Quality Assurance Procedures for Digital Radiography

Charles E. Willis, Ph.D., DABR
Associate Professor
Department of Imaging Physics
The University of Texas M.D. Anderson Cancer Center
Houston, Texas

Learning Objectives:
- Review components of a QA program and show how they apply to DR.
- Understand how some conventional tests should be modified for a digital radiographic system integrated into an electronic image management system.
- Identify key references and standards that can be useful in QA of DR.

Quality Assurance (QA) is...
- All activities that ensure consistent, maximum performance from physician and imaging facility (NCRP 99; 1988)
- Mandated in radiology by ACR Standards
- Often confused with Quality Control (QC)
  - AKA QI, CQI, PI, TQM = constantly seeking improvement
  - Vehicle for providing highest quality medical care

Alternate definition of Quality Assurance (QA)

Are we operating the devices properly?
Are the devices, themselves, operating properly?
Are the devices properly supported?
Some traditional components of a QA Program

- QA Committee
- Policies and Procedures
- Reject Analysis
- Radiologist Film Critique
- Operator QC Activities
- Service Events
- Technologist Inservice training
- Medical Physicist QC Activities
- Incident investigation/troubleshooting

Quality Control is ...

- Most tangible aspect of QA
- "...a series of distinct technical procedures which ensure the production of a satisfactory product."
- Four major aspects:
  - Acceptance testing of new equipment or post major repair
  - Establishment of baseline performance
  - Diagnosis of changes in performance before radiologically apparent
  - Verification of corrective action

Who is responsible for QC?
("It takes a village ..." Sen. H. Clinton, Health Care Expert)

- Physician responsible for clinical service is ultimately responsible
- Medical Physicist oversees the program
- QC Technologist makes day-to-day measurements, verify post-repair integrity
- Service engineer carry out repairs, PM, calibrations

“What’s my motivation?”
(unknown screen actor)

- Regulatory Compliance
  - Title 12, Code of Federal Regulations (CFR) Part 20, Standards for Protection against Radiation
  - State regulations http://www.tdh.state.tx.us/radiation/
- Standards of Care
  - ACR Standard for Diagnostic Medical Physics Performance Monitoring of Radiographic and Fluoroscopic Equipment
  - ACR Radiography and Fluoroscopy Accreditation Program
  - NCRP Report No. 99 “Quality Assurance for Diagnostic Imaging”
  - Nationwide Evaluation of X-ray Exposure Trends (NEXT)
  - Reference Values
- Providing the highest quality medical care
- MANAGING RADIATION DOSE!!!

Many factors affect image quality and patient dose

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<tr>
<th>Factor</th>
<th>Contrast</th>
<th>Resolution</th>
<th>Noise</th>
<th>Patient Dose</th>
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<td>Beam filtration</td>
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Where can we find instructions for how to perform QC tests?


Medical Physicist’s Worst Nightmare

- “They’re installing the new DEMI-RAD™ system tomorrow.”
- “We need you to come tell us if it’s okay to use with patients.”
- “BTW, we’re scheduling patients on it for Monday.”

Your first thoughts …

- “What the heck is a DEMI-RAD™?”
- “How bad do I need this job?”
- “Where is that monograph from the AAPM 2004 Summer School?”
Is this a plausible scenario?

- 3 categories of DR plus CR
- 17 DR manufacturers of 37 products plus 5+ CR vendors
- This was 4 years ago

What is “Acceptance”?

- Acceptance is a process whereby a customer determines whether ...
  - “newly installed imaging equipment is functioning as designed,
  - “complies with regulatory standards, and
  - “produces high quality images.”
- Data gathered during acceptance testing establishes a baseline for later quality control (QC) testing.
- There are legal, financial, and warranty consequences to acceptance.

Acceptance testing is an opportunity ...

- To identify and resolve discrepancies prior to clinical use
- To become familiar with the controls and operation of the equipment
- For Continuing Education on new technology and products

Acceptance testing (AT) could be as simple as an inspection and inventory.

