DICOM Implementations for Digital Radiography

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Disclosures

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Learning Objectives

• Projection radiography and DICOM
• Requirements and design of DX objects
• Implementation strategies
  – Creator of images (modality)
  – Consumers of images (PACS/workstations)
• Status and adoption
• Purchasing strategies
Relevance of DICOM

• DICOM is only an interface/integration tool
• Most benefits of digital detectors unrelated:
  – Quality and characteristics of acquired images
  – Rapid patient turn-around (no processing wait)
• But, DICOM has services to improve …
  – In-room and enterprise-wide workflow
  – Hanging efficiency
  – Distributed consistency of image appearance
DICOM and Workflow

• Bad “old” days:
  – modality operator types in patient and study identification and often makes mistakes
  – such mistakes -> PACS/RIS mismatch with requests, wrong routing, “lost” studies, etc.

• DICOM Modality Worklist
  – choose from pick-list of tasks (+/- bar code)
  – greatly reduces such errors
  – more “header” information pre-populated
Each “instance” of a task is a “procedure step” (an entry on a worklist)

Modality Worklist (MWL)
Purchasing Guideline #1

Do not buy a DX or CR or PACS without DICOM Modality Worklist!

Why?

Single greatest DICOM-related contributor to improved system productivity
Worklist vs. IHE SWF Profile

• Integrating the Healthcare Enterprise
• Scheduled Workflow Integration Profile
• Includes DICOM Modality Worklist
  – Additional assumptions and constraints
• Modality Performed Procedure Step
  – Lets RIS/PACS know what was done, completion
• Storage Commitment
  – Makes sure images have been stored, before locally purging
DICOM Storage (Transfer)

• DICOM consists of services for storage (transfer) of images, presentation states and reports across the network and on media.

• Other DICOM services for query and retrieval of objects, workflow management, storage management and printing.
DICOM Storage Objects

• Projection radiography objects
  – Computed radiography (CR)
  – Secondary capture (SC) - for film/screen
  – X-ray Angio/Radioflouroscopy (XA/XRF)
  – Digital X-Ray (DX, MG, IO)

• Cross-sectional objects
  – Computed Tomography (CT)
  – Magnetic Resonance (MR)
  – Ultrasound (US), Nuclear Medicine (NM) ...
DICOM Storage Objects

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DICOM CR Image Object

• CR
  – doesn’t describe new detectors well
  – no useful grouping images by series
  – multiple exposures per image allowed
  – anatomy, view etc. poorly described
  – grayscale not defined
  – relation to x-ray intensity not defined
  – processed vs. unprocessed controversy
DICOM Issues for a PACS

- Services adequate (store, Q/R etc)
- Application (esp. reporting) limitations:
  - routing of images (worklist or station)
  - identification of image/exam type
  - grouping of images
  - layout of images
  - grayscale appearance of images
DX Design Goals - Technologies

• Support established technologies
  – Computed Radiography
  – Thoravision (selenium drum)
  – Optically scanned film
  – CCĐs for small area (dental, mammo bx)

• Support more recent technologies
  – large flat panels (+/- scintillator)
  – slit scans, etc.
DX Design Goals - Features

• New technology & new characteristics
• Characteristics of image pixel data
  – Contrast changes & image processing
  – Relationship to X-ray intensity
• Quality control needs description of
  – Acquisition
  – Detector behavior & identification
  – Dose
DX Design Goals - PACS Issues

• Modality and PACS vendors/groups traditionally have separate goals

• Cost effective deployment of digital detector technology may well depend on efficient image management and efficient soft copy reading

• Encourage attractiveness of digital detectors by improving PACS usability & productivity
Digital X-Ray WG Goals

- Support new digital detector technology
- Reuse existing DICOM facilities
- Support for PACS integration
- Enhance workflow/productivity
- Consistent image appearance
- Support advanced applications
- Support regulatory requirements
Identifying the PACS Needs

- **Image management functions of PACS**
  - matching images with request
  - matching images with old studies
  - routing images to reading worklist/station based on request/anatomy/physician

