(Informatics) Standards for Quantitative Imaging

David A. Clunie

PixelMed Publishing & CoreLab Partners

Affiliations & Disclosures

- **CTO, CoreLab Partners, Princeton, NJ**
- **PixelMed Publishing, Bangor, PA**

- **Editor, DICOM Standard**
- **Co-chair, IHE Radiology Tech. Committee**
- **Member, QIBA CT Volumetry Committee**

What is Quantitative Imaging?

- ***"Quantitative imaging is the extraction of quantifiable features from medical images for the assessment of normal or the severity, degree of change, or status of a disease, injury, or chronic condition relative to normal … includes the development, standardization, and optimization of anatomical, functional, and molecular imaging acquisition protocols, data analyses, display methods, and reporting structures … permit the validation of accurately and precisely obtained image-derived metrics with anatomically and physiologically relevant parameters, including treatment response and outcome, and the use of such metrics in research and patient care."***

RSNA QIBA

"https://www.rsna.org/QIBA_.aspx"

What is Quantitative Imaging?

- ***"Quantitative imaging is the extraction of quantifiable features from medical images for the assessment of normal or the severity, degree of change, or status of a disease, injury, or chronic condition relative to normal … includes the development, standardization, and optimization of anatomical, functional, and molecular imaging acquisition protocols, data analyses, display methods, and reporting structures … permit the validation of accurately and precisely obtained image-derived metrics with anatomically and physiologically relevant parameters, including treatment response and outcome, and the use of such metrics in research and patient care."***

RSNA QIBA

"https://www.rsna.org/QIBA_.aspx"

Opportunities for Standardization

- **Methods, protocols & metrics**
- **Performance standards & benchmarks**
- **Evaluation methods**
- **Encoding of images & results**
- **Terminology & codes**

Opportunities for Standardization

- **Methods, protocols & metrics**
- **Performance standards & benchmarks**
- **Evaluation methods**
- ***Encoding of images & results***
- ***Terminology & codes***

Sound familiar ?

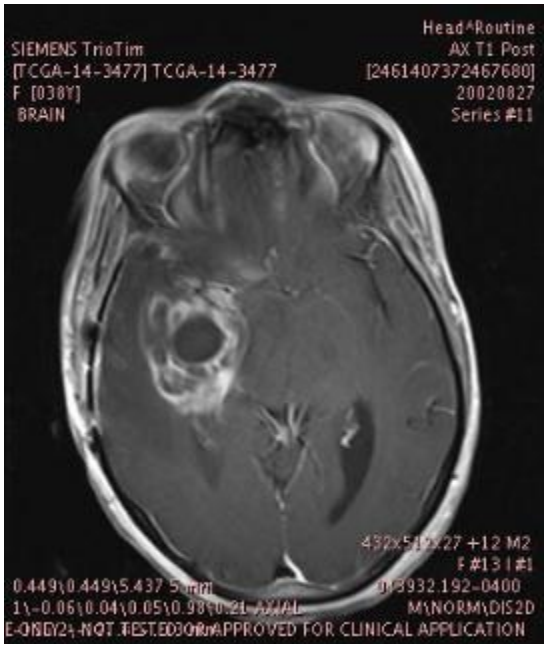
- **DICOM standards in clinical practice**
  - Images from modalities
  - Derived images – e.g., CBF
  - ROIs – e.g., CT Hounsfield units, PET SUV
  - Size measurements – distance, area, volume
- **“Quantitative” imaging is nothing new**
  - different emphasis than narrative reporting

Greater Rigor in Deployment

- **Narrative reporting**
  - see it, compare it, dictate it
- **Quantitative reporting**
  - see it, analyze it, measure it, code it, re-use it
- **Same standards**
  - greater need for numbers & codes
  - more structure

