Motivation

- Need to distribute results for review
- Create with multiple tools in different formats
- Reviewers without access to original tool
- Measurement technique comparisons
- Imaging bio-marker development/testing
- Image-based clinical trials, esp. oncology
- Change in measurements over time
- Clinical practice for individual patients

Results Characteristics

- What is recorded?
  - measurements – distance, volume, density, etc.
  - coordinates – what region on image measured
- Context?
  - identification of subject (patient), lesion, etc.
  - identification of reader
  - identification of technique
  - position in time (change over time, no change)

Results Organization

- Single object per measurement
- Single object for all measurements at one time
- Single object per reader per time point
- Single object per reader all time points
- Single object per image with all measurements for all readers
- …

Use-Cases

- QIBA CT Volumetry 1B Round 2
  - lung cancer volume measurement
  - multiple independent readers
  - two time points
  - some cases no change, some with change
  - volume & automatically erived distance
    - standard DICOM SR and DICOM Segmentation format
    - clinical trials results information model
    - organized as one object per lesion per reader
  - reading tool is not distributable for review

Use-Cases

- QIBA CT Volumetry 1A
  - phantom lung nodules differing size and shape
  - multiple independent readers
  - one time point
  - two different (incompatible) reading tools used
  - distance
    - proprietary format
    - one object per image containing multiple readers & lesions
  - volume
    - variant of DICOM RT Structure Set
    - one object per reader per lesion
  - reading tools are not distributable for review

Hierarchical Model

- Subject
  - Reader
    - Time Point
      - Lesion
        - Region (-> link to image coords)
          - Measurement (e.g., Volume)

Hierarchical Model

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        - » Volume = 355 mm3
      - Lesion = 2
        - » Volume = 3896 mm3
    - Time Point = 2011/07/01
      - Lesion = 1
        - » Volume = 471 mm3
      - Lesion = 2
        - » Volume = 3801 mm3
  - Reader = 2
    - …

One Annotation Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        - Volume = 355 mm3
      - Lesion = 2
        - Volume = 3896 mm3
    - Time Point = 2011/07/01
      - Lesion = 1
        - Volume = 471 mm3
      - Lesion = 2
        - Volume = 3801 mm3
  - Reader = 2
    - …

One Time Point Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        - » Volume = 355 mm3
      - Lesion = 2
        - » Volume = 3896 mm3
    - Time Point = 2011/07/01
      - Lesion = 1
        - » Volume = 471 mm3
      - Lesion = 2
        - » Volume = 3801 mm3
  - Reader = 2
    - …

One Reader per Subject Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        - » Volume = 355 mm3
      - Lesion = 2
        - » Volume = 3896 mm3
    - Time Point = 2011/07/01
      - Lesion = 1
        - » Volume = 471 mm3
      - Lesion = 2
        - » Volume = 3801 mm3
  - Reader = 2
    - …

Tabular Presentation

Subject	Reader	Time Point	Lesion	Volume mm3
0001	Reader 1	2010/06/01	1	355
0001	Reader 2	2010/06/01	1	375
0001	Reader 1	2010/06/01	2	3896
0001	Reader 2	2010/06/01	2	4764
0001	Reader 1	2011/07/01	1	471
0001	Reader 2	2011/07/01	1	289
0001	Reader 1	2011/07/01	2	3801

Tabular Presentation

- Can be sorted by different columns
- Easy to add derived computations
  - e.g., % difference from mean volume
- Exportable to spreadsheet tools (e.g., Excel)
- Exportable to statistical tools (e.g., R)
- Easy to feed selected columns to chart tools
- Cells and rows can be hyperlinked to images
  - e.g., hyperlink a volume to the ROI outline

Structured vs. Unstructured

- Structured input defines individual elements
  - measurements are recorded
    - as opposed to recalculated from coordinates each time
  - measurements & units distinct & related to image
    - coordinates linked to measurement
    - different types of measurement coded (not free text)
  - individual context elements distinct
    - e.g., patient, lesion, reader encoded separately
- Unstructured annotations
  - user enters free text (e.g., “Reader 1 Lesion 1)
  - text and coordinates linked, or
  - text and coordinates co-located but not linked

Results Formats

- DICOM Structured Reports
  - general purpose hierarchical data format
  - primitives for codes, measurements, coordinates
  - references to images, segmentations
  - needs a “template” to define information model
  - no widely adopted standard templates for oncology quantitative measurements over time
  - author has defined template for internal use in contract research, and has reused it for QIBA

Results Formats

- DICOM Segmentations
  - rasterized (pixel array) of values matching image
  - encoding of lesions
    - Binary - which voxels are included in lesion
    - Probability maps – probability voxel is included
  - encoding of “label maps”
    - E.g., atlas of tissue types corresponding to voxels
  - does not contain measurements
    - intended to be referenced from a DICOM SR

DICOM RT Structure Sets

- Developed for and long history of use with Radio-Therapy Planning applications
- Generic mechanism for 3D contours
  - set of coplanar iso-contours
  - 3D patient-relative coordinates
- Image co-ordinates
  - often 1:1 correspondence of 3 coordinate with original image slices and voxels (though not required)
- Measurements
  - very limited, if any, measurements in file
  - recalculated on re-loading
  - could be referenced from a DICOM SR (though unusual)