- **Softcopy reading functions of PACS**
  - images in correct order & orientation
  - images with appropriate grayscale
Failure to Meet PACS Needs

• Radiologists can’t read
  – images without request
  – request without images
  – images without old images
  – images not on reading worklist or station

• Radiologists won’t read or read slowly
  – images in wrong order or upside down
  – images with wrong contrast
Productivity - Image Hanging
Satisfying the PACS Needs

• Emulate all the functions of film
  – Visual cues
    ➢ for file clerk/technologist/radiologist
  – Flashed identification
  – Lead markers
  – Wax pencil marks
  – Well defined, repeatable grayscale
Management Features of Film

Visual Cues to Human:
- Modality = X-ray
- Anatomy = Skull
- Projection = Lateral
- Row Direction = Ant
- Col Direction = Feet

Wax Pencil:
- Enlarged Sella

Grid Used = Yes

Grayscale: Film type & exposure

Collimator Edges

Lead Marker:
- Laterality = L
- Projection = L

Flashed ID:
- Patient Name
- Patient ID
- Patient DOB
- Patient Sex
- Physician
- Institution

Wax Pencil: Film Number
Hanging a Film

Old Lateral

New Lateral

New Frontal

New Townes

Old Study

New Study
Hanging a Film

- Extract films from patient folder
- Sort into old and new films
- Verify patient name & ID on each film
- Arrange into desired hanging order
  - Match old with new for same anatomy/view
- Turn/flip to correct orientation
  - Left on right of viewbox, feet on bottom
- Turn on lightbox, +/- use bright light
Displaying an Image

• Receive studies from worklist/prefetch
• Match modality/anatomy with protocol
• Per protocol:
  – arrange old and new images
  – arrange by anatomy/laterality view
  – rotate/flip image based on orientation
  – annotate images as desired
  – select from available contrast choices
Display Hanging Protocols

Old Study

New Study

Old Lateral
New Lateral
New Frontal
New Townes
Information for Hanging

Modality: Mammography
Anatomic Region: Breast
Image Laterality: L
View Code: Medio-Lateral Oblique
Patient Orientation: A\FR
### DICOM Support for Hanging Modality

<table>
<thead>
<tr>
<th>CR Image</th>
<th>DX Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Non-specific</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Optional, text</td>
</tr>
<tr>
<td>Laterality</td>
<td>Optional</td>
</tr>
<tr>
<td>View</td>
<td>Optional, text</td>
</tr>
<tr>
<td>Orientation</td>
<td>Optional</td>
</tr>
</tbody>
</table>

**Key distinguishing feature of DX object family:**

- **More critical attributes are required**
- **More critical attributes are coded**
Purchasing Guideline #2

**Insist on DX support in both modality (CR and DX) and PACS workstations!**

Why?

Hanging of projection images difficult without mandatory, coded attributes
It takes two (+1/2) to tango ...

- DX support in modality
- DX support in PACS image manager/archive
- **DX support in PACS Workstation**

- Just storing and displaying the images conventionally is not enough to show benefit - need to *USE* the extra information
- Difficult to ascertain from conformance statements
Purchasing Guideline #3

Insist on hanging protocols driven by DX coded attributes in PACS workstations!

Why?

Mandatory, coded attributes from modality yield no benefit if they are never used
DICOM & Hanging Protocols

- Supplement 60
- Defines a standard format for central storage and interchange of hanging protocols
- Potential for a site or physicians personal hanging protocols to be:
  - Configured centrally
  - Exchanged between workstations and PACS from different vendors
- Start asking your vendors if they plan to support this
Implementing DX Objects

• SCU (the modality or x-ray system)
  – source of mandatory attributes
  – orientation of the image
  – contrast/processing choice

• SCP (the PACS or workstation)
  – take advantage of new attributes
    ➢ routing/reading worklist improvement
    ➢ hanging or default display protocols
  – standardization of existing practice
DX Modality Design

