DICOM Implementations for Digital Radiography

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Disclosure & Acknowledgements

- CTO RadPharm
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- Industry co-chairman of DICOM Committee
- Formerly contractor to GE Medical Systems

- DICOM Working Groups 2 (DX), 11 (Display)
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
Where does DICOM fit in?

- 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 Performed Procedure Step (MPPS)

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
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/Radiofluoroscopy (XA/XRF)
  – Digital X-Ray (DX, MG, IO)

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

[Images of breast scans with 'X' and '✓' symbols indicating correct and incorrect hanging]

Left:

- Left Lower Quadrant (LLQ)
- Left Upper Quadrant (LUQ)
- Right Lower Quadrant (RLQ)
- Right Upper Quadrant (RUQ)

Right:

- Right Lower Quadrant (RLQ)
- Right Upper Quadrant (RUQ)
- Left Lower Quadrant (LLQ)
- Left Upper Quadrant (LUQ)
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

**Grayscale:** Film type & exposure

**Collimator Edges**

**Lead Marker:**
- Laterality = L
- Projection = L

**Grid Used:** Yes

**Wax Pencil:**
- Enlarged Sella
- Film Number

**Flashed ID:**
- Patient Name
- Patient ID
- Patient DOB
- Patient Sex
- Physician
- Institution
Hanging a Film

Old Lateral

New Lateral

New Frontal

New Townes

Old Study

New Study

Technology
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

Technology

Workstation

Old Study

New Study

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

<table>
<thead>
<tr>
<th></th>
<th>CR Image</th>
<th>DX Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Non-specific</td>
<td>More specific (Required), coded</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Optional,text</td>
<td>Required (Required), coded</td>
</tr>
<tr>
<td>Laterality</td>
<td>Optional</td>
<td>Required (Required), coded</td>
</tr>
<tr>
<td>View</td>
<td>Optional,text</td>
<td>Required (Required), coded</td>
</tr>
<tr>
<td>Orientation</td>
<td>Optional</td>
<td>Required (Required), coded</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 receiver/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.
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

- Enter: • kVP, mA, S
- Generator
- Enter: • Anatomy, • View
- DICOM
- kVP, mA, S
- Default orientation
- DICOM

- Enter: • Anatomy, • View
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- kVP, mA, S
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Enter:
• kVP, mA, S

Generator

Enter:
• Anatomy
• View

kVP, mA, S
Anatomy
View
Default orientation

DICOM

DICOM
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*
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 or build 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
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

Goal: Identical perceived contrast everywhere!
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

Standard Display Function

Standardized Display A

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?
Sigmoid (Logistic) Curve

Figures courtesy of Guy Hersemeule, GEMS

\[
OUT = \frac{Output\_range}{1 + \exp\left(-\frac{4(IN-WC)}{WW}\right)}
\]
Purchasing Guideline #5

**Insist on GSDF calibration and full DX image support in both modality and PACS workstations!**

Why?

Consistency of appearance is impossible unless both ends are calibrated to similar expectations - the DICOM DX/GSDF is the only standard way to do that.
Status of Adoption

• Modality - DX (not mammography)
  – 5 that do (Canon, GE, Hologic, Konica, SwissRay)
  – 3 that do not (Kodak, Philips, Siemens)

• PACS - support DX object for storage
  – 24 that do, 6 that do not, 5 unknown (35) (last year 9 of 13)

• 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 - still disappointing, especially modalities
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 supporting
  – to risk depending on extra DX attributes
• 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
• Assumptions in DX object design are incorrect (???)
  – more work for technologist to save radiologist time?
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 integration of services
• Improve weaknesses identified in standard
• New standard services
  – e.g. WG 11 Hanging Protocols effort
Summary of Guidelines

• Do not buy a DX or CR or PACS without DICOM Modality Worklist
• 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 in both modality and PACS workstations