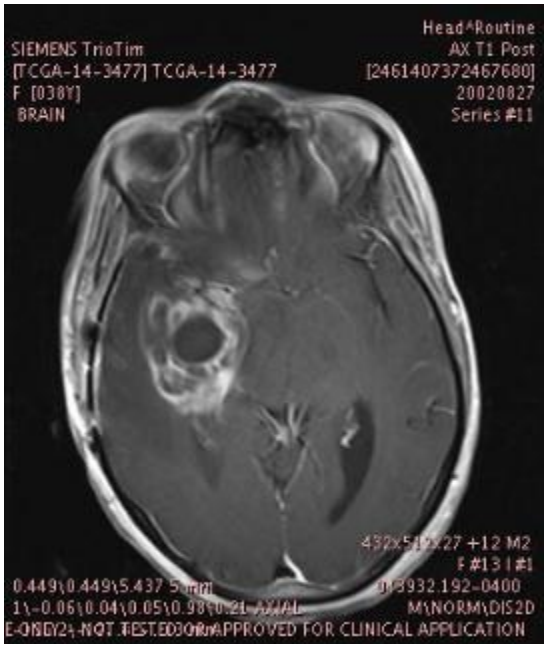
See It

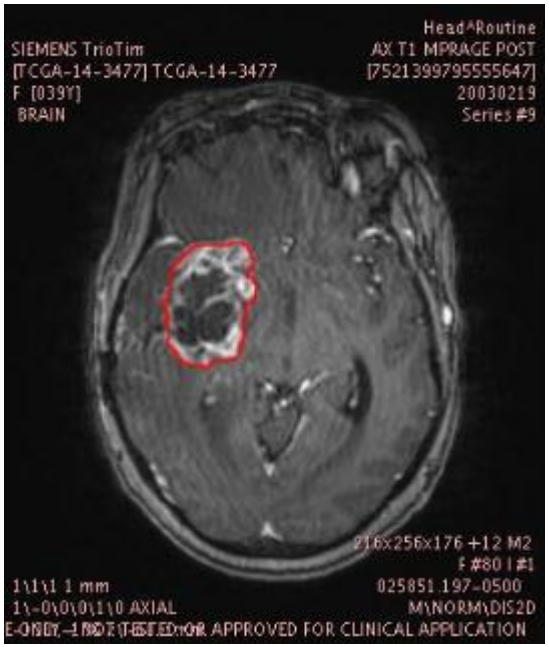
- **Hairy mass…**



See It, Analyze It, Measure It

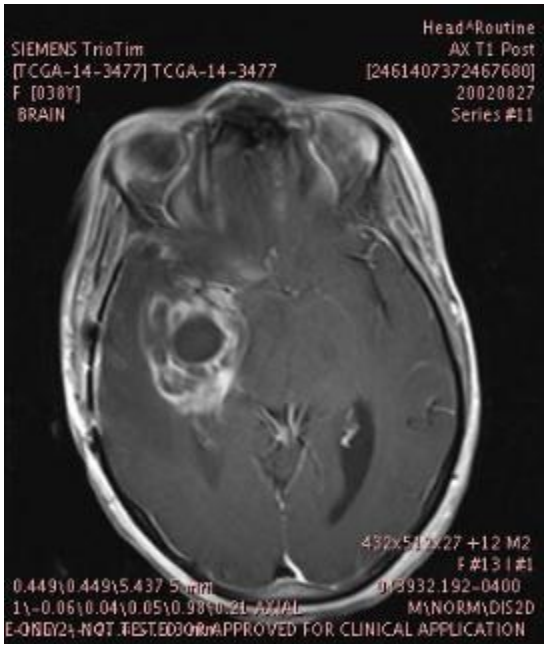
- **Segmented Lesion Volume 31,524 mm^3**





Code It

- **Why, how, what, where …**



(R-F8106,SRT, “Grand mal seizure”)

(24587-8,LN,“MR brain w/wo IVC”)

(F-04E4E,SRT,“Brain mass lesion”)

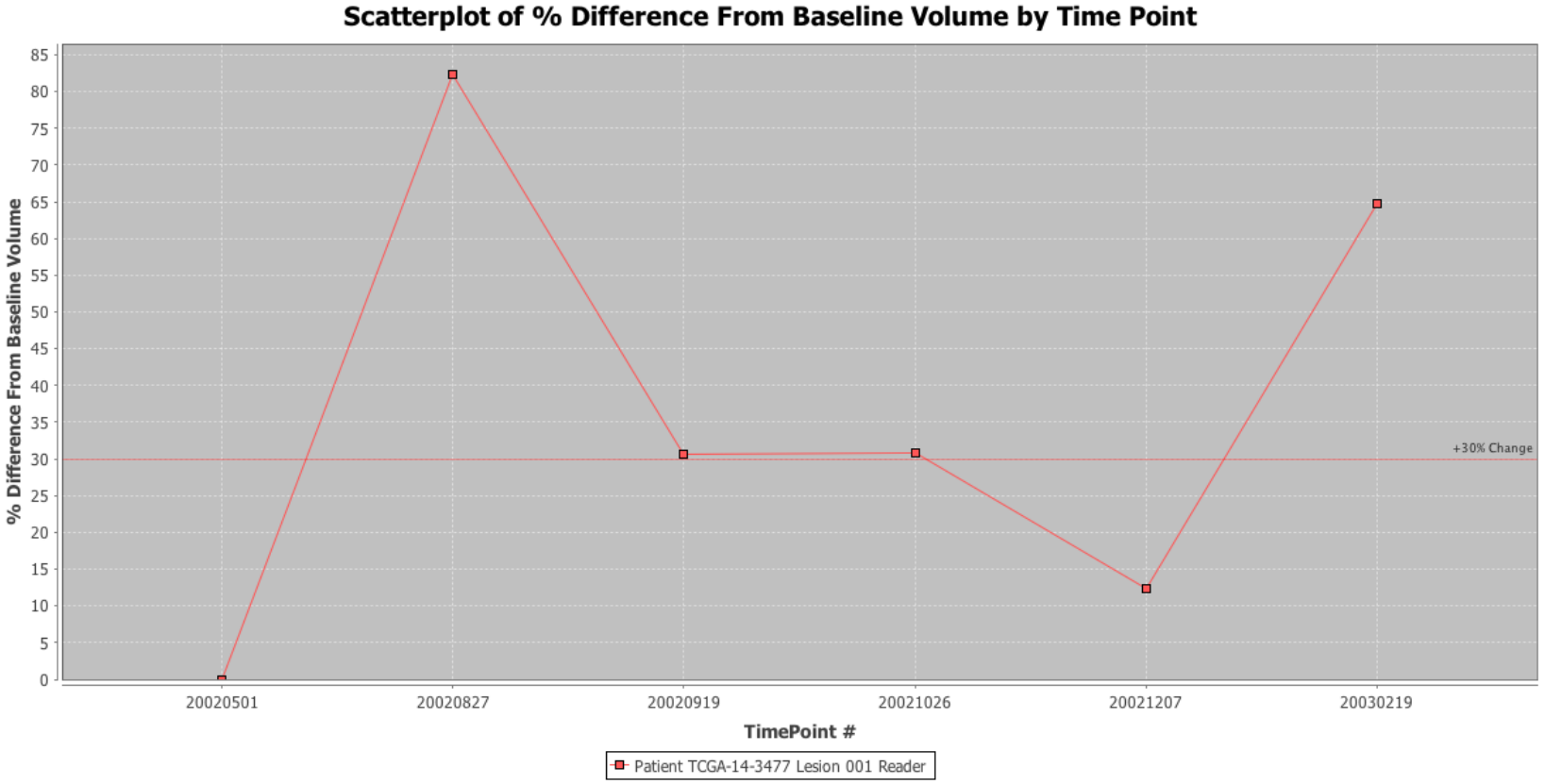
(RID6061,RADLEX, “Circumferential enhancement”)

