ITART 2010 – June 22, 2010

Quantitative Imaging Symposium:

How Can We Improve Quantification?

Edward F. Jackson, PhD
Department of Imaging Physics
ejackson@mdanderson.org

THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History®

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The promise of quantitative imaging

•Patient stratification in order to decide on alternative treatments	Predict
•Analysis of heterogeneity within and across lesions *(can assess varying pharmacokinetics, receptor status, proliferative/apoptotic rates, …)*	Virtual Biopsy
•Early prediction of treatment response •Basis for modifying therapy	During Tx
•Monitoring for Treatment Efficacy	After Tx
•Longitudinal monitoring and evaluation *(can be done before then after treatment, substituting for longitudinal tissue biopsy)*	Follow-up

Buckler, *et al.*, *A Collaborative Enterprise for Multi-Stakeholder Participation in the Advancement of Quantitative Imaging*, submitted, *Radiology*

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Objectives

- Ultimate goal: Translating single site successes to clinical practice!
- MR will be the modality used in this session to illustrate some specific morphological and functional applications and their associated challenges.
- General themes and challenges illustrated for MR are applicable to all quantitative imaging biomarkers, regardless of modality.
- The overall challenges discussed address the following situations:
  - single vendor, single site applications
  - multiple vendor, single site applications
  - multiple vendor, multiple site applications

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So…what is Quantitative Imaging?

The Toward Quantitative Imaging (TQI) task force of the RSNA definition:

- *"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. Quantitative imaging includes the development, standardization, and optimization of anatomical, functional, and molecular imaging acquisition protocols, data analyses, display methods, and reporting structures. These features 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."*

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What are the issues?

- Limitations of the selected imaging biomarker technique
- Data acquisition
  - Optimization, standardization, harmonization
  - Agent selection and standardization
  - Patient prep and injection technique (site, rate, delay, *etc.*) standardization
  - Acquisition protocol implementation
  - Motion mitigation, if necessary
  - Site qualification
  - Ongoing QC
- Data analysis and display
  - Optimization, standardization, harmonization
  - Motion mitigation / registration
  - Validation against vetted databases
  - Ongoing QC
- Structured reporting
- Imaging biomarker qualification / validation

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OK, so what are the challenges?

General quantification challenges

– Lack of standards (acquisition, analysis, and reporting)
  - Varying measurement results across vendors and centers

– Lack of support from imaging equipment vendors
  - No documented competitive advantage of QIB (regulatory or payer)
    – Varying measurement results across vendors
    – Varying measurement results across time for any particular vendor

– Highly variable quality control procedures
  - QC programs, if in place, not specific for *quantitative* imaging
    – Varying measurement results across centers

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Why use MR measures as imaging biomarkers?

- Exquisite soft tissue imaging with multiple contrast mechanisms
  – Lesion size / volume assessment
  – "Multispectral" data for image segmentation (T_1, T_2, post-Gd T_1, *etc.*)
- No ionizing radiation
- Functional imaging assessments
  – Dynamic Contrast Enhanced MRI (DCE-MRI)
    - Microvascular volume, flow, permeability (extraction-flow) measures
  – Diffusion MRI
    - Cell density/volume measures
  – MR Spectroscopy
    - Biochemical measures
  – Others, including blood oxygen level dependent (BOLD) MR for hypoxia

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General challenges in MR quantification

Arbitrary (and spatially- / temporally-dependent) signal intensity units

- Magnitude and homogeneity of the main magnetic field (B_0)
  - Higher B_0 better signal-to-noise; homogeneity impacts image uniformity and spatial accuracy
- Magnetic field gradient nonlinearity and/or miscalibration
  - Spatial accuracy depends strongly on gradient subsystem characteristics
- Radiofrequency (RF) coil dependency: RF coil type, sensitivity profiles, subject positioning within the coil
  - Image signal uniformity; impact on longitudinal signal intensity measures
- Slice profile variations (with RF pulse shape, flip angle, *etc.*)
  - Slice thickness depends on pulse sequence and RF pulse shape; prescribed thickness and measured thickness differ, especially for fast imaging techniques
- System stability issues (RF & gradient subsystems, B_0, RF coils, *etc.*)
  - Quality control programs are critical for reproducible measures!