DICOM Presentation States

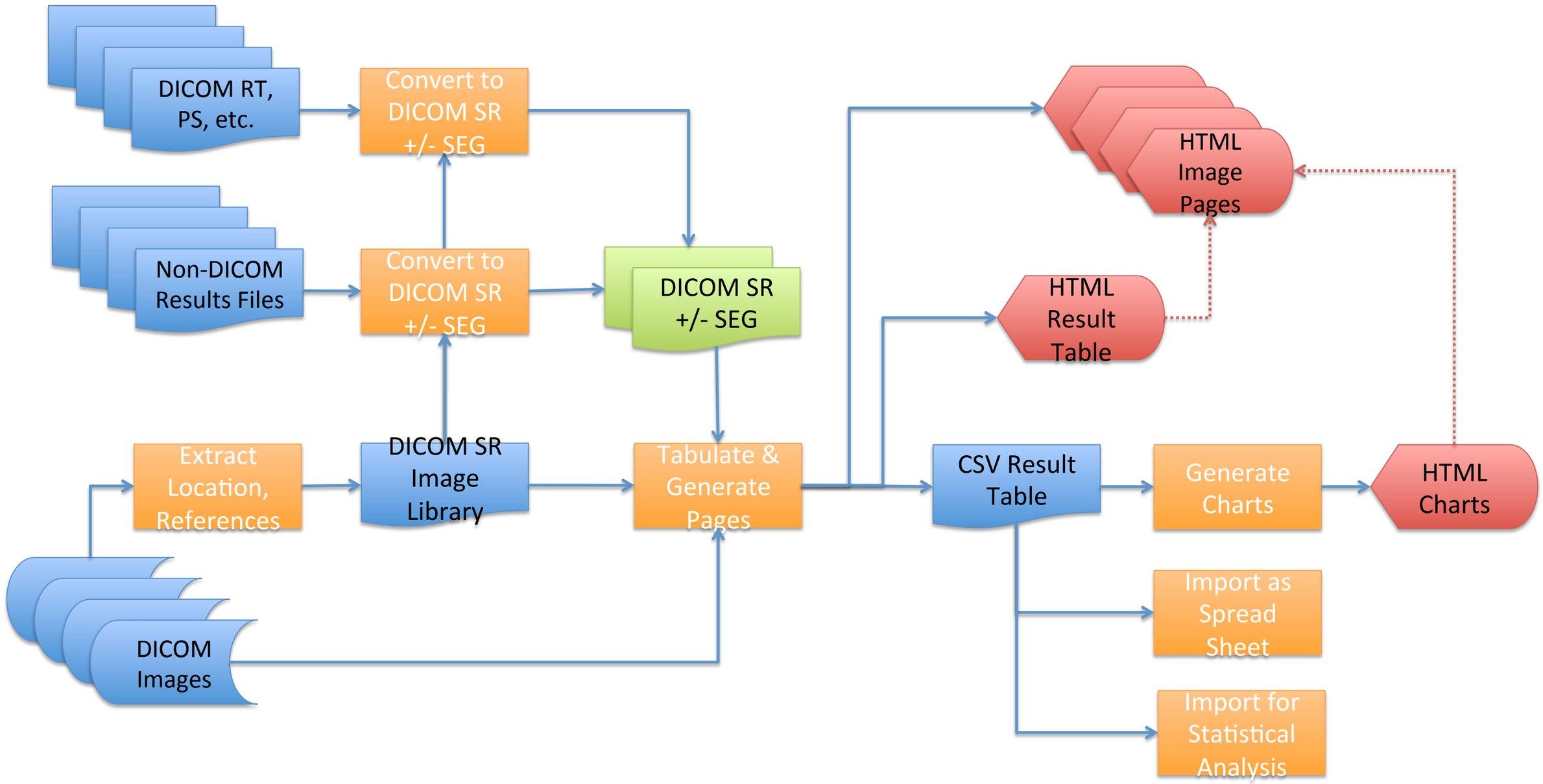
- Intended for rendering, not interpretation
- Commonly implemented in PACS for simple annotation capture
- Unstructured
  - text and graphics are not semantically linked
  - text is free text, not coded, and no structured measurements
  - with discipline entering text, structured content can be parsed from free text retrospectively

Process Flow

- Create DICOM SR
  - that conform to a basic template
  - subject/reader/time point lesion/measurement
- Tabulate results
  - include hyperlinks to rendered images with ROIs
  - compute any derived statistics
- Generate charts from tables
  - e.g., scatter plots, waterfall plots

Process Flow

- ROIs
  - if SR references segmentation, use it
  - if SR contains coordinates (2D or 3D), use them
  - if not, convert coordinates to SR coordinates
    - e.g., RT Structure Set 3D coordinates to SR 2D
  - if not, convert raster to segmentation
    - e.g., LIDC Max tool PMAP to DICOM SEG
- Image Library
  - extract image characteristics for re-use
  - e.g., position, orientation, spacing, UIDs
  - store in SR Image Library template
  - saves repeating this (reading image headers) many times