(T-A250D,SRT,“Right Temporal Lobe)

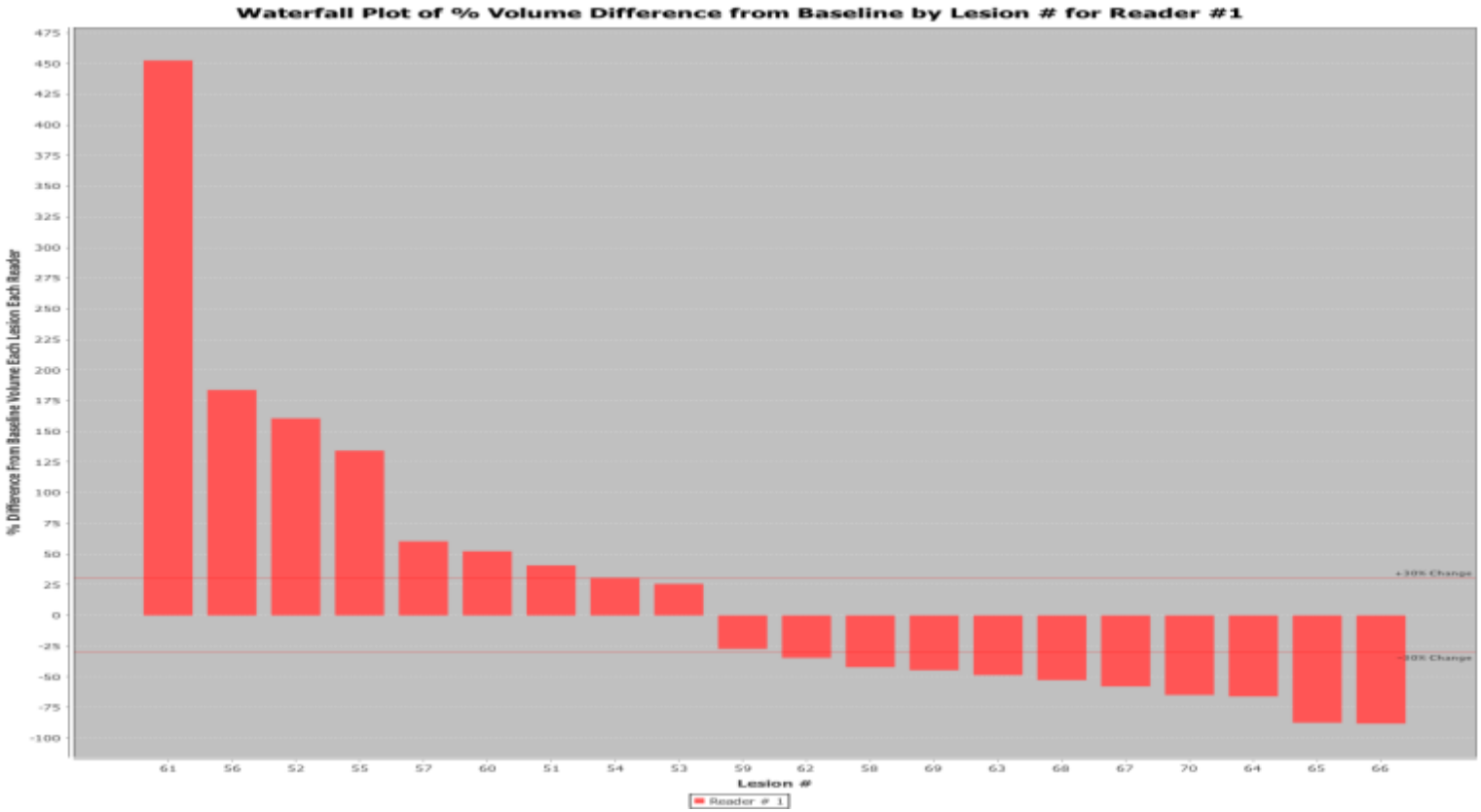
Tabulate It

Lesion #	TimePoint #	Volume	Auto LD	Auto SD	% From Baseline Volume
1	20020501	24120	57	27	0
1	20020827	43990	58	31	82
1	20020919	31524	46	37	31
1	20021026	31554	59	35	31
1	20021207	27081	49	27	12
1	20030219	39748	55	37	65