• Distinguish
  – add-on systems
  – integrated systems

• Goal is minimize operator’s burden
  – don’t re-enter information
  – take advantage of known information

• Is a trade-off when necessary
  – PACS efficiency prioritized over modality
Generator Protocol Data

Enter:
• kVP, mA, S

Generator

kVP, mA, S

Enter:
• Anatomy
• View

DICOM
Generator Protocol Data

Generator

DICOM

Enter:
• kVP, mA, S

kVP, mA, S

Enter:
• Anatomy
• View

Anatomy

View

Default orientation

Enter:
• Anatomy
• View

kVP, mA, S

Anatomy

View

Default orientation
Generator Protocol Data

- Too coarse, e.g. Chest Lat = Oblique
  - make it more granular, including L or R
- Complete attributes in DICOM
  - Technique (kVP, mA, S) and derived dose
  - Anatomy and view
  - Default or preferred orientation
- Select frequency/contrast processing
Sources of Data

- Generator protocol selection
- Detect/select collimation
- Physical gantry (e.g. upright bucky)
- Detect/select filtration on tube
- Detect/select grid
- Detector values and statistics
Determining Orientation

• Use to describe/change orientation:
  – view e.g. PA not AP
  – geometry e.g. upright bucky
  – pixels arranged as viewed from tube side

• Therefore:
  – pixels on right towards patient’s right
  – pixels at bottom towards patient’s feet
  – either describe or flip to “normal” view
Determining Orientation

**Operator selects ...**
- Image Laterality: L

*From angle and direction of gantry rotation ...*
- View Code: Medio-Lateral Oblique

**Therefore ...**
- Patient Orientation: A\FR

Already in natural view sense so don’t need to flip top/bottom
Laterality/Orientation Problems

- May require a user interface to enter
- May require an operator action enter/confirm
- Mandatory, but operator/vendor may lie!
- Multiple parts on same exposure/detector
- Badly implemented
  - flip left/right AP/PA chest
- Safety related issue
DICOM Support for Routing

• Coded and mandatory attributes help
  – Modality+anatomy+view

• Still critical need for Modality Worklist
  – To supply identifiers that match IS/PACS
  – Patient ID/Name/Study ID
  – Study Instance UID

Don’t buy a modality or PACS without (a good) modality worklist !!!
Purchasing Guideline #4

Choose a DX Modality that populates attributes with minimal impact on operator productivity!

Why?

Many sources of information are automatically obtainable or re-usable, and in-room productivity gains are too valuable to sacrifice unnecessarily.
And now for something completely different ...
Consistency of Appearance

• Correct grayscale transformations
  – crucial to create “film-like” appearance
  – crucial for distributed consistency of appearance
• Display (& print) devices vary greatly
• Incorrect contrast is a source of
  – inefficiency
  – dissatisfaction
  – fatigue
  – errors in diagnosis
Image Presentation

Acquire

Display

Print
Problems of Inconsistency

- Appearance chosen on one display device
- Rendered on another with different display
- Mass expected to be seen is no longer seen

mass visible  mass invisible
Distributed Image Consistency

Identical perceived contrast
Grayscale Transformations

- Pre-DX (CR) DICOM - optional & arbitrary
- DX family - mandatory & standard
- Two key elements
  - appropriate choice of contrast function
    - linear (window center/width) or non-linear LUT
    - automated choice(s) based on anatomy/view
  - standard device independent output space
    - DICOM Grayscale Standard Display Function
    - perceptually linear P-Values
Device Independent Contrast

Standard Display Function

Standardized Display A

Standard Display Function

Standardized Display B

P-Values: 0 to $2^n - 1$
Implementing Consistency

• **Modality implementation**
  – operator or machine chooses contrast (window or VOI LUT) targeted to standard display function rather than specific film/camera/monitor
  – must support DX image as an SCU
    ➢ may or may not send window values, non-linear LUT

• **PACS workstation implementation**
  – must support DX image as an SCP
    ➢ *must support application of non-linear LUT*
  – display must be standardized
  – display must be calibrated
  – quality control process in place
  – open question - how does user then adjust the image?
Window
Center/Width

Selects range of values to map
Lookup Table (LUT)
Encodes any shape of function

Pixels

Lookup Table (LUT)

Display

Encodes any shape of function
Sigmoid (Logistic) Curve

Figures courtesy of Guy Hersemeule, GEMS
Purchasing Guideline #5

Insist on GSDF calibration and full DX image (including VOI LUT) support in modality, QC and PACS workstations!