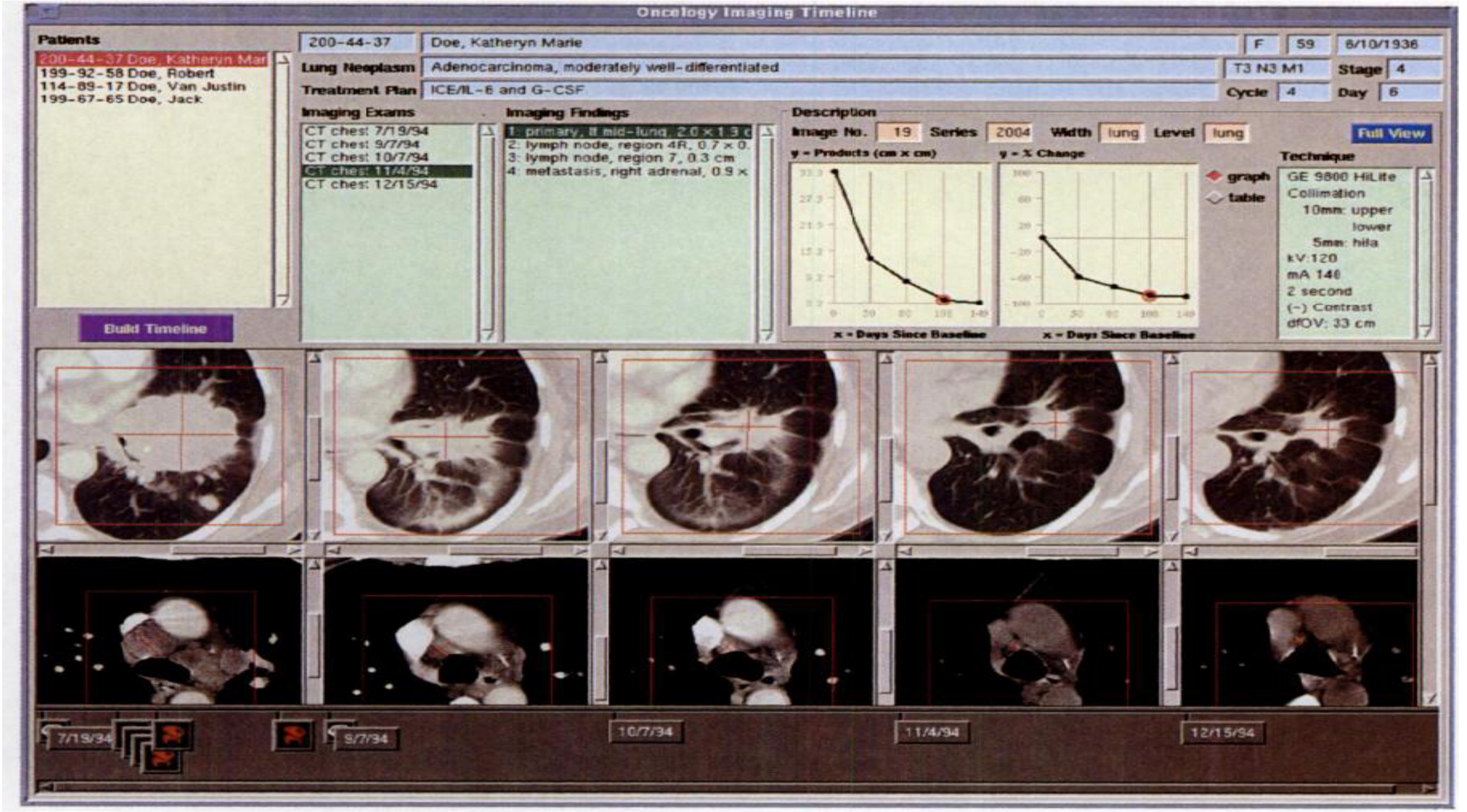

DICOM RT, PS, etc.
Convert to DICOM SR +/- SEG
Non-DICOM Results Files
Convert to DICOM SR +/- SEG
DICOM SR +/- SEG
HTML Image Pages
HTML Result Table
Extract Location, References
DICOM SR Image Library
Tabulate & Generate Pages
CSV Result Table
Generate Charts
HTML Charts
DICOM Images
Import as Spread Sheet
Import for Statistical Analysis