Graph It


Scatterplot of % Difference From Baseline Volume by Time Point
% Difference From Baseline Volume
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
+30% Change
20020501
20020827
20020919
20021026
20021207
20030219
TimePoint #
Patient TCGA-14-3477 Lesion 001 Reader

Aggregate It and Visualize It



Re-Use It

- **Quantitative analysis need not be a “dead end”**
  - can just transcribe or cut-and-paste numbers into a dictated or plain text report
  - pre-populated “merge” fields created from structured input provide a productivity and quality gain
  - can indeed save pretty tables & graphics as a PDF
  - but … much better to be able to re-use structure, numbers, codes next time for comparison, searching and basis for quality improvement metrics

Informatics Standards

- **Approved medical device products**
  - already exist for quantitative image analysis & use in clinical practice
- **Inputs & outputs**
  - can they be standardized?
  - can they be stored & visualized in the PACS?
- **Change over time course of patient**
  - can these devices read and use each others' results?

Images In

- **Modalities make DICOM images**
  - often do not populate critical attributes for quantitative imaging in a standard way
  - anatomy, protocol, technique, contrast, timing
  - workflow challenge – copy from modality work list
  - user entry – need a place on screen, need to do it
  - copy to header – sometimes standard lags behind
  - quantitative pixel values – physical units

Measurements Out

- **Regions of Interest (ROI)**
- **Per-voxel values (“parametric maps”)**
- **Intermediate work products**
  - spatial registration (rigid & deformable)
  - fiducials
  - real-world values (physical units)

Measurements Out

- **DICOM encoding of ROIs**
  - Private elements (evil & must be stopped)
  - Curves in image (weak semantics, old, retired)
  - Overlays in image (weak semantics)
  - Presentation States (weak semantics, PACS favorite)
  - Structured Reports (best choice, but more work)
  - RT Structure Sets (coordinates only)
  - Segmentations (per-voxel ROIs; use with SR)

DICOM Structured Reports

- **Hierarchical structure**
  - codes, numbers, coordinates, image references, etc.
- **Flexibility is constrained by templates**
  - just as XML is constrained by DTD or Schema
- **Standard DICOM binary representation**
  - easily stored in PACS though visualization remains challenging
  - easily transcoded to XML for processing
- **Widely used in existing quantitative modalities**
  - echo-cardiography, obstetric ultrasound

DICOM SR – Questions & Answers

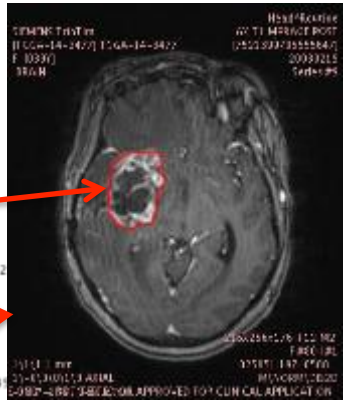
- **Basic structure is name-value pair**
  - name is the “question” (code)
  - value is the “answer” (text, code, numeric, etc.)
- **Different style choices possible, e.g.**
  - (M-54000,SRT,“Necrosis”) = (G-A203,SRT,“Present”)
  - (F-00005,SRT,“Finding”) = (M-54000,SRT,“Necrosis”)
- **Template of questions & value sets**
  - populated by human (pick lists from value sets)
  - encode image processing results (e.g., detect signal or pattern)
  - rule based (e.g., too small to measure)

