal content samples collected by FSIS. Submission sheets and/or electronic files are included with shipments. Each agency works with *Enterococcus* from different sources; therefore, the acquisition of isolates is different for each group. For additional information please consult each agency's website.

CDC- Human *Enterococcus* isolates are no longer tested.

FDA – Gram-positive organisms isolated from retail meat and seafood are received frozen by the FDA/CVM/NARMS laboratory from the retail meat surveillance sites. Each isolate is assigned a unique CVM/NARMS number prior to analysis. (<https://www.fda.gov/animal-veterinary/antimicrobial-resistance/national-antimicrobial-resistance-monitoring-system>)

USDA FSIS - *Enterococcus* isolates from post-mortem animal cecal contents of dairy cattle, beef cattle, swine, broilers and turkeys from federally inspected slaughter and processing plants (Cecal Sampling Program) were isolated and characterized by FSIS Eastern Laboratory.

B. Subculturing for Isolate Purity

1. Subculture isolate onto a BAP.
2. Incubate the BAP overnight at 36±1°C for 18-24 hours.
3. Pick a single colony and subculture to 2nd BAP, incubate as above.

If there is no growth on the plate after 24 hours, re-incubate the plate for 48 hours. If there is no growth after 48 hours, go back to the original culture and re-streak for isolation. If there is still no growth, record no growth and ask site to resend. If an isolate displays contamination/mixed culture, a selective media (Enterococcosel Agar) may be used to isolate and purify *Enterococcus* from the sample.

C. Isolate Storage

FDA - Since FDA receives and stores all isolates frozen, the isolate is streaked for purity twice, tested and refrozen. All isolates are stored in a -70 to -80°C freezer.

USDA FSIS – Isolates are frozen in LB with 15-20% glycerol and stored in a -70 to -80°C freezer.

D. Identification and Speciation of *Enterococcus*

FDA - Isolates are identified using the V2C or MALDI-TOF using an isolated colony from the 2nd BAP plate. If the V2C or MALDI-TOF fails to produce a definitive identification, additional testing is done using molecular identification methods.

USDA FSIS - All isolates are identified using the V2C.

E. Antimicrobial Susceptibility Testing of *Enterococcus*

1. Gently invert a Sensititre 0.5 McFarland Polymer Turbidity Standard several times and place it in the nephelometer.
2. Press CALIBRATE on the keypad. Calibration is complete when the center green nephelometer LED is lit.
3. Label a gram positive Sensititre™ panel (CMV#AGP) with the isolate number. Ensure the desiccant is orange. Do not use the panel if the desiccant is green.

Steps 4 through 11 should be completed within 15 minutes.

4. Using a sterile swab, transfer several colonies from a pure culture on an 18-24 hr blood agar plate to a sterile 5 ml tube of demineralized water. Vortex well.
5. Adjust the suspension to a 0.5 McFarland equivalent by using the AIM nephelometer.
6. Transfer 10 µl of the suspension to a sterile 11 ml tube of Sensititre Cation-Adjusted Mueller-Hinton Broth with TES. This transfer is performed with a sterile, extra long pipette tip. Vortex well.
7. Aseptically replace the Mueller-Hinton tube cap with a disposable dosing head.
8. Place the panel in the AIM.
9. Open the dosing head clamp, invert the inoculated Mueller-Hinton tube and insert it in the clamp.
10. Select the full panel dosing pattern on the LCD touchscreen display of the AIM. Select 50 µl as the required dispensing volume for the panel. Once the panel and dispensing volume are selected, press the center green image on the LCD of the AIM to begin dispensing into each well of the panel.
11. Remove the panel and seal it with a clear plastic adhesive seal. Ensure that all wells are covered.
12. Repeat steps 4-11 for each additional test isolate and QC isolate to be tested.
13. Colony counts are performed at least weekly (see [Colony Counts](#), p.20).
14. Panels should be read visually using the Vizion or manual mirror at 18-20 hours.
15. Vancomycin should be read manually at 24 hours.
16. After results are read, check QC strain results to make sure they are within limits. If they are not, follow corrective procedures recommended by CLSI (M07-ED11).

17. In a timely manner, review the minimum inhibitory concentration (MIC) results for abnormalities as outlined in the section [Criteria for Retesting of Isolates.](#)

F. Interpretive Criteria

For categorizing susceptibility, breakpoints were adopted from the most recent version of the CLSI document M100. Refer to the NARMS Integrated Report Data Tables for a reference table showing *Enterococcus* breakpoints.