Earlier Work by Others

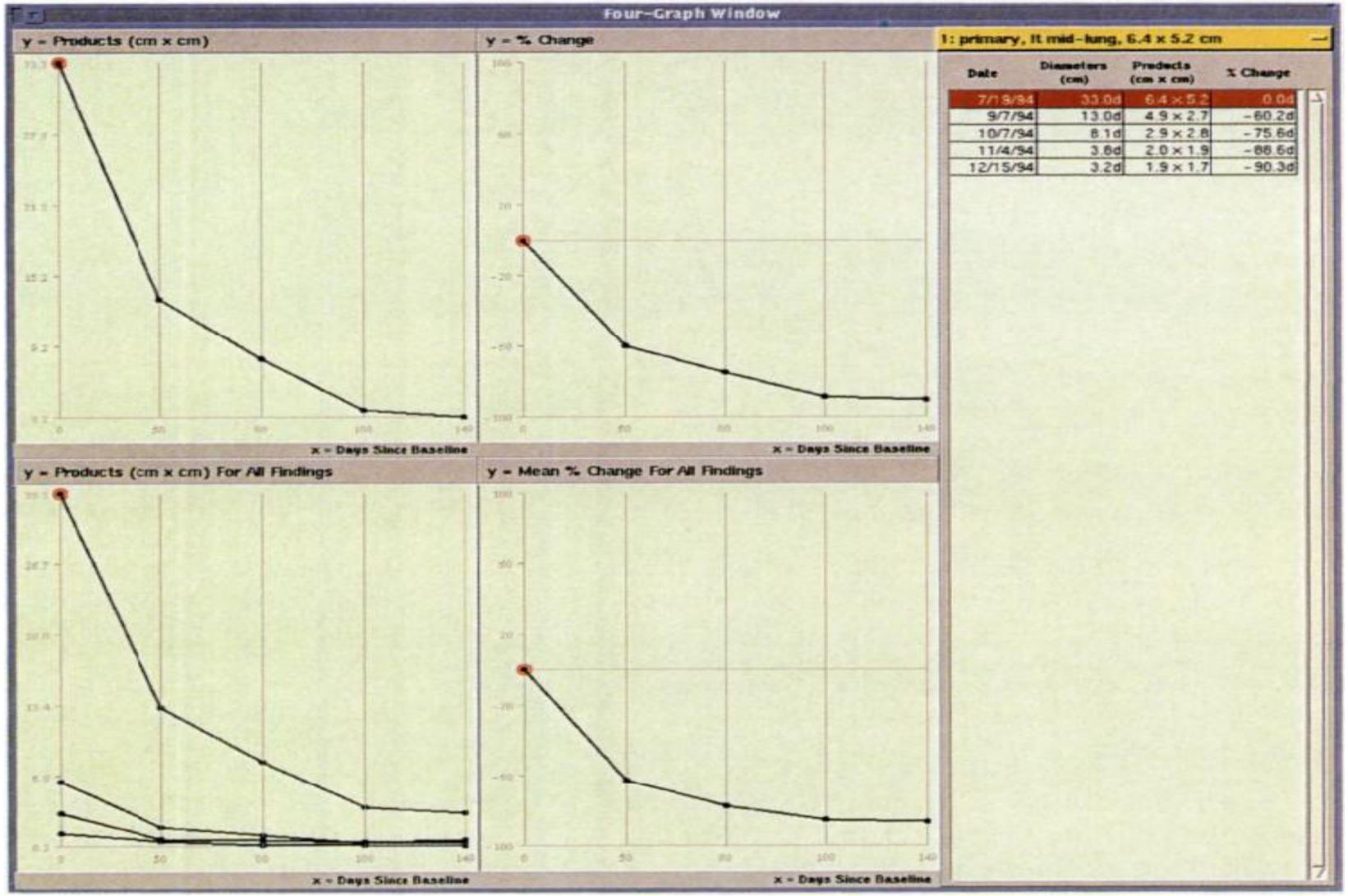
- Aberle 1996 – Thoracic Oncology Imaging Timeline (OITL)
  - regions of interest defined during reporting
  - change in lesion size over time for single patient
  - table of lesion size
  - graphs of size change
  - visualization of size change

