Molecular Laboratory Design, QA/QC Considerations

Rachel Lee, Ph.D.
Texas Department of State Health Services

NBS Molecular Training Workshop
March 7, 2017
Laboratory Regulatory and Accreditation Guidelines

- **US Food and Drug Administration (FDA):**
  - Approves kits and reagents for use in clinical testing
  - Proposed oversight for Laboratory Developed Test

- **Clinical Laboratory Improvement Amendments (CLIA):**
  - Regulations passed by Congress 1988 to establish quality standards for all laboratory testing to ensure the accuracy, reliability and timeliness of patient test results regardless of where the test was performed

- **College of American Pathologists (CAP):**
  - Molecular Pathology checklist

- **International Organization for Standardization standards**
  - ISO 17025:2005 General requirements for the competence of testing and calibration laboratories
  - ISO 15189:2012 Medical laboratories -- Requirements for quality and competence

- **State Specific Regulations**
  - NY Clinical Laboratory Evaluation Program (CLEP)
American College of Medical Genetics (ACMG)
Professional Guidelines

- Clinical and Laboratory Standards Institute (CLSI)

**MM14-A2**
*Design of Molecular Proficiency Testing/External Quality Assessment; Approved Guideline—Second Edition*

**MM17-A**
*Verification and Validation of Multiplex Nucleic Acid Assays; Approved Guideline*

Preview Sample Pages

This guideline provides recommendations for analytic verification and validation of multiplex assays, as well as a review of different types of biologic and synthetic reference materials.
Professional Guidelines

- Clinical and Laboratory Standards Institute (CLSI)

**NBS06-A**

Newborn Blood Spot Screening for Severe Combined Immunodeficiency by Measurement of T-cell Receptor Excision Circles; Approved Guideline

**MM05-A2**

*Nucleic Acid Amplification Assays for Molecular Hematopathology; Approved Guideline—Second Edition*

Preview Sample Pages

This guideline addresses the performance and application of assays for gene rearrangement and translocations by both polymerase chain reaction (PCR) and reverse-transcriptase PCR techniques, and includes information on specimen collection, sample preparation, test reporting, test validation, and quality assurance.
Professional Guidelines

- Association of Molecular Pathologists

The Journal of Molecular Diagnostics

Volume 17, Issue 2, March 2015, Pages 107–117

Special article

Reporting Incidental Findings in Genomic Scale Clinical Sequencing—A Clinical Laboratory Perspective: A Report of the Association for Molecular Pathology

Madhuri Hegde\*,†,‡, Sherri Bale\*,§, Pinar Bayrak-Toydemir\*,¶,‖, Jane Gibson\*,†‡, Linda Jo Bone
Jeng\*,††, Loren Joseph\*,‡‡, Jordan Laser\*,§§, Ira M. Lubin\*,¶¶, Christine E. Miller\*,∥∥, Lainie F. Ross\*,†∥∥, Paul G. Rothberg\*,†††, Alice K. Tanner\*,†,‡, Patrik Vitazka\*,§, Rong Mao\*,∥∥
Molecular Laboratory Design
Contamination

- Introduction of unwanted nucleic acids into specimen
  - the sensitivity of PCR techniques makes them vulnerable to contamination

- Repeated amplification of the same target sequence leads to accumulation of amplification products in the laboratory environment
  - A typical PCR generates as many as $10^9$ copies of target sequence
  - Aerosols from pipettes will contain as many as $10^6$ amplification products
  - Buildup of aerosolized amplification products will contaminate laboratory reagents, equipment, and ventilation systems
Nucleic acid amplification procedures (e.g., PCR) are designed to minimize carryover (false positive results) using appropriate physical containment and procedural controls.

