Fundamentals of digital image structure and application (clinical application/visualization)

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Digital imaging

- วัตถุประสงค์ของการบรรยาย
- ผู้เข้าอบรมมีความรู้ความเข้าใจเบื้องต้นในเรื่อง
  - คำย่อและ standard ต่างๆ ทางรังสีวิทยาและ Medical IT
  - PACS Component และการนำมาใช้
Digital imaging

• Abbreviation and terminology
• PACS and related issues
Digital imaging

• Abbreviation and terminology

• PACS and related issues
Digital imaging

• ACR
  – American College of radiology
• CPT
  – Current Procedural Terminology
• DICOM
  – Digital Imaging and Communications in Medicine
• EMR (EHR)
  – Electronic Medical Records (Electronic Health Records)
• HL 7
  – Health Level Seven
• HIPAA
  – Health Insurance Portability and Accountability Act
• IHE
  – Integrating the Healthcare Enterprise
Digital imaging

• HIS
  – Hospital Information System

• RIS
  – Radiological information system

• PACS
  – Picture Archiving and Communication System

• SNOMED CT
  – Systematized Nomenclature of Medicine

• ICD 10
  – International Classification of Diseases

• IEEE
  – Institute of Electrical and Electronics Engineers, Inc

• LOINC
  – Logical Observations: Identifiers, Names, Codes
Digital imaging

• Modalities
  – Type of Equipments

• Modality worklist
  – List of patients for that modality

• Workflow

• PACS administrator
Practice Parameters and Technical Standards

The ACR Practice Parameters and Technical Standards help advance the science of radiology and improve the quality of service to patients. They promote the safe and effective use of diagnostic and therapeutic radiology by describing specific training, skills and techniques. Learn more »

The ACR Practice Guidelines and Technical Standards for 2013 are currently presented on the website.

The 2014 ACR Annual Meeting and Chapter Leadership Conference (AMCLC) had many interesting developments. First, the name “Practice Guidelines and Technical Standards” has been changed to “Practice Parameters and Technical Standards”. Second, the CT Lung Cancer Screening Parameter document was adopted as amended at AMCLC and is currently available on this website. The rest of the 2014
  – CPT Current Procedural Terminology was developed by the American Medical Association in 1966.
  – These codes are used for the **billing of medical procedures**.
  – Each year, an annual publication is prepared, that makes changes corresponding with significant updates in medical technology and practice.
Digital imaging

• The Digital Imaging and Communications in Medicine (DICOM) Standard
  – was developed for the transmission of images and
  – is used internationally for Picture Archiving and Communication Systems (PACS).

• This standard was developed by the joint committee of the ACR (the American College of Radiology) and NEMA (the National Electrical Manufacturers Association) to meet the needs of manufacturers and users of medical imaging equipment for interconnection of devices on standard networks.
Digital imaging

• Abbreviation and terminology

• PACS and related issues
Digital imaging

• Basic knowledge
  – Terms and definitions
    • HIS, RIS, PACS, DICOM, HL7, IHE, Modalities, Modality worklist, PACS administrator, **Workflow**
  – PACS components
Radiology workflow

• Requests go into radiology department
  –Something magically happens

• Images and reports come out
Radiology workflow

• Eliot Siegel:
  – In a film-based environment with no PACS or RIS: request to report; How many STEPS?
  – 59 steps
  – Our study (ultrasound): in a PACS-based environment with an RIS, but no interface between the systems: request to report; STEPS?
  – 32 steps
Hospital Information System (HIS)

- Hospital information system (HIS)
  - Patient information database
  - *Physician order entry*
  - *Report distribution*
  - Support of Clinical and Medical Patient Care Activities in the Hospital
  - Administration of the Hospital’s Daily Business transactions (financial, personnel, payroll, bed census etc.)
  - Evaluation of Hospital Performance and Cost, and projection of the long-term forecast
Radiology Information Systems (RIS)

• Similar to HIS but of smaller scale

• Link to Hospital Information System (HIS)
  ▪ *Order entry*
  ▪ *Billing and Master Record*

• Link to Clinical Management System (CMS)
  ▪ *Prefetch for Clinical Visit Scheduling*

• Patient demographics
WORKFLOW

WITHOUT RIS

WITHOUT PACS
With RIS
Without PACS
RIS without PACS

HIS ↔ RIS + FILMS

Outside Radiology → Radiology Department
RIS without PACS
RIS without PACS
Radiology/PACS Imaging
Minutes for Exam/Report Process