G. Quality Control (QC) for testing *Enterococcus*

1. Antimicrobial Susceptibility Testing
 - a. **Control Strains-** *E. faecalis* ATCC 29212, *E. faecalis* ATCC 51299, *E. coli* ATCC 25922 and *Staphylococcus aureus* ATCC 29213.
 - b. **Frequency:** The QC strains are tested either daily or weekly and whenever a new lot of sterile water, MHB, or panels are used.
 - c. **Control strain storage-** Maintain stock cultures at -80°C for prolonged storage. The control strain is plated from the freezer onto a BAP. A second pass on BAP is completed.
 - d. **Media-** For each new lot number of panel, uninoculated MHB is dispensed into the panel and the panel is then incubated for a sterility test.
2. Quality Assurance

Inter-Agency: AST and identification methods are exchanged bi-annually among agencies for comparability of results.
3. All final data are audited internally within each individual agency to ensure the accurate reporting of results.

Whole Genome Sequencing

NARMS Salmonella, Campylobacter, E. coli, and select Enterococcus are sequenced as part of routine surveillance on the Illumina MiSeq and HiSeq platforms. Data is made publicly accessible in GenBank from FDA and FSIS in the umbrella bioproject PRJNA290865; and CDC in the umbrella bioprojects PRJNA290730, PRJNA239251, and PRJNA218110. Resistance genotype information is also being reported on the NARMS website as part of NARMS Now.

Salmonella isolates that are analyzed in Denver Laboratory are sequenced on the Illumina MiSeq platform. The data is accessible in GenBank bioproject PRJNA186035.

Quality Controls for Antimicrobial Susceptibility Testing

The overall performance of the test system should be monitored by running QC each day the test is performed or, if satisfactory performance is documented (see CLSI criteria in Document M07-A10, Chapter 4), testing may be done weekly. Colony counts should also be performed weekly to ensure the final inoculum concentration is accurate.

Performance is satisfactory if no more than 3 out of 30 consecutive results for a given antimicrobial/QC organism combination are outside of the acceptable limits (CLSI documents M100 and M45 for *Campylobacter*).

If more than 3/30 results are out of control, try to determine the cause of the error and immediately retest the antimicrobial/QC strain combination for a total of 5 consecutive test days.

- If all 5 results are satisfactory, no further action is required.
- If any of the 5 results are unsatisfactory, additional sources of error should be investigated and the other NARMS laboratories should be contacted. It may be necessary to obtain a new QC strain or test materials, review test procedures, or obtain instrument service. Until the problem is resolved, reporting results and continued testing will depend on a careful assessment of the facts in consultation with the other NARMS laboratories.

In addition to routine QC testing, the CLSI (document M07-ED11) directs that QC testing should be run on each new batch of reagents and panels and that one panel should be incubated uninoculated to check for sterility. If the QC fails, the lot should be rejected.

The frozen stocks of quality control strains used for *in vitro* testing are obtained directly from the American Type Culture Collection (ATCC). Since repeated passage *in vitro* can alter strain characteristics, in-house QC strain stocks should be replenished only by purchase of fresh stock from a strain repository such as the ATCC.

Equipment and Method Quality Control

AIM Auto-Inoculator, ARIS and Vizion

To ensure the equipment is well maintained, annual preventative maintenance is performed on each piece of equipment by a ThermoFisher Scientific/Trek Diagnostics service technician. In the event problems arise with equipment, service calls are placed to ThermoFisher Scientific/TREK Diagnostics. Loaner equipment is sent to the lab while the equipment is being serviced.

Colony Counts

1. Colony counts are recorded for each test run. At a minimum, colony counts are performed on the first test isolate and at least one QC organism each day antimicrobial susceptibility testing is performed.
2. From the positive control well of the inoculated panel, transfer 10 μ l using a pipettor to 10 ml water, broth or appropriate diluent and mix by vortexing.
3. Spread plate 100 μ l from the inoculated water, broth or diluent to each of two BAPs. Ensure there is not excessive moisture on the plate surface prior to plating the suspension.
4. Incubate colony count plates with MIC panels at the appropriate temperature for that organism.
5. Average the number of colonies on the two plates and then multiply by 10^4 to obtain the total number of CFU/ml.
6. The inoculum should be between $1.0 \times 10^5 - 1.0 \times 10^6$ CFU/ml.