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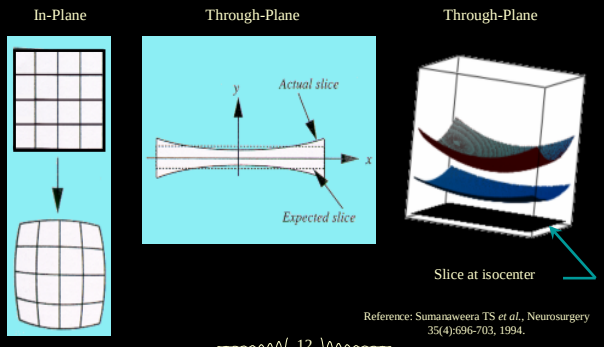
Gradient field nonlinearity effects



Reference: Sumanaweera TS *et al.*, Neurosurgery 35(4):696-703, 1994.

Precision / accuracy not just scanner dependent

- System Limitations
  - Poor B_0 homogeneity
  - Linear scale factor errors in the gradient fields
  - Field distortion due to induced eddy currents
  - Nonlinearities of the gradient fields

Even if the scanner is "perfect", the measured value may be inaccurate…

- Object-Induced Effects
  - Chemical shift effects (fat / water displacement, in-plane and slice)
  - Intravoxel magnetic susceptibility differences (particularly air-tissue)
  - Effects are minimized with non-vendor specific appropriate acquisition parameters, but at the expense of SNR. (Importance of acquisition protocol optimization and standardization!)

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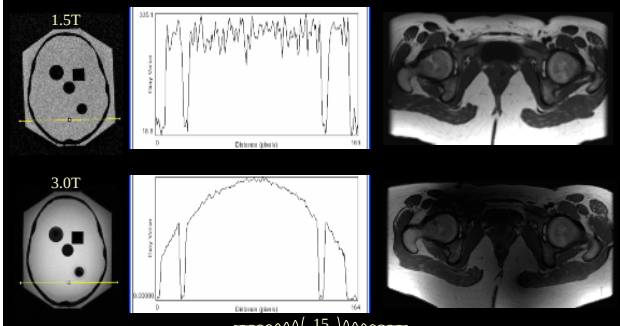
B_1 coil response non-uniformity

B_1 response non-uniformity



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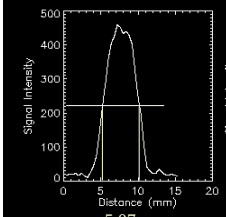
General challenges in MR quantification

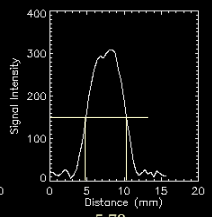
Slice profile variations (with RF pulse shape, flip angle, *etc.*)

5 mm spin-echo



5.07 mm

5 mm fast gradient-echo



5.78 mm

Typically, faster imaging sequences use increasingly truncated RF pulses resulting in thicker slice profiles for a given prescribed slice thickness. This gives rise to increased partial volume averaging effects and a concomitant loss of spatial resolution.

Flip angle calibrations can also be negatively affected.

General challenges in MR quantification

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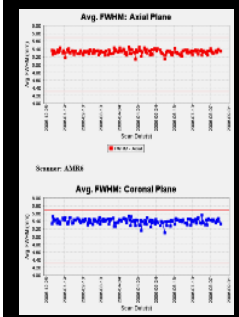
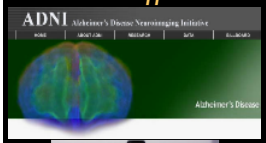


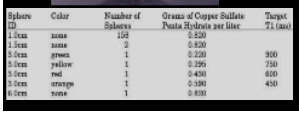
For quantitative imaging, particularly in longitudinal studies, a rigorous quality control program is critical.

Key components of frequent QC tests:

- Geometric accuracy
- Signal-to-noise ratio (or low contrast object detectability)
- Uniformity
- Contrast response
- Slice thickness
- High contrast spatial resolution
- Center frequency
- Transmit gain

Difficult? Perhaps, but it can be done!