![Bar chart showing minutes for exam/report process comparison between 1999 and RIS systems. The chart includes categories such as sending film report, collecting, reading, sorting, dark room, procedure, and reception. The data indicates a reduction in time for most processes in the RIS system.]
With RIS
With PACS
NOT integrated
With RIS, With PACS (not integrated)
With RIS
With PACS
(integrated)
Referring Clinician
1. Physician order entry on HIS
9. Report available on HIS

Transportation Aide
2. Transport patient to dept.
6. Transport patient back

Technologist
3. Choose patient from modality worklist
4. Obtain images
5. Check images for quality

Radiologist
7. Review images and reports
8. Dictate study with voice recognition system

HIS
RIS
PACS
With RIS, With PACS, (integrated)
Enterprise PACS
• Basic knowledge
  — Terms and definitions

  • HIS, RIS, PACS, DICOM, HL7, IHE, Modalities, Modality worklist, PACS administrator, Workflow

  — PACS components,
What is PACS?

P: Picture: *Images file, Movie file, VDO file & Reports*

A: Archive: *Online, Near line, Offline*

C: Communication: *Display, Networking, Transfer Protocols*

S: System: *Components & Architecture*
Components of PACS

- Image Acquisition
- Database
- Network
- File maintenance
- Image display
Components of PACS

• Image Acquisition
• Database
• Network
• File maintenance
• Image display
Image Acquisition

• THINK DIGITAL!!

• DICOM 3.0 STANDARD, Gateway Interface

• Computed Radiograph (CR)

• Direct Radiograph (DR)

• CT, MRI, PET CT

• Digital Fluoroscope, Digital Angiogram

• Ultrasound, Mammogram, Nuclear medicine,

• Scanner, Video capture
• **Computed radiograph (CR)** - Phosphor storage plates capture image in a direct digital form.

• **Digital Radiograph (DR)** - a form of X-ray imaging, where digital X-ray sensors are used instead of traditional photographic film.

• **Scanner, VIDEO capture**
  – Video capture-frame grabbing. Analog to digital conversion
  – Film digitizers (scanner) - superior contrast and spatial resolution over video capture-laser, CCD
• Computed radiograph (CR)
• Digital Radiograph (DR)
  – Different artifacts from films
    • Can occur during
      – Acquisition,
      – Post acquisition
      – Display
  – Display Pitfall is different from films
    • Different blind spot
    • Using invert grey scale for pulmonary nodule
Components of PACS

• Image Acquisition
• Database
• Network
• File maintenance
• Image display
We are at an Inflection Point in Healthcare - TRENDS

Total Data Healthcare Providers (PB)

- Admin
- Imaging
- EMR
- Email
- File
- Non Clin Img
- Research

Data Explosion projected to reach 35 Zetabytes by 2020, with a 44-fold increase from 2009.

Medical Imaging Archive Projection Case from just 1 healthcare system


*Other names and brands may be claimed as the property of others
What’s Creating this Explosion?

- Medical Imaging (PACS Data, Electronic Patient Records)
- Video Surveillance
- Growth Of Mobile Users
- Increased Access To Broadband
- Smart Devices (Smart Electric Grids, Smart Buildings)
- Non-Traditional IT Devices (RFID Readers, Navigation Systems)
Clinical and non-clinical imaging makes up for 45% of total data volume.

Estimated total Healthcare data volume in 2012 (N.A.): 5.4 Exabytes, growing 35% per year.
Properties of image

- Bit depth (9 bits or higher for digital mammogram)
- Grayscale or color
- Resolution in pixel

- Example image size of mammogram = 4k x 5k x 12 bit = 30 MB
### Image Resolution/ Bit depth

<table>
<thead>
<tr>
<th>U/S</th>
<th>DF</th>
<th>CR</th>
<th>CR Mammogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>256 x 256</td>
<td>8 bit</td>
<td>1k x 1k</td>
<td>2k x 2.5k</td>
</tr>
<tr>
<td>65 KBytes</td>
<td>10 bit</td>
<td>10 bit</td>
<td>12 bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.25 MByte</td>
<td>7.5 MByte</td>
</tr>
</tbody>
</table>
Database