NOTE: This item is primarily directed at ensuring adequate physical separation of pre- and post-amplification samples to avoid amplicon contamination. The extreme sensitivity of amplification systems requires that the laboratory take special precautions. For example, pre- and post-amplification samples should be manipulated in physically separate areas; gloves must be worn and frequently changed during processing; dedicated pipettes (positive displacement type or with aerosol barrier tips) must be used; and manipulations must minimize aerosolization. In a given run, specimens should be ordered in the following sequence: patient samples, positive controls, negative controls (including “no template” controls in which target DNA is omitted and therefore no product is expected). Enzymatic destruction of amplification products is often helpful, as is real-time measurement of products to avoid manual manipulation of amplification products.

Evidence of Compliance:
✓ Written procedure that defines the use of physical containment and procedural controls as applicable to minimize carryover
Potential Sources of Contamination

- Cross contamination between specimens
- Amplification product contamination
- Laboratory surfaces
- Ventilation ducts
- Reagents/supplies
- Hair, skin, saliva, and clothes of lab personnel
What Happens If Lack Of Contamination Control

- Incorrect results
- Require extensive cleanup
- Loss of creditability
- Financial and performance impact
How to Control Contamination

- Laboratory design
- Laboratory practices
- Chemical and enzymatic controls
Setting Up a Molecular Laboratory

- Mechanical barriers to prevent contamination
- Spatial separation of pre- and post-amplification work areas
  - Area 1 – Reagent preparation
  - Area 2 – Specimen/control preparation, PCR set-up
  - Area 3 – Amplification/product detection, plasmid preparation
- Physically separated and, preferably, at a substantial distance from each other
Unidirectional Flow

- Both personnel, including cleaning personnel, and specimens
- Amplification product-free to product-rich
- Remove PPE before leaving one area
- Avoid or limit reverse direction
- Reusable supplies in the reverse direction need to be bleached.
Unidirectional Workflow

Backflow traffic – must be restricted to minimum!

Reagent Preparation Room/Area
- Reagent Storage
- Reagent Preparation
- Master Mix Preparation

Sample Preparation Room/Area
- Specimen Preparation
- Nucleic Acid Isolation

Amplification Room/Area
- Amplification
- Detection Analysis

Airflow Outward
- Permitted workflow

Airflow Inward
- Restricted workflow

CLSI MM19-A Establishing Molecular Testing in Clinical Laboratory Environments
Features of the 3 Areas

• Each area has separate sets of equipment and supplies
  • Refrigerator/freezer (manual defrost)
  • Pipettes, filtered tips, tubes, and racks
  • Centrifuge, timers, vortex
  • Lab coat (color-coded), disposable gloves, safety glasses, and other PPE
  • Cleaning supplies
  • Office supplies
  • Ventilation system

• Dead air box with UV light – serves as a clean bench area
Features of the 3 Areas

- Air pressure
  - Reagent Prep – Positive
  - Sample Prep - Negative
  - Postamplification - Negative

- Reagent Prep – Single entrance, reagents used for amplification should not be exposed to other areas

- Specimen Prep – Specimens should not be exposed to post-amplification work areas

- Size of each area should consider space for equipment and bench space needed for preparation
Laboratory Design Example
http://fx.damasgate.com/the-pcr-laboratory/
Two Areas Only

- Area 1 – Reagent prep, specimen prep, and target loading – use of laminar-flow hoods
- Area 2 – Amplification/product detection
Alternative to Spatial Separation

- Class II biological safety cabinet
- Dedicated areas for each work phase
- Unidirectional
- Automated specimen processing station/closed-tube amplification and detection system
Core Laboratory Concept

- On site – e.g. combine with microbiological testing
- Off site – e.g. academic institute
Other Laboratory Design Considerations

- Temperature and humidity requirements
- Exhaust ventilation
- Water quality
- Electric outlet
- Back-up power system
- Eye wash
- Ergonomic assessment
- Need for storage area
- Need for waste disposal area
Laboratory Practices