DICOM SR – details inside

- CONTAINS: CONTAINER: Time Point [SEPARATE]
  - HAS OBS CONTEXT: TEXT: Subject Time Point Unique Identifier = 1.3.12.2.1107.5.1564572511.384.1353518214.8
  - HAS OBS CONTEXT: TEXT: Procedure Description = MRI Brain w/+ w/o Contrast
    - HAS PROPERTIES: UIDREF: Study Instance UID = 1.3.6.1.4.1.14519.5.2.1.2783.4001.230122590826962481167637416253
    - HAS PROPERTIES: CODE: Modality = Magnetic Resonance
    - HAS PROPERTIES: DATE: Study Date = 20021207
    - HAS PROPERTIES: TIME: Study Time = 165411
  - CONTAINS: CONTAINER: Lesion [SEPARATE]
    - CONTAINS: UIDREF: Tracking Unique Identifier = 1.3.12.2.1107.5.1564572511.1752.1353368560.7
    - CONTAINS: CODE: Calibration = No
    - CONTAINS: CONTAINER: Measurement Object [SEPARATE]
      - CONTAINS: UIDREF: Measurement Object UID = 1.3.12.2.1107.5.1564572511.2560.1353371564.19
      - CONTAINS: CODE: Measurement Object Type = Volume
      - HAS OBS CONTEXT: DATETIME: Observation Creation DateTime = 20121120003244
      - HAS OBS CONTEXT: DATETIME: Observation Modification DateTime = 20121121175419
      - CONTAINS: CODE: Discarded = No
      - CONTAINS: CONTAINER: Image Region [SEPARATE]
        - CONTAINS: CONTAINER: Image Sub-region [SEPARATE]
          - CONTAINS: CODE: Include Flag = Yes
          - CONTAINS: CODE: Segmentation Method = Random Walker 3D
          - CONTAINS: NUM: Area = 957.772564572239 mm2
          - CONTAINS: NUM: Volume = 27080.9186434825 mm3
            - HAS CONCEPT MOD: CODE: Measurement Method = Integration of sum of closed areas on contiguous slices
          - CONTAINS: NUM: Attenuation Coefficient = 688.37109375 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Mean
          - CONTAINS: NUM: Attenuation Coefficient = 204 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Minimum
          - CONTAINS: NUM: Attenuation Coefficient = 1520 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Maximum
          - CONTAINS: NUM: Attenuation Coefficient = 681 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Median
          - CONTAINS: NUM: Attenuation Coefficient = 259.674053 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Standard Deviation
          - CONTAINS: NUM: Attenuation Coefficient = 14137088 Unspecified
            - HAS CONCEPT MOD: CODE: Derivation = Total
          - CONTAINS: NUM: Pixel Count = 20537 count
          - CONTAINS: IMAGE: Region Raster = 1.2.840.10008.5.1.4.1.1.66.4 : 1.2.276.0.7230010.3.1.4.1564572511.384.1353521414.70 (PS 1.2.840.10008.5.1.4.1.1.11.1 : 1.2.276.0.7230010.3.1.4.1564572511.384.1353521414.6
        - CONTAINS: CODE: Measurement Object Type = Biorthogonal Line Segments
        - CONTAINS: CONTAINER: Simple Measurement [SEPARATE]
          - HAS OBS CONTEXT: CODE: Automation = Automated
          - CONTAINS: NUM: Long Axis = 49.4704627990723 millimeter
            - INFERRED FROM: SCOORD: Source of Measurement = POLYLINE (179.733993530273,280.515991210938,205.328002929688,178.141006469727)
              - SELECTED FROM: IMAGE: = 1.2.840.10008.5.1.4.1.1.4 : 1.3.6.1.4.1.14519.5.2.1.2783.4001.305229386844192035439159616449[Frame 1] (PS 1.2.840.10008.5.1.4.1.1.11.1 : 1.2.276.0.7230010.3.1.4.1564572511
          - CONTAINS: NUM: Short Axis = 26.6379356384277 millimeter
- CONTAINS: CONTAINER: Time Point [SEPARATE]

DICOM SR – as visualized

Date	Volume	Auto LD	Auto SD
20021207	27080	49	27
…	…	…	…



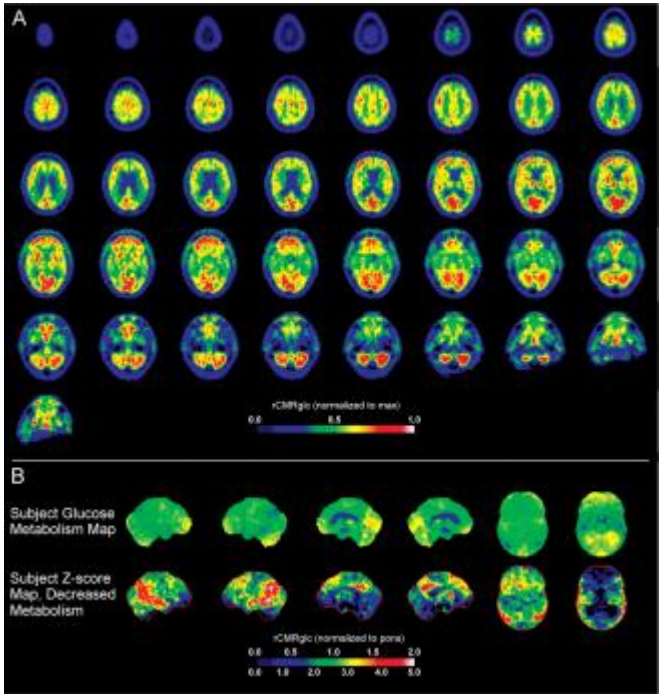
DICOM RT Structure Sets

- **Simple structure**
  - focus is iso-contour 3D coordinates of regions to treat & spare
  - very limited semantics
  - no standard or extensible measurements beyond simple volume
- **Standard DICOM binary representation**
  - easily transcoded to other DICOM objects like SR or PS if 3D (patient-relative) to 2D (image-relative) coordinate mapping is available (e.g., via source images or an SR image library)
- **Widely used in existing RT & non-RT workstations**
  - also understood by many academic software tools