**CT** 512 x 512 x 8 bits

= 256 KB /images Average 400 images/study = **100 MB**

**MRI** 512 x 512 x 8 bits

= 256 KB/images Average 400 images/study = **100 MB**

**Plain film (Plain radiograph)**

= (2K) 2048 x 2048 x 12 bits = **10 MB/study**

**Mammogram** 4096 x 5625 x 12 bits

= 30-40 MB per image x 4-6 Images

**Ultrasound, Nuclear medicine, Scanner, Digital Fluoroscopy**
**Mammogram** 4096 x 5625 x 12 bits

= 30-40 MB per image

- If you have roughly 35 MB of data per image and you acquire 6 images per patient, and you have 10,000 patients, you will **need 2.1 TB of storage per year**

- There are certainly practices that read ≥50,000 mammography studies per year.
  - How many years of comparison studies do we need? Five? Ten?
  - This means that we may all need to start learning about a new unit of data: **the petabyte (10^{15})**.
Components of PACS

• Image Acquisition
• Database
• Network
• File maintenance
• Image display
Network

• Acquisition (Modality) network (DICOM 3.0)

• Information network

  (HL-7, IHE – Integrating the healthcare enterprise)

• Architecture
Network

• Acquisition (Modality) network (DICOM 3.0)

• Information network
  \[(HL-7, IHE – Integrating the healthcare enterprise)\]

• Architecture
Network

• Acquisition (Modality) network (DICOM 3.0)
• Information network (HL-7, IHE)
• Architecture (central, distributed)
PACS – Central Architecture

DICOM Modality

Gateway or Frame Grabber

Film Digitizer

CR/DR QA Workstation

Data Base Server

Diagnostic Workstations (DICOM)

Clinical Workstations (DICOM)

Web Server

Archive

Non-DICOM Modality

Computed Radiography or DR

RIS
Central Architecture

• Image Server and Database Manager is the HEART
• Any image, any where, any time
• Unique central copy
• Easy update of data
• Requires high performance servers
• Potential single point of failure at server
• Bandwidth demanding
Distributed Architecture

- Exams are routed from modality to selected workstations
- Complex routing algorithms based on department / user preference
- Difficult to support concurrent review of images
- Less destructive for failure at database server
Components of PACS

- Image Acquisition
- Database
- Network
- File maintenance
- Image display
File Maintenance

- Short term storage
- Long term storage
- Depends on Database
File maintenance

• Storage (How many needed to be stored?)
• The images expected to be viewed by client view station
• GB short term up to 3 weeks
• TB long term up to 1 year
• Petabyte
• Everything always online
• Cloud technology
Image compression;

- JPEG, JPEG-LS, JPEG-2000 or MPEG
- Reversible (lossless) or irreversible (lossy).
- Current FDA policy does not allow irreversible compression of digital mammograms.
- The burden remains on the responsible physician to assure that the image quality is sufficient to achieve a diagnostically acceptable goal.
ACR

• IT Reference Guide for the Practicing Radiologist: Display
  Published 2013 ©Copyright American College of Radiology
• ACR–AAPM–SIIM PRACTICE GUIDELINE FOR DIGITAL RADIOGRAPHY (revised 2012)
• ACR–AAPM–SIIM TECHNICAL STANDARD FOR ELECTRONIC PRACTICE OF MEDICAL IMAGING (revised 2012)

RCR(UK)

• The adoption of lossy image data compression for the purpose of clinical interpretation:
  • The Royal College of Radiologists of UK, April 2008

German

• German commission on radiology protection
The compression ratio recommendations are as follows.

<table>
<thead>
<tr>
<th>MODALITY</th>
<th>COMPRESSION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiography</td>
<td>10:1</td>
</tr>
<tr>
<td>Skeletal radiography</td>
<td>10:1</td>
</tr>
<tr>
<td>CT (all areas)</td>
<td>5:1</td>
</tr>
<tr>
<td>Mammography</td>
<td>20:1</td>
</tr>
<tr>
<td>MR</td>
<td>5:1</td>
</tr>
<tr>
<td>US</td>
<td>10:1</td>
</tr>
<tr>
<td>Digital angiography</td>
<td>10:1</td>
</tr>
<tr>
<td>Radiotherapy CT</td>
<td>No compression</td>
</tr>
</tbody>
</table>

http://www.rcr.ac.uk/docs/radiology/pdf/IT_guidance_LossyApr08.pdf
## Data compression of X-ray images