- Use of positive displacement pipettes and disposable filtered pipette tips
- Avoid production of aerosols when pipetting
- Use of sterilized single-use plasticware
- Use of cleanroom sticky floor mats
- Minimizes the risk of amplicon carry-over on clothing, hair and skin
  - Hairnet
  - Dedicated safety glasses
  - Disposable labcoat/gown, color-coded preferred
  - Gloves, need to change periodically
  - Shoe covers
More Laboratory Practices

- Clean punches between samples
- Use of nuclease free or autoclaved water
- Aliquot oligonucleotides – multiple freeze thaws will cause degradation
- Always include a blank (no template) control to check for contamination
- Use of electronic data system (flow of paper)
- Wipe test (swab test)
  - Monthly
  - Detect, localize, and remove contamination
  - Identify the source of the contamination
Decontamination Approaches

- Clean the work area & equipment routinely
  - Clean the PCR workstation at the start and end of each work day/run (UV light, 70% ethanol, fresh 10% sodium hypochlorite, DNA Away)
- Clean the exterior and interior parts of the pipette
- Clean the equipment
- Clean the doorknobs, handle of freezers
Chemical and Enzymatic Controls

- Work stations should all be cleaned with 10% sodium hypochlorite solution (bleach), followed by removal of the bleach with ethanol and water.
- Ultra-violet light irradiation
  - UV light induces thymidine dimers and other modifications that render nucleic acid inactive as a template for amplification
- Enzymatic inactivation with uracil-N-glycosylase
  - Substitution of uracil (dUTP) for thymine (dTTP) during PCR amplification
  - New PCR sample reactions pre-treated with Uracil-N-glycosylase (UNG) – contaminating PCR amplicons are degraded leaving only genomic DNA available for PCR
Quality Controls

Monitor all steps of analytical procedure

- Types of Control
- Frequency and Number of Controls
- Evaluation of Controls and Calibrators
Types of Controls

• Internal Control
  • Internal positive amplification controls to detect failure of DNA extraction or PCR amplification
    • Reagent or equipment issues
    • Integrity of DNA sample
    • Presence of inhibitory substance

• External Control
  • Positive control
  • Negative control (normal, wild type)
  • No template control (extraction blank)
  • Blank
Internal Controls

Reference gene (e.g. RNaseP)
External Controls

- Positive and negative controls:
  - Inhibitors
  - Component failure
  - Interpretation of results
- Sources:
  - Residual DBS
  - PT samples
  - QC materials

- No template controls and Blanks:
  - Nucleic acid contamination during extraction
  - Nucleic acid contamination during PCR
Frequency and Number of External Controls

- Based on risk
- Ideally should represent each target allele and include in each run, but may not be feasible when:
  - Highly multiplex genotypes
    - Systematic rotation of different alleles as positives
    - Specimens representing short and long amplification products to control for differential amplification
  - Rare alleles
- Quantitative PCR
  - External controls should represent more than one concentration, e.g. low and high positives and negative, covering the analytical measurement range
  - Daily run or with each runs
- After equipment maintenance, new operator, new reagent lot/shipment
Calibrators

- Calibrator copy levels should cover analytic cut-offs
Size Marker

- Include in each run that involves size separation
Evaluation of Controls and Calibrators

- **Pass/Fail Criteria** – established during validation study
  - **Parameters**
    - Specific PCR product bands
    - Specific DNA fragments
    - Quantity or Ct of reference gene
    - Quantity or Ct of targeted marker
    - Slope, R2, and Y-intercept of Calibrator curve
  - **Threshold**
    - Presence or absence of DNA bands
    - Above or below LoB
    - Above or below cut-offs
    - Within Mean ± 2SD, Mean ± 3SD, or Mean ± 10%
  - % of controls acceptable
  - Impact the entire run or only affected samples
Allele drop-out (ADO)

- The failure of a molecular test to amplify or detect one or more alleles

- Potential causes:
  - DNA template concentration
    - Incomplete cell lysis
    - DNA degradation
  - Non-optimized assay conditions
  - Unknown polymorphisms in target sites
  - Reagent component failure
  - Interfering substance, [http://www.aphl.org/aphlprograms/newborn-screening-and-genetics/Pages/Assuring-Laboratory-Quality.aspx](http://www.aphl.org/aphlprograms/newborn-screening-and-genetics/Pages/Assuring-Laboratory-Quality.aspx)