- Verification that what was purchased was indeed delivered and installed.
- Purchasing agent, radiological technologist, or biomedical engineer may not recognize missing critical components.

What about functional tests?

- May test all operator controls to determine if they function.
- May test the manufacturer’s claims of performance.
- May test specific performance that was crucial to the selection of this equipment.
  - May or may not be contract provisions
  - Ex: Throughput
- May test compliance/conformance with industry standards of practice.
  - Ex: DICOM, IHE
- May test whether manufacturer’s installation instructions were followed.
- May collect “engineering data” for later reference.

Clinical Acceptability is the trump card!

- Any Diagnostic Radiographic Imaging System must produce images of sufficient quality to support clinical diagnosis at reasonable radiation dose to the patient.
  - Physician defines diagnostic quality
  - Regulatory bodies may define reasonable dose, else comparison to standard of care
- Humans must be able to safely operate the equipment

Machines that produce radiation are subject to government regulations

- Irrespective of the detector technology, you must assess the degree to which the x-ray generator allows the precise and reproducible control of the primary imaging technique factors
  - kilovoltage (kVp)
  - tube current (mA)
  - exposure duration (msec)
- Evaluation of Automatic Exposure Control (AEC) devices differs because “consistent and reproducible Optical Density (OD)” is no longer an appropriate criterion.
- Evaluation of focal spot size (“measure me first!”) and “congruence / positive beam limitation may differ.
- Total filtration (HVL) and leakage radiation are measured the same.

Lesson #1: Tests that rely on the receptor to assess generator performance must be modified.

Non-invasive kVp measurement of a DR system

Lesson #2: Tests that involve production of large amounts of radiation require protection of the image receptor.

Sensors in beam

No sensors in beam...
It might be nice to have the DEMI-RAD™ service engineer present during testing

- To assist you with operation of the machine
  - Test modes
  - Vendor-supplied tests
- To provide technical references such as the service manual or installation instructions
- To observe your measurements
  - to "share the experience"
  - in case of "questions" from the factory
- To correct deficiencies on-the-spot when possible

Let's consider the “DEMI-RAD™” system to be a “black box”

- Gain
- Characteristic
- Uniformity
- Contrast
- Sharpness
- Noise
- Artifacts
- Dose

How can I test the imaging functions of a “black box”?

- A fixed input should produce a specific output (Gain).
- Output should bear a specific relationship to input (aka Characteristic function).
- Input that is uniform in two dimensions should produce uniform output (aka Flat-field).
- Projected details will be represented in the output with a particular contrast and sharpness.
- Output will contain noise related to noise in the input and internal sources of noise.
- Output should be free from artifacts.
- Identical black boxes should produce similar output.
- Output should be free from signal from previous output (erase).
- Output involves a penalty, that is, radiation dose to the patient

What is “output”?

- Could be laser-printed film
  - Measure with densitometer
- Could be luminance from monitor
  - Measure with photometer
- Could be digital values
  - Measure with Region of Interest (ROI) or Pixel tool by viewer software
  - Code values (CV) = Pixel values (PV) = grayscale values (GY) = quantization levels (QL)
- Could be derived indicator of exposure
  - Includes "metadata" from the DICOM header
  - Must address calibration of both output device and measurement device before collecting acceptance data
Important information about DR acquisition and processing is in metadata

- CR vs. DX object
- Mandatory vs. optional vs. private tags
- Automatic vs. manual entry of data
- PACS interpretation of metadata

Lesson #3: Assessment of DR performance likely involves access to DICOM images

Gain

- Set technique factors according to manufacturer specification
- Measure/calculate the radiation exposure to the detector
- Measure the output of the system
- Complications
  - Auto-ranging
  - Bucky factor