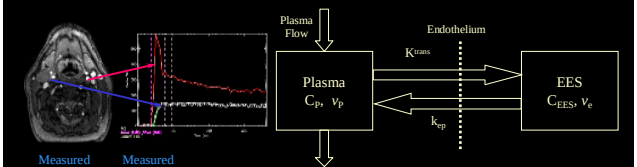
- Multicenter, multivendor study
- Optimized pulse sequence / acquisition parameters for each platform
- MagPhan/ADNI phantom scan at each measurement point
- Access to vendor gradient correction parameters
- With full correction for gradient nonlinearities and optimized acquisition strategies, spatial accuracies of ~0.3 mm can be obtained over a ~180 mm diameter spherical volume

http://www.loni.ucla.edu/ADNI/

Raising the bar – Functional MR measures

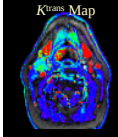
- General MR quantification challenges
  - Lack of standards (acquisition, data processing, and reporting)
    - Varying measurement results across vendors and centers
  - Lack of support from imaging equipment vendors
    - Varying measurement results across vendors
    - Varying measurement results across time for any particular vendor
  - Highly variable quality control procedures
    - Varying measurement results across centers
- Raising the bar: From morphological to functional MR biomarkers
  - DCE-MRI and DSC-MRI (microvascular extraction-flow, volume, *etc.*)
  - Diffusion MRI (cellular density, cell volume fraction)
  - MR Spectroscopy (biochemical concentrations)
  - BOLD MRI (oxy- / deoxyhemoglobin ratio)

Dynamic contrast enhanced MRI



$$C_L(t) = v_P C_P(t) + v_e C_{EES}(t)$$

$$C_{EES}(t) = K^{trans} \int_0^t C_P(t')\ e^{-k_{ep}(t-t')}\ dt'$$



C_p = [Gd] in plasma (mM) = C_b / (1-Hct)
C_{EES} = [Gd] in extravascular, extracellular space (mM)
K^{trans} = endothelial transfer constant (min^{-1})
k_{ep} = reflux rate (min^{-1})
v_P = fractional plasma volume, v_e = fractional EES volume (= K^{trans} / k_{ep})

Standardized parameters as proposed by Tofts *et al.*, *J Magn Reson Imaging*, 10:223-232, 1999.

What are the challenges with DCE-MRI?

Signal intensity data from tumor and vascular ROIs

$$\Delta R_1 = \frac{1}{TR}\ln\left[\frac{\left(1-\cos\alpha\, e^{-TR R_{1,0}}\right)-\frac{S}{S_0}\cos\alpha\left(1-e^{-TR R_{1,0}}\right)}{\left(1-\cos\alpha\, e^{-TR R_{1,0}}\right)-\frac{S}{S_0}\left(1-e^{-TR R_{1,0}}\right)}\right]+R_{1,0}$$

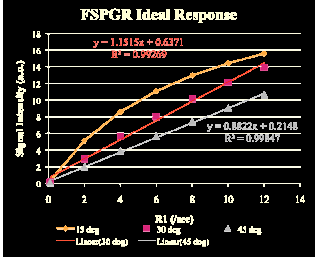
$$[Gd] = \frac{R_1 - R_{1,0}}{r_1} = \frac{\Delta R_1}{r_1}$$

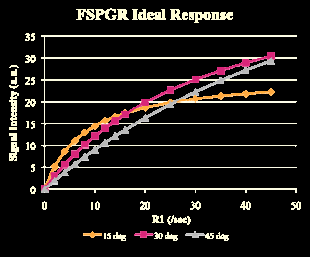
$$C_L(t) = \frac{K^{trans}\int_0^t C_p(t')e^{-k_{ep}(t-t')} + v_p C_p(t)}{1-Hct}$$

Determine v_P, K^{trans}, and k_{ep}, from non-linear Marquardt-Levenberg fitting of $C_L(t)$ and $C_p(t)$ data

What are the challenges with DCE-MRI?

Theoretical Response (ignoring R2*)





DCE-MRI data acquisition challenges

- Pulse sequence
  - Contrast response must be well characterized and maintained for duration of study (or a process for compensation for changes must be developed)
- Temporal resolution
  - Must match choice of pharmacokinetic model and parameters of interest
    - Must be rapid (≤~2-5 s) for generalized kinetic model with estimation of v_p
    - Recommended to be ≤10 s for any pharmacokinetic model
- T1 measurements
  - Required if contrast agent concentration is used in modeling
  - Must be obtained in reasonable scan time
  - Must be robust as uncertainties in T1 estimates propagate to output measures