Why?

Consistency of appearance needs both ends to be calibrated to similar expectations - the DICOM DX, VOI LUT support and GSDF calibration are the standard solution.
Capturing Presentation Changes After Acquisition

- Operator or modality encode presentation information in original image object
  - Processed image “for presentation”
  - Default or selected window or LUT

- Capturing subsequent adjustments
  - By operator or radiologist
  - Excessive to save new (large) image objects
  - Grayscale Presentation State Storage (GSPS)
  - One or more “snapshots” of state separate from images
Purchasing Guideline #6

*Insist on Grayscale Presentation State Storage support for DX in QC and PACS workstations!*

Why?

Consistency of appearance resulting from operator or radiologist adjustments needs to be captured and propagated.
What about “processing”?

- Detector-specific proprietary processing
- “Post-processing” of presentable images
- Achieving interoperability requires that processing be performed at acquisition
- Proprietary processing must not be required in review and diagnostic workstations
Purchasing Guideline #7

*Insist that processing be performed during acquisition, not at workstations!*

Why?

Interoperability cannot be achieved if proprietary processing required on PACS workstations for acceptable image appearance.
But when?
Status of Adoption

- **Modality - DX (not mammography or CR plates)**
  - 7 do (Anexa, Canon, CMT, GE, Hologic, Konica, Lodox, SwissRay)
  - 4 do not (Kodak, IDC, Philips, Siemens)

- **PACS - support DX object for storage**
  - 32 that do, 2 that do not, 4 unknown (38)
  - 3 more that do compared with 2004 (another 2 dead)

- **PACS workstation support for DX/VOI LUT/GSDF**
  - unknown - a level of detail not in conformance statements
  - especially with respect to
    - driving hanging protocols and orienting images for display
    - support of calibrated displays
    - VOI lookup tables, not just linear windowing

- **In summary - universal on PACS, modalities disappointing**
Delays in Adoption - Why?

- Modality vendors worry PACS won’t take DX images
  - mitigate with “fallback” to CR if DX not supported
- PACS vendors see too few DX systems
  - to justify adding DX support
  - to risk depending on extra DX attributes
  - to justify taking advantage of DX-specific features
  - to justify supporting VOI LUTs properly
- Users (customers) aren’t very demanding
  - with respect to hanging protocols in workstations
  - with respect to distributed, inter-vendor, image consistency
  - tolerate extensive site-specific tweaking and workarounds
Strategies going forward

• Educate users about what is possible
• Educate vendors about what users need
• Encourage IHE to consider “payload” (content of and which DICOM image objects), not just workflow
• Improve weaknesses identified in standard
• New standard services
  – e.g. DICOM Hanging Protocols
IHE and DX Images

- IHE does not address the “payload” of what is stored in images
- Does not require the Acquisition Modality actors to use the DX IOD
- Does not require any particular behavior of Image Display actors with regard to hanging images
- Does require that the VOI LUT and GSDF be supported for DX IOD
Summary of Guidelines

- Do not buy a DX or CR or PACS without DICOM Modality Worklist (and IHE SWF profile)
- Insist on DX support in both modality (CR and DX) and PACS workstations
- Insist on hanging protocols driven by DX coded attributes in PACS workstations
- Choose a DX modality that populates attributes with minimal impact on operator productivity
- Insist on GSDF calibration and full DX image support (including VOI LUT) in modality, QC and PACS workstations
- Insist on Grayscale Presentation State Storage support for DX in QC and PACS workstations
- Insist that processing be performed during acquisition, not at workstations