Exposure indicators in Computed Radiography - exposure delivered to detector

- Fuji
  - S number: Sensitivity Number
    - $1\text{ mR at }80\text{kVp} = 200$
    - $200/S \times X$
- Kodak
  - EI: Exposure Index (mbels)
    - $1\text{mR at }80\text{kVp} + 1.5\text{mm Al and }0.5\text{mm Cu} = 2000$
    - $+300 \text{ EI} = 2X \text{ and } -300 \text{ EI} = 1/2X$
- Agfa
  - lgM, logarithm of the Median of the histogram, (bels)
    - $20\text{µGy at }75\text{kVp} + 1.5\text{mm Cu} = lgM= \pm 0.3$
    - $+0.3 \text{lgM} = 2X \text{ and } -0.3 \text{lgM} = 1/2X$
- Konica
  - S value, similar to Fuji

Exposure indicators in Direct Radiography - exposure delivered to patient

- GE
  - DAP, Dose Area Product, $\text{dGy-cm}^2$
  - "ESE", Entrance Skin Exposure, mGy, at 25 cm (default)
- Philips/Beimens/Thompson (Trexel)
  - DAP
  - EI: Exposure Index or Indicator, similar to S (Philips - exception)
- Canon (exception)
  - REX, Reached Exposure Value, (Brightness, Contrast)
- Hologics (semi-exception)
  - Exam Factor, Center of Mass of log E Histogram, old
  - DAP and "Accumulated Dose" for exam, new
- SwissRay
  - mA, sec, field size, kVp, no exposure indicator, old
  - New: similar to Agfa lgM
There is a documented tendency to overexpose in CR and DR

- Oversight of exposure factor selection is impossible without an exposure indicator

How much exposure was used?

  - QA based on exposure indicators reduces doses
- Willis Radiol(2002) 32:745-750
  - 33% dose reduction if exposure indicator target followed
- AAPM Task Group #116 is effort to standardize indicators
Exposure Indicator
from image of calibrated stepwedge, REX adjusted until each step disappears

Characteristics function
- Vary the input
  - Change mAs
  - Stepwedge
- Measure output
- Complications
  - Digital Look-up Tables (LUT)
  - Auto-ranging
  - Energy dependence of code values: Beam hardening

Spectral dependence of characteristic function

A very fancy calibrated stepwedge

AGFA Test Object 75 kVp +1.5 mm Cu, 47 µGy exit
Display processing curve for Chest from ROI of each step of image of calibrated stepwedge

“Linear” Display processing Look-up Table (LUT) is actually log-linear

REX depends strongly on Brightness and Contrast setting!

Flat-field

- Using large Source-to-image Distance (SID), produce a uniform input.
- Inspect and measure the uniformity of the output.
- Complications
  - Heel effect: if possible, rotate detector 180°
  - Backscatter: Pb backing or tabletop
  - Fixed SID

Uncorrected DR image is inherently non-uniform

How many defects are acceptable?

Lesson #5: Assessing the receptor may require access to uncorrected image.

Non-uniformities are corrected by “flat-fielding”

Artifacts related to gain and offset correction

GE DR

Canon DR

Lesson #6. A grayscale histogram is also helpful in assessing the receptor.

Contrast: what kind?

- **Contrast**
  - slope of detector characteristic
- **Contrast resolution**
  - Detector ability to distinguish features of similar signal level
  - Grayscale bit depth
- **Contrast detectability**
  - Observer ability to distinguish features of similar signal levels
Same exposure conditions

Identical machine, same exposure conditions

Calibrated step wedge: ROI indicates loss of latitude

LucAl Chest phantom w/QC object
Spatial resolution
- \( f(d) \) (digital matrix size), i.e. pixel dimensions
- Nyquist frequency = \( \frac{1}{2} \) sampling rate
  (need two pixels to represent a line pair)
- Bar patterns oriented orthogonal to matrix, else 1.414 factor high

Practical resolution is less than the Nyquist frequency

Factors besides sampling compromise sharpness
- X-ray focal spot dimensions
- Blur in Indirect DR and CR
- Optical and mechanical imprecision in IDR and CR
- Afterglow in fast-scan dimension in CR