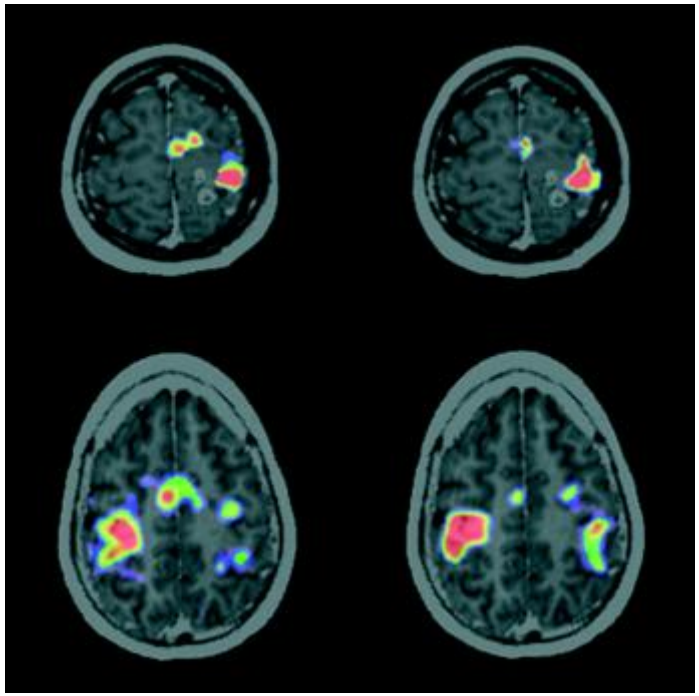
DICOM Presentation States

- **Intended to preserve appearance**
  - grayscale pipeline (window)
  - spatial transformation (pan/zoom)
  - annotation (text, overlays, vector graphics)
- **Lack semantics**
  - what does text “mean”?
  - which graphic is it associated with?
- **Overall, a poor choice for quantitation**
  - may be all that is available in many PACS (to create & view)