http://radiographics.rsna.org/content/16/3/669

Aberle 1996 - OITL



Aberle 1996 - OITL

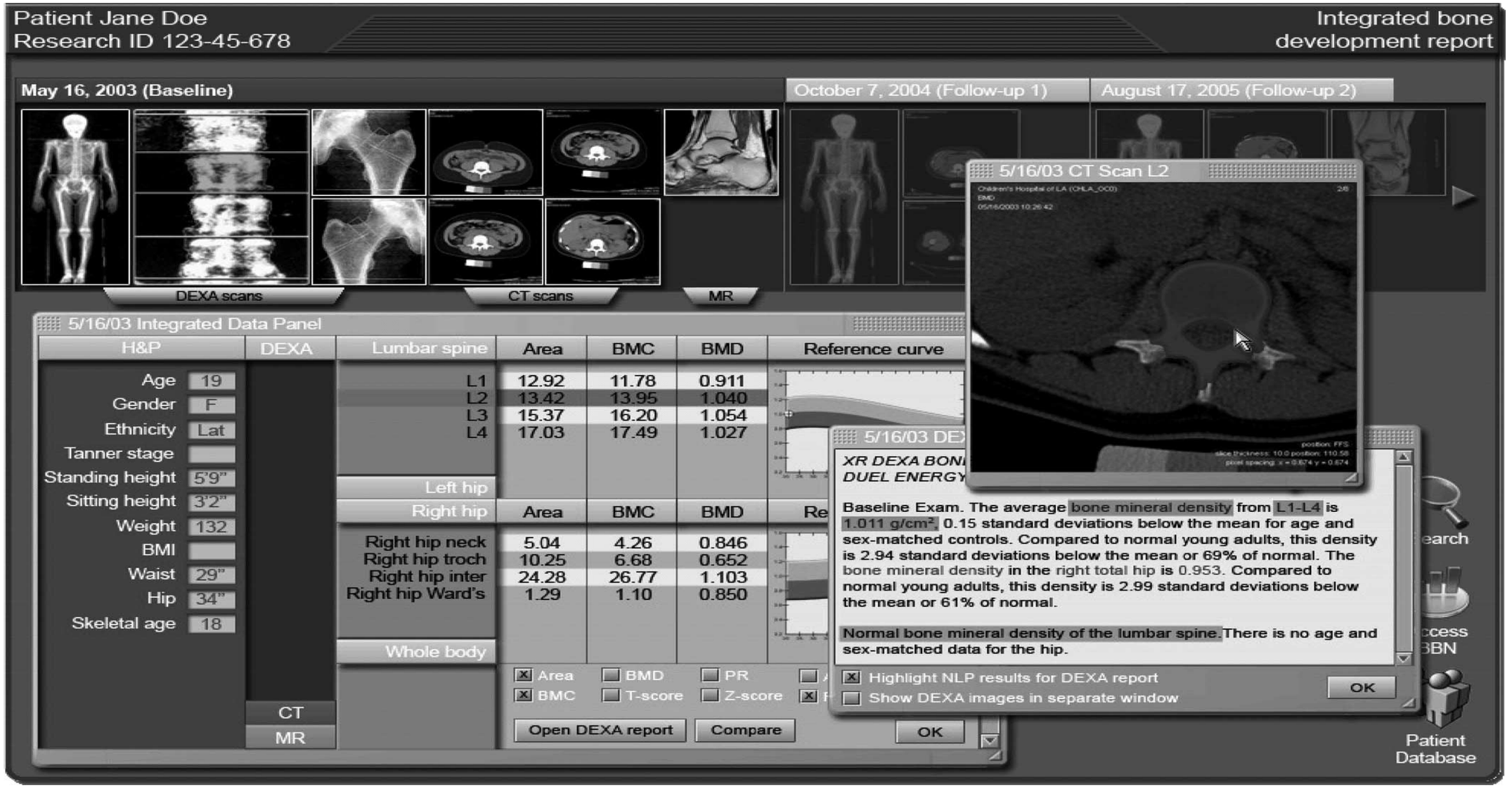


Earlier Work by Others

- Bui 2007 – TimeLine
  - more generalized, configurable approach
  - data access and integration
  - data mapping, reorganization and clustering
  - hierarchical problem-centric views
  - emphasis on temporal chronologies & clustering
  - adaptable format mapping methods