Limit of resolution is where Modulation Transfer Function (MTF) has decreased to 10%
Primary, unavoidable source of noise in radiographic imaging is quantum noise
- Absolute magnitude of quantum noise increases with $\sqrt{D}$
- Standard deviation of ROI is an indication of noise
- Complication
  - Non-linear Characteristic function

Combination of quantum noise and anatomic noise limits low contrast detection

When pixel value is proportional to $\log D$, SD of ROI should be proportional to $D^{-1/2}$

$\text{SD pixel} = 0.0126x - 0.4943$
$R^2 = 0.9982$

$\text{SD mR/Ave mR} = 0.0126x - 0.4943$
$R^2 = 0.9982$

SNR should improve with exposure

$y = 2.4057 \ln(x) + 19.987$

$R^2 = 0.9984$

Variation in Exposure-dependent SNR is improved by gain and offset calibration

Eleven GE DR systems, LucAl Chest phantom at 125 kVp
SNR from central ROI of "for processing" image

Before calibration
After calibration

Lesson #1: Performance data on large numbers of DR systems under simulated clinical conditions are needed to establish action limits

New artifacts from the discrete nature of DR

- Interference pattern between fixed grid lines and down-sampling rate for display
- Disappeared on zoom
- Bad choices
  - Display default magnification factor
  - Line rate of grid

Configuration management

Main Department Orthopedic Department
**Entrance Exposure**

- Position representative material between tube and detector:
  - CDRH phantoms
  - ANSI/AAPM phantoms
  - ACR Phantoms
  - Acrylic/lucite blocks
  - Cu or Al filter on collimator \(\Rightarrow\) scatter-free
- Use appropriate clinical technique settings.
- Use AEC if appropriate.
- Measure entrance exposure and record output.
- Compare to regulations, national trends, or reference levels.


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**Erasure**

- Re-usable image media (RIM)
- Consequences of poor erasure
  - “Ghost” structures
  - Noise
- Immediately subsequent to normal exposure, produce image with no input and high gain setting. Inspect output.

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**Anthropomorphic phantoms**

- Approximate clinical subject
- Complication: non-human histogram

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**When is an anthropomorphic phantom not anthropomorphic?**

- "Lawyer" Phantom
- Inadequate subject contrast

Before calibration | Post calibration

\[ S = 283, L=1.8 \]

\[ S = 557, L=1.6 \]
Phantoms may not adequately represent radiographic projections of human anatomy

Pass/fail criteria: How do you know?

- Government regulations
- Specifications and service manuals
- Scientific literature
- Comparison with other devices or customer experience

Summary of four additional tests

- Flat-field => Gain and uniformity
  - Manufacturer's conditions
  - Measure exposure
- Calibrated Stepwedge => detector characteristic, display processing, contrast, noise
- Bar patterns => spatial resolution
- Erasure => "base plus fog"
- Entrance exposure => patient dose
  - Not an extra test!

A postscript on Quality Control...

- Still necessary with digital radiography
- Repeat acceptance tests periodically and incidental to service events
- Routine QC must be performed by operators/supervisors of system
Institute processes to detect, correct, report, and document errors.

- Check images before release and archive.
- Exercise vigilance over rejected images.
  - Analyze reasons for repeated exams
  - Take action based on the analysis

Perform and document cleaning and maintenance on a regular basis.

Automated evaluations of the image receptor

What do you do with the QC data?

- Because systems are relatively new, manufacturers are uncertain about longitudinal data
- Lower limit for test is MTF @ 2.5 lp/mm = 17%
- CsI(Tl) is hygroscopic - columnar structure is degraded
- Both systems depicted required detector replacement
Involve all local resources in a team approach to the QC effort.

- Radiologist
  - Ultimate responsibility for quality of images
  - Department can provide only the lowest quality that is acceptable to radiologist
- Radiology Administrator
  - Responsible for efficiency of imaging operations
- Radiology Lead Technologist
  - First-line supervision of quality control operations
- Clinical Engineer
  - Responsible for equipment life cycle management
- Medical Physicist
  - No other person has image quality as first priority

References:
Comprehensive QC Plan for CR