Recommendation by the German Commission on Radiological Protection

### Table 1: Compression ratios

<table>
<thead>
<tr>
<th>Imaging method</th>
<th>Organ</th>
<th>Compression ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>brain</td>
<td>1 : 5</td>
</tr>
<tr>
<td>CT</td>
<td>abdomen</td>
<td>1 : 8</td>
</tr>
<tr>
<td>CT</td>
<td>thoracic soft tissues</td>
<td>1 : 8</td>
</tr>
<tr>
<td>CT</td>
<td>lung</td>
<td>1 : 8</td>
</tr>
<tr>
<td>CT</td>
<td>skeleton</td>
<td>1 : 8</td>
</tr>
<tr>
<td>CR/DR</td>
<td>lung</td>
<td>1 : 10</td>
</tr>
<tr>
<td>CR/DR</td>
<td>musculoskeletal system</td>
<td>1 : 10</td>
</tr>
<tr>
<td>CR/DR</td>
<td>abdomen</td>
<td>1 : 10</td>
</tr>
<tr>
<td>CR/DR</td>
<td>mammography</td>
<td>1 : 15</td>
</tr>
<tr>
<td>MR</td>
<td>all applications</td>
<td>1 : 7</td>
</tr>
<tr>
<td>RF/XA</td>
<td>fluoroscopy/DSA/coronal angiography</td>
<td>1 : 6</td>
</tr>
</tbody>
</table>

CT: Computer tomography  
CR/DR: Digital radiography (imaging plates/flat panel detectors)  
MR: Magnetic resonance imaging  
RF/XA: Fluoroscopy/angiography
Components of PACS

- Image Acquisition
- Database
- Network
- File maintenance
- Image display
Hard Copy:  Film/ Laser printer
Soft copy:  Workstation
Display characteristics

- \( L_0 \) (Luminance of light-box with no film present): 2000 cd/m\(^2\)
- \( L_a \) (ambient room light reflected by film): 10 cd/m\(^2\)
- \( D_{\text{min}} \) (minimum optical density obtainable on film): 0.20
- \( D_{\text{max}} \) (maximum optical density desirable on film): 3.00
Display characteristics

- Hard copy - D max determined by a concentration of silver halide on film
  
  A small influence by ambient light (room light)

- D min determined by light box brightness and film fog

- Soft copy - D max determined by the ambient light and reflectivity of the tube surface
Image display,
Workstation characteristics
Display characteristics
Workstation characteristics

• Graphic bit depth
• Liquid crystal display (LCD) technology
• Graphic interface
• Image presentation size
• Presentation support features
• Ergonomic factors
Display characteristics
Luminance response, Pixel pitch and display size

• The pixel pitch of a monitor determines the maximum spatial frequency that can be presented in an image.

• For monitors used in diagnostic interpretation, it is recommended that the pixel pitch be about 0.200 mm and not larger than 0.210 mm.
Display characteristics

Luminance response, Pixel pitch and display size

• Good visualization of the full scene is achieved when the diagonal display distance is about 80 percent of the viewing distance.

• At 2/3 meter, this corresponds to a diagonal size of 53 cm (21 inches). Monitors with a pixel array size of 1,500 x 2,000 and a pixel pitch of 0.210 will have a diagonal size of 52.5 cm.
<table>
<thead>
<tr>
<th>Device Type</th>
<th>Viewing Distance inches (cm)</th>
<th>Diagonal Size inches (cm)</th>
<th>Pixel Pitch μm per pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small handheld</td>
<td>10 (25)</td>
<td>7.5 (19)</td>
<td>78</td>
</tr>
<tr>
<td>Tablet handheld</td>
<td>15 (38)</td>
<td>11 (29)</td>
<td>117</td>
</tr>
<tr>
<td>Laptop</td>
<td>20 (51)</td>
<td>15 (38)</td>
<td>156</td>
</tr>
</tbody>
</table>
## Retinal display