http://dx.doi.org/10.1109/TITB.2006.884365

Bui 2007 - TimeLine

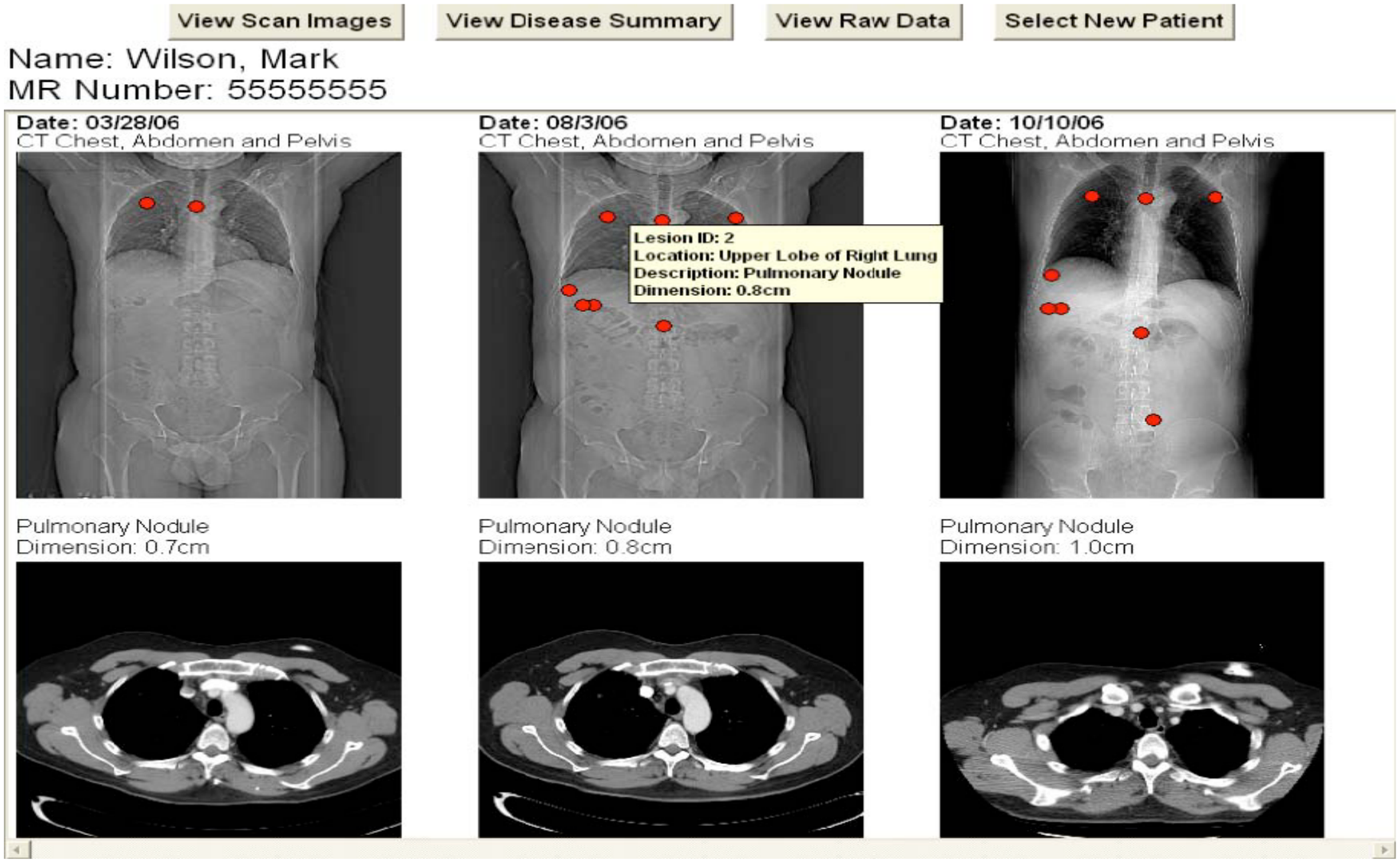


Earlier Work by Others

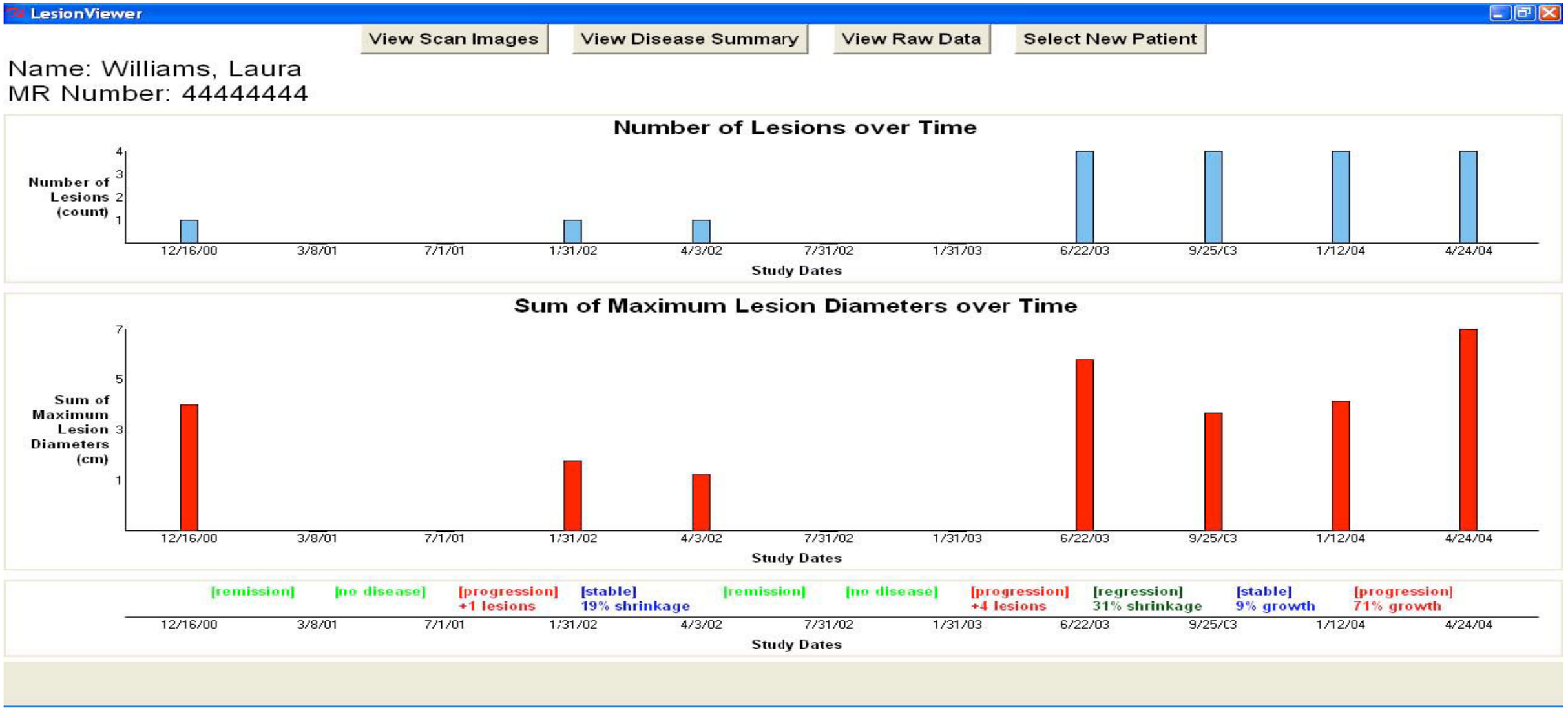
- Levy 2007 – LesionViewer
  - serial oncology studies
  - anatomical summary of lesion location
  - direct navigation to visualization of location
  - temporal abstraction of lesion behavior

http://dx.doi.org/10.1109/TITB.2006.884365

Levy 2007 - LesionViewer



Levy 2007 - LesionViewer



Earlier Work by Others

- AVT 2009 – Algorithm Validation Toolkit
  - NCI caBIG *in vivo* Imaging Workspace project
  - Measurement Variability Tookit (MVT) component
    - tabulation and charting
    - interface with R statistics package
  - only supports proprietary NCI AIM format