Parametric Maps

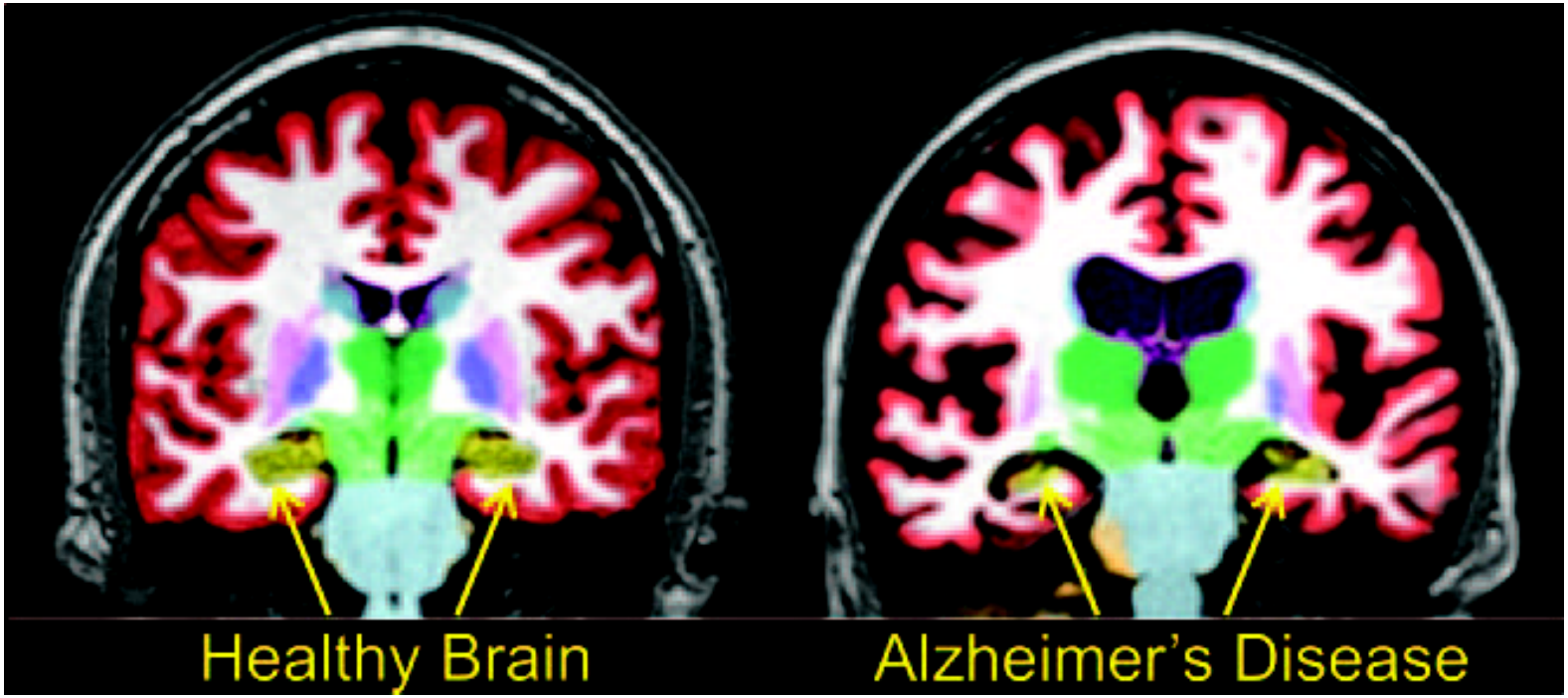


Foster N L et al. Brain 2007;130:2616-2635



Meyer P T et al. J Neurol Neurosurg Psychiatry 2003;74:471-478

Label Maps



Brewer J et al. AJNR 2009; 30:578-580

DICOM Parametric & Label Maps

- **Per-voxel encoding of numeric or label values**
- **Ordinary images but not just "pretty pictures"**
  - modality-specific or secondary capture; single or multi-frame
- **Segmentations (label maps)**
  - binary, probability, fractional occupancy
  - multiple segments (multiple labels)
- **Currently limited to integer values**
  - can provide (linear) rescaling to floats (usable by any viewer)
  - future extension to floating point voxels (or private SOP Class)
- **Leave "fusion" (superimposition) to application**
  - Blending Presentation State to specify what to fuse

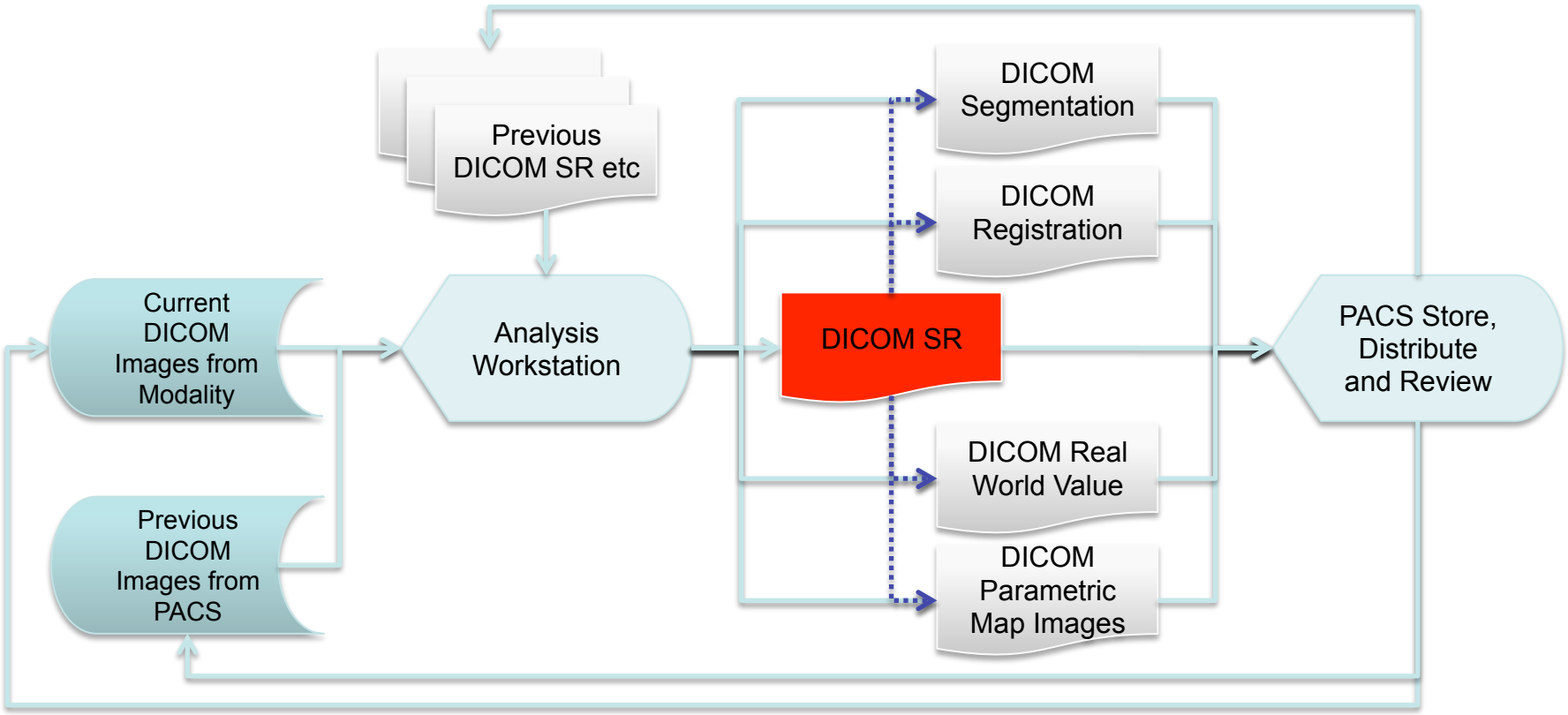
DICOM Registration & Fiducials

- **Mapping between 3D coordinates**
  - DICOM Registration – rigid matrix
  - DICOM Deformable Registration
- **Location of specific points**
  - DICOM Fiducial
- **Used to save manual or automated results**
  - save application state for further work later
  - re-use for other purposes (e.g., sync'd scrolling)

DICOM Real World Value Maps

- **Separate pipelines based on pixels**
  - what to show on the display
  - what the pixel (voxel) “means”
- **e.g., MR pixel values**
  - signal intensity windowed for display
  - mapped to physical unit (e.g. velocity for phase contrast)
- **DICOM implementation**
  - within image or separate object (e.g., derived later)
  - linear equation or LUT, applied to all or sub-set of range
  - point operation (all voxels) (unlike US Region Calibration)

Putting it all together …



What about Codes?