- Major concern for screening laboratories
  - Confirmation of mutation inheritance in families may not an option
False Amplification

Potential causes:

- Non-optimized assay conditions
- Unknown polymorphisms in target sites
  - Gene duplications
  - Oligonucleotide mis-priming at related sequences
    - Pseudogenes or gene families
- Oligonucleotide concentrations too high
- Nucleic acid cross-contamination
What to do if control fails?
Proficiency Testing

- Assessment of the Competence in Testing
- Required for all CLIA/CAP certified laboratories
- Performed twice a year
- If specimens are not commercially available alternative proficiency testing program has to be established (specimen exchange etc.)
Molecular Assay Proficiency Testing and Reference Material Sources

- CDC NSQAP
- CAP
- In-house samples
- Round-robin with other NBS laboratories
- Corielle
- European Collection of Authenticated Cell Cultures (ECACC)
- United Kingdom National External Quality Assessment Service (UK NEQAS)
- EuroGentest
- Acrometrix
- Advanced Biotechnologies
- Asuragen
- Diagnostic Hybrids
- Horizon Discovery
- Invivoscribe
- LGC Standards
- Maine Molecular Quality Controls
- Molecular Controls
- QIAGEN Marseille (formerly Ipsogen)
- Qnostics
- Seracare Life Sciences
- Zeptometrix
Reagents

- Labeling Reagents:
  - Content, quantity, concentration
  - Lot #
  - Storage requirements (temperature etc.)
  - Expiration date
  - Date of use/disposal

- Know your critical reagents (enzymes, probes, digestion and electrophoresis buffers) and perform QC checks as appropriate
Critical Molecular Assay Components

- Nucleic Acids: Prepare aliquots appropriate to workflow to limit freeze-thaw cycles
  - Primers and probes
  - dNTPs
  - Genomic DNA
    - 4-8°C
    - -15 to -25°C
- Enzymes
  - Benchtop coolers recommended
- Fluorescent reporters
  - Limit exposure to light
  - Amber storage tubes or wrap in shielding (foil)
CAP Requirement on TAT

- CBG.20140 Out-of-Range/Invalid Results Phase II

There is a policy for reporting positive (out of range) or invalid results to the submitting location and other appropriate entities to allow for patient follow-up within a timeframe appropriate to ensure maximum health benefit.

NOTE: Positive results include those results that are outside of the expected range of testing results established for a particular condition. Invalid results include situations where the laboratory is unable to complete the screening process due to an unsuitable specimen, test, or incomplete information. The findings must be communicated in a manner consistent with the urgency of the intervention needed. For situations requiring repeat screening or confirmatory testing, the laboratory must clearly communicate the timing of the actions to be taken.

Results must be reported to the submitting location (at minimum) within 7 days of specimen receipt and within 3 days for specimens received for tests requiring additional action (e.g. invalid or positive). The records should indicate when results were reported and who received the results. In cases where the testing laboratory is responsible for documenting that a return specimen has been received and analyzed, appropriate records should attest to specimen receipt, testing and result reporting.
Other QA/QC Considerations

- Validation studies
- Sample acceptance and tracking
- Specimen storage
- Laboratory Cleanliness, and Waste Disposal
- Instrument Maintenance and Calibration
- Instrument/Method Comparison
- Document Management
- Personnel Training and Competency
- Periodic Review of QA/QC
- COOP Plan
Take Home Messages

- Separate laboratory spaces for Reagent Prep, Sample Prep, and Amplification and Detection
- Precautions and special laboratory practices must be made to minimize the risk of contamination
- A Quality Control Plan to monitor the quality of testing process and detect errors should be in place for each new test before it’s implemented.
- Continuous quality improvement is essential