Criteria for Retesting of Isolates

Repeat testing of an isolate must be done when one or more of the following conditions occur:

- No growth on panel
- Growth in all wells
- Multiple skip patterns
- Apparent contamination in wells or isolate preparation
- Unlikely or discordant susceptibility results (Table 1)
- Growth in the negative control well or no growth in the positive control well

If an isolate is retested, data for all antibiotics should be replaced with the new test results. *Categorical changes may require a third test (and may indicate a mixed culture).*

Uncommon test results (Table 2) may represent emerging resistance phenotypes. Retesting is encouraged.

Table 1. Unlikely or Discordant Resistance Phenotypes

Organism(s)	Resistance Phenotype	Comments
<i>Salmonella</i> and <i>E. coli</i> ⁵	Nalidixic Acid ^R (≥ 32) AND Ciprofloxacin ^S (≤ 0.06)- <i>Salmonella</i>	The stepwise selection of mutations in the QRDR ⁶ does not support this phenotype
	Nalidixic Acid ^S (≤ 16) AND Ciprofloxacin ^R (≥ 4)- <i>Salmonella</i> and <i>E. coli</i>	
	Ceftriaxone ^R (≥ 4) AND Ampicillin ^S (≤ 8)	The presence of an ESBL ⁷ or AmpC beta-lactamase should confer resistance to Ampicillin.
	Ampicillin ^S (≤ 8) AND Amoxicillin-Clavulanic Acid ^R ($\geq 32/16$)	
	Sulfisoxazole ^S (≤ 256) AND Trimethoprim-Sulfamethoxazole ^R ($\geq 4/76$)	
<i>Campylobacter jejuni</i> and <i>coli</i>	Nalidixic Acid ^S (≤ 16) AND Ciprofloxacin ^R (≥ 1)	In <i>Campylobacter</i> , one mutation is sufficient to confer resistance to both Nalidixic Acid and Ciprofloxacin
	Nalidixic Acid ^R (≥ 32) AND Ciprofloxacin ^S (≤ 0.5)	
<i>Campylobacter jejuni</i>	Erythromycin ^S (≤ 4) AND Azithromycin ^R (≥ 0.5)	Erythromycin is a class representative for 14- and 15-membered macrolides (Azithromycin, Clarithromycin, Roxithromycin, and Dirithromycin)
	Erythromycin ^R (≥ 8) AND Azithromycin ^S (≤ 0.25)	
<i>Campylobacter coli</i>	Erythromycin ^S (≤ 8) AND Azithromycin ^R (≥ 1)	
	Erythromycin ^R (≥ 16) AND Azithromycin ^S (≤ 0.5)	
<i>Campylobacter fetus</i> and <i>lari</i>	For <i>C. fetus</i> and <i>C. lari</i> isolates: Nalidixic Acid ^S (≤ 16) OR Ciprofloxacin ^S (≤ 1)	<i>C. fetus</i> and <i>C. lari</i> are intrinsically resistant to quinolones. Consider likelihood of misidentification

⁵ CDC- in addition to *Shigella* and non-cholerae *Vibrio*

⁶ Quinolone resistance-determining regions

⁷ Extended-spectrum beta-lactamase

Table 2. Uncommon Resistance Phenotypes

Organism	Exceptional Resistance Phenotype
<i>Salmonella</i> and <i>E. coli</i>	<ul style="list-style-type: none">• Pan-resistance• Resistance to Azithromycin (≥ 32)• Resistance to Ceftriaxone (≥ 4) and/or Meropenem (≥ 4) AND Ciprofloxacin (≥ 1) and/or Nalidixic Acid (≥ 32)• Resistance to Colistin (≥ 4)
<i>Campylobacter</i>	<ul style="list-style-type: none">• Pan-resistance• Not susceptible to Florfenicol (>4)• Resistance to Meropenem (≥ 2)
<i>Enterococcus</i>	<ul style="list-style-type: none">• Pan-resistance• Resistance to Avilamycin (≥ 16 <i>E. faecalis</i>, ≥ 32 all other species)• Resistance to Linezolid (≥ 8)• Not susceptible to Daptomycin (≥ 8)• Not susceptible to Tigecycline (≥ 0.5)• For <i>E. faecium</i> and <i>E. faecalis</i> isolates: resistance to Vancomycin (≥ 32)

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