- **DICOM uses external lexicons**
  - SNOMED
  - LOINC
  - RADLEX
  - defines DCM codes & definitions only if no good home
- **EHR push towards more reliable codes**
  - e.g., in USA, strong emphasis on codes in Meaningful Use
  - RIS, modalities and PACS implementations could do better
  - institutions really need to standardize internal procedure codes

Codes for Quantitative Imaging

- **Codes needed for**
  - entities, e.g., lesions, tumors, tissue types
  - location, e.g., anatomic site
  - characteristics, e.g., edges, enhancement
  - measurements, e.g., volume, sum of areas, mean
  - units, e.g., HU, mm
- **Availability**
  - many already - SNOMED, LOINC, RADLEX, DCM, NCI, UCUM
  - more being defined every day
  - can use private codes in the interim & re-map later

Reality Check

- **The standards exist - are they implemented?**
  - widely, where use is critical & reimbursable (e.g. SR in echo and OB US, RTSS in radiotherapy planning & QC)
  - increasingly so elsewhere, as quantitation grows in popularity (e.g., oncology, esp. PET)
- **Need better and more widespread toolkit support**
  - many toolkits do include basic multi-frame, SR and XML
  - many need more convenient APIs for abstractions
- **Need greater 3rd party viewer & workstation support**
  - many still use “proprietary” annotation formats, e.g., Osirix

What is a “standard” anyway?

- **Generic definition**
  - *“something established by authority, custom, or general consent …” (Merriam-Webster)*
- **Technical Standards definition**
  - *“an established norm or requirement about technical systems … usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices” (Wikipedia)*

What is a “standard” anyway?

- **Standards are developed by “Standards Organizations”**
  - “*any organization whose primary activities are developing, coordinating, promulgating, revising, amending, reissuing, interpreting, or otherwise producing technical standards that are intended to address the needs of some relatively wide base of affected adopters” (Wikipedia)*

DICOM as a Standard

- **DICOM is a standard**
  - whether you like it or not
  - long history of modality & PACS vendor support
  - global investment & representation of stake holders
  - open – free to get it and free to implement it
  - commonality across many modalities & applications
  - grows in sophistication to meet evolving technology
  - patient and workflow centric

Anti-Standards - Vendors

- **Many systems do not go beyond images**
  - mistaken perception that DICOM is only for images
  - hampered by lack of platform toolkit support
  - do not see value in “sharing” (or saving) results
  - users satisfied with secondary capture screen shots
  - believe it is sufficient to save/restore “state” locally
  - or hidden inside private data elements or SOP Class
  - so, “Yet Another Proprietary File Format” (YAPFF)

Anti-Standards - Academics

- **Many academics don't like DICOM**
  - DICOM is "old-fashioned" (e.g., not XML based)
  - not funded to be at the DICOM development table
  - easier to make up your own format than to learn
  - so, "Yet Another Academic File Format" (YAAFF)
  - research funding leadership - "Not Invented Here"
  - legitimate legacy of working code predating DICOM
  - effort to retain required identifiers through pipeline

Anti-Standards & Wrong Standards

- **AIM**
- **Analyze**
- **GIPL**
- **MINC**
- **NIfTI**
- **NRRD**
- **VTK**
- **BMP**
- **JPEG**
- **PNG**
- **TIFF**
- **NetPBM**
- **HDF**
- **NetCDF**

Translation to Clinical Practice

- **“Benchmark to Bedside”**
  - for “quantitative imaging” to reach clinical practice, tools and standards must be commercially viable
- **No place for YA[PA]FFs & generic formats**
  - no patient & workflow metadata
  - no support in PACS
  - little or no support in viewers & workstations
  - can claim is a “standard” but doesn’t make it so

Beyond the Scope …

- **Many other related standard activities**
  - DICOM WG 23 Application Hosting
  - DICOM WADO-WS and WADO-RS access
  - IHE Post-Processing Workflow
  - IHE XDS and cross-enterprise quantitation
  - Specific research & clinical trials projects
  - DICOM De-identification (Sup 142)
  - …

Conclusion

- **Pretty pictures are not enough**
  - saving a screen shot/PDF to view in PACS is better than nothing
  - but doesn't enable further searching, analysis or re-use
- **Standards are needed and already exist to fully support quantitative imaging in clinical practice**
  - most gaps are in implementation and deployment, not missing standards
  - DICOM will be extended as needed
  - "chicken & egg" problem with implementation is not an excuse

Conclusion

- **No place for non-standard or inappropriate formats**
  - not just for input, but output as well
  - for results from commercial products to be distributable and survive migration (version/product/vendor), must use standards
  - for academic quantitative projects to be translated to clinical practice, they must embrace existing, true “standards”, (i.e., DICOM), not “made up” formats they claim to be “standards”
- **Greater use of standard codes is probably inevitable**
  - creates opportunity for better tools to search & mine content