<table>
<thead>
<tr>
<th>Model</th>
<th>PPI (pixels per inch)</th>
<th>Resolution</th>
<th>Total Pixels</th>
<th>Typical viewing distance (in/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPhone 4/4S and iPod Touch (4th generation)</td>
<td>326</td>
<td>960×640</td>
<td>614,400</td>
<td>10 inches (25 cm)</td>
</tr>
<tr>
<td>iPhone 5/5C/5S and iPod Touch (5th generation)</td>
<td></td>
<td>1136×640</td>
<td>727,040</td>
<td></td>
</tr>
<tr>
<td>iPad (3rd/4th generation/iPad Air)</td>
<td>264</td>
<td>2048×1536</td>
<td>3,145,728</td>
<td>15 inches (38 cm)</td>
</tr>
<tr>
<td>iPad Mini (2nd generation)</td>
<td>326</td>
<td>2048×1536</td>
<td>3,145,728</td>
<td>15 inches (38 cm)</td>
</tr>
<tr>
<td>MacBook Pro (3rd generation) 15&quot;</td>
<td>220</td>
<td>2880×1800</td>
<td>5,184,000</td>
<td>20 inches (51 cm)</td>
</tr>
<tr>
<td>MacBook Pro (3rd generation) 13&quot;</td>
<td>227</td>
<td>2560×1600</td>
<td>4,096,000</td>
<td>20 inches (51 cm)</td>
</tr>
</tbody>
</table>
Technical and radiological image quality comparison of different liquid crystal displays for radiology:

Francina EM Dams et al. Medical Physics and Technology, Department of Radiology, Albert Schweitzer Hospital, Dordrecht, The Netherlands

- 3-megapixel Barco®, Eizo®, and NEC® displays and a 6-megapixel Barco display.
- According to the tested criteria, all the displays had comparable image quality; however, there was a three-fold difference in price between the most and least expensive displays.

This article was published in the following Dove Press journal: Medical Devices: Evidence and Research
31 October 2014
Figure 6: Screenshot shows scanning pattern of a radiologist viewing a bone radiograph with a nonoptimized software interface. Eyes were fixated for 20% of the time on the nondiagnostic menu areas rather than on the diagnostic content of the image. Circles are points where the eye stops (fixations); lines show the order in which fixations were generated.
เมื่อจะมี reading Monitor

• ทราบ workstation and display characteristics ของ monitors
• เตรียมแสงสว่างของห้องให้พอเหมาะ
• เตรียมระยะที่นั่งในการดู monitor
• Calibration monitor สม่ำเสมอ และขอ report ของ calibration
• กรณีให้ vendor ดูแล ต้องขอ report เนื้อหาใน report ที่ควรสนใจ
  – ความสว่างของ backlight, grey scales, bit depth, spatial resolution, death pixels
Status
Review the status of your workstation and the QAWeb Server connection

Configuration
See information about the configuration of your display system, and adjust local settings

Test Patterns
Judge the display system's quality by reviewing common used test patterns

Service Level
Review your service level settings, and upgrade your service level
• ยกตัวอย่างความสว่าง ของจอ

• diagnostic monitors used for interpretation should be at least 350 cd/m2

• For the interpretation of mammograms, Lmax should be at least 420 cd/m2
Auto-calibration

Display

Brand : Barco
Type : MDCC-6130
Serial Number : 1890287873
Workstation : WB02SPAC1404.bmc.bumrungrad.com

Result

Task Result : OK
Execution Time : Dec 18, 2014 7:42 PM ICT
Result Details

Calibration Policy

  Display Function : DICOM GSDF
  Luminance : Maximized Lifetime
  Chroma : Native White
  Black Luminance : Native Black
  Reading Room : X-Ray Diagnostic Reading Room
  ULT : Disabled

Calibration Parameters

  Method : Full Calibration

Calibration Values

  L min : 0.45 Cd/m²
  L max : 499.82 Cd/m²
  L ambient : 0.05 Cd/m²
  Chroma : x: 0.302 y: 0.326
• With all of the knowledge we have, can we use mobile devices to READ and official report imaging study??

YES, BUT....Considered

Resolution, Ambient, Viewing distance, viewing angle and compression
Planning for PACS: A Comprehensive Guide to Nontechnical Considerations

Mervyn D. Cohen, MB, ChB, MD, Lori L. Rumreich, MBA, Kimberley M. Garriot, S. Gregory Jennings, MD

• FINANCIAL JUSTIFICATION
• VENDOR SELECTION
• TECHNOLOGY ISSUES
  — Hardware
  — Software
  — Network and IT
• DISASTER PLAN
• SECURITY
• SPACE AND ENVIRONMENT ISSUES
• PROJECT IMPLEMENTATION
Take home message

• PACS - Basic knowledge is important
Thank you for your attention