Disclosure: author was involved in AVT RFP and sub-contractor to Siemens Corporate Research on AVT use-case development and testing

https://wiki.nci.nih.gov/display/AVT/Algorithm+Validation+Toolkit+%28AVT%29+Project+Pages

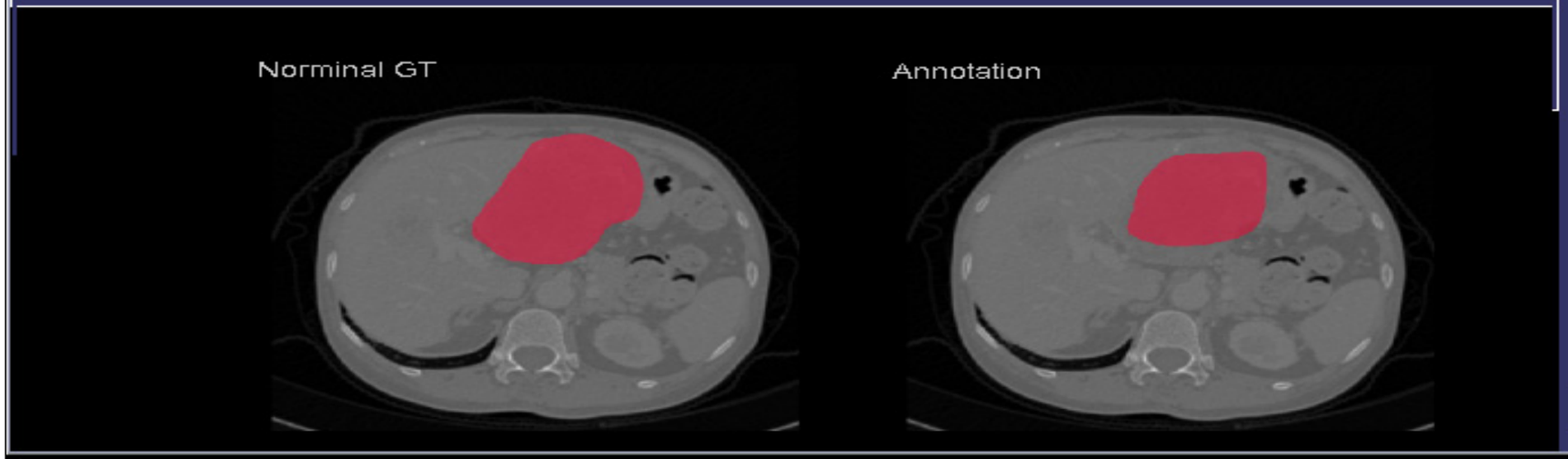
XIP | User: wustl | Suspend | Cancel | Exit

Computation Results

Subject Name	Rel VolDifferen...	SurfDistance(Avera...	Surface Distance(RMS)[...	Surface Distance(Maxim...	Volume Overlap[%]
LTS_IMG01	1.33747	0.33584	0.517345	2	93.38901
LTS_IMG02	78.8215	7.56008	8.99904	18.2481	9.685699
LTS_IMG03	11.4208	0.560206	0.852003	2.6543	70.1677
LTS_IMG04	5.70567	1.76527	2.77575	13.3707	77.781296
LTS_IMG05	24.5516	2.60058	3.84065	13.1668	67.9256
LTS_IMG06	8.13259	0.592667	0.894234	3.15362	78.9365
LTS_IMG07	48.2725	8.57166	10.012	26.0819	47.2082
LTS_IMG08	44.4414	7.37036	8.67253	22.3928	47.052
LTS_IMG09	97.8516	2.70283	3.91401	13.2583	49.0714
LTS_IMG10	25.8335	1.66703	2.21645	7.30861	69.5749
Mean	34.6369	3.37275	4.2694	12.1635	61.0792
SD	32.6547	3.19619	3.63071	8.41635	23.6128
CV	0.942774	0.94765	0.850403	0.691934	0.386592

Outliers | Plotting

Relative VolumeDifference: Top 25%	Surface Distance(RMS): Top 25%	Volume Overlap: Bottom 25%
LTS_IMG02	LTS_IMG02	LTS_IMG02
LTS_IMG07	LTS_IMG07	LTS_IMG07
LTS_IMG09	LTS_IMG08	LTS_IMG08



AVT

Statistics Analysis

Methods: Add | Custom | Del

Comparison to be Analyzed	Statistical Method
All Measurements	Mean
All Measurements	SD
All Measurements	CV

Outlier Analysis

Threshold: Add | Del

Comparison to be Analy...	Outlier Criteria
Relative VolumeDifference	Top 25%
Surface Distance(RMS)	Top 25%
Volume Overlap	Bottom 25%

Plotting

Charts: Add | Del

Plotting title	Chart
Bland-Altmann of Volume	Bland-Altmann
Scatter of Volume	Scatter
Surface Distance (RMS)	Scatter

PLOT

BACK | RUN

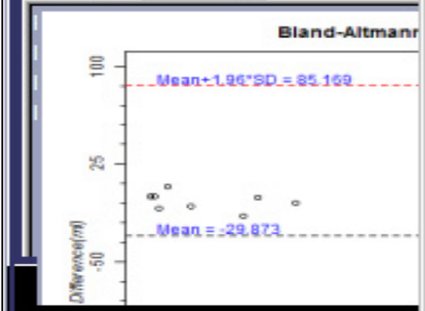
Finish calculation

XIP | User: wustl | Suspend | Cancel | Exit

Computation Results

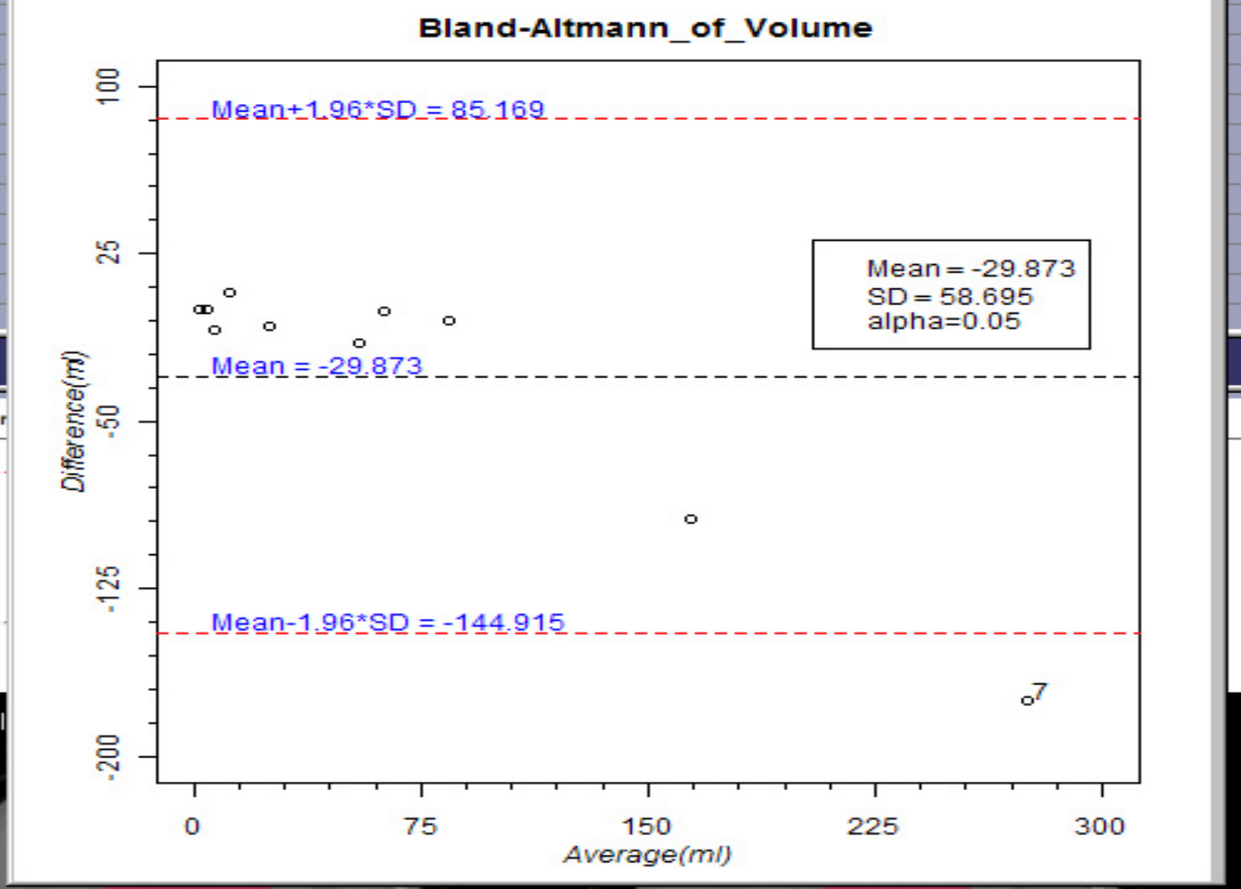
Subject Name	Rel VolDifferen...	SurfDistance(Avera...	Surface Distance(RMS)[...	Surface Distance(Maxim...	Volume Overlap[%]
LTS_IMG01	1.33747	0.33584	0.517345	2	93.38901
LTS_IMG02	78.8215				
LTS_IMG03	11.4208				
LTS_IMG04	5.70567				
LTS_IMG05	24.5516				
LTS_IMG06	8.13259				
LTS_IMG07	48.2725				
LTS_IMG08	44.4414				
LTS_IMG09	97.8516				
LTS_IMG10	25.8335				
Mean	34.6369				
SD	32.6547				
CV	0.942774				

Outliers | Plotting



Normina

Plot Window



AVT

Statistics Analysis

Methods: Add | Custom | Del

Comparison to be Analyzed	Statistical Method
All Measurements	Mean
All Measurements	SD
All Measurements	CV

Outlier Analysis

Threshold: Add | Del

Comparison to be Analy...	Outlier Criteria
Relative VolumeDifference	Top 25%
Surface Distance(RMS)	Top 25%
Volume Overlap	Bottom 25%

Plotting

Charts: Add | Del

Plotting title	Chart
Bland-Altmann of Volume	Bland-Altmann
Scatter of Volume	Scatter
Surface Distance (RMS)	Scatter

PLOT

BACK | RUN

Finish calculation