DCE-MRI data acquisition challenges

- Spatial resolution
  - Must be adequate for target lesion size and application
- Anatomic coverage
  - Should fully cover target lesion(s) & include appropriate vascular structure
- Motion
  - Effects should be mitigated prospectively during acquisition and/or retrospectively, *e.g.*, rigid body or deformable registration

DCE-MRI data analysis challenges

Many choices to be made:

- Mitigation of motion effects (if necessary)
  - Retrospective (rigid body, deformable)
- Vascular input selection
  - Manual ROI vs. automated identification of vascular structure pixels
  - Reproducibility
- Lesion ROI(s)
  - Definition criteria
  - Reproducibility
- Fits of single averaged pixel uptake curve or pixel-by-pixel fits
- Modeling of: gadolinium concentration (requiring T1 mapping) or simple change in signal intensity data
- Reporting of results (structured reporting)

Single-vendor, single-site studies

Major challenges:

- Acquisition protocol optimization
  - Pulse sequence and acquisition parameter optimization for:
    - contrast response
    - temporal resolution (for dynamic imaging)
    - spatial resolution
    - anatomic coverage
  - Application specific phantom needed for initial validation scans and ongoing quality control
    - phantom acquisition and data analysis protocols
    - established frequency of assessment and data reporting
- Mechanism for detecting and addressing changes in measured response due to system upgrades (Quality Control)
  - Vendors focused on “competitive advantage” in radiology, not on quantitative imaging applications; no focus on maintaining signal response characteristics over time

From single- to multi-vendor studies

Major challenges:

- Acquisition protocol harmonization
  - Pulse sequence and acquisition parameter selection for matched:
    - contrast response
    - temporal resolution (for dynamic imaging)
    - spatial resolution
    - anatomic coverage
  - Application specific phantom needed for initial validation scans and ongoing quality control
    - phantom acquisition and data analysis protocols
    - established frequency of assessment and data reporting
  - Can be achieved, but requires effort at start up and, subsequently, constant monitoring for changes in hardware/software (need for ongoing quality control)
- Vendors focused on "competitive advantage" in radiology, not on quantitative imaging applications

From single- to multi-center studies

Major challenges:

- Acquisition protocols
  - Harmonization across centers and vendors
  - Distribution and activation of protocols
    - Distribute/load electronically (ADNI)
    - Provide expert training and initial protocol load/test
    - Develop / utilize local expertise
  - Compliance with protocol
    - Local radiologists, technologists
- Widely varying quality control
  - Ranging from specific for a given imaging biomarker, to ACR accreditation, to none
  - Even if QC program is in place, it may not test parameters relevant to the study
- "Scanner upgrade dilemma"
- Data management and reporting

How can we move forward?

To move MR imaging biomarkers from exploratory / secondary endpoints to primary endpoints:

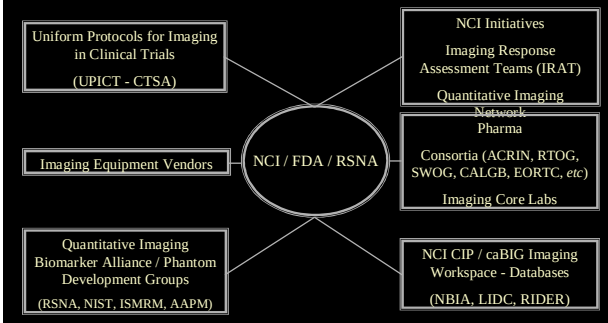
- To quote George Mills (former Director, FDA/CDER): "Precision is the goal." However, "multi-center trial designs = variations in imaging." Do not assume anything but, instead, "discover and adjust for differences".
- Standardized data acquisition and analysis techniques are needed.
- Vetted phantoms should be available to quantitatively characterize vendor-specific acquisition techniques for a particular MR imaging biomarker (lesion morphology, perfusion, diffusion, MR spectroscopy, *etc.*).
- Application specific phantoms should be used in the site validation phase for every clinical trial and periodically during the longitudinal study.
- Vetted test data need to be publically available to users in order to test new releases of analysis software.

How can we move forward?

To move MR imaging biomarkers from exploratory / secondary endpoints to primary endpoints:

- Repeatability (test/retest) studies are needed for any new MR-based imaging biomarker.
- Additional imaging biomarker to tissue-based and outcome measure comparisons are needed.

Quantitative MR imaging initiatives



What are we doing to get there?

Quantitative MR Imaging Initiatives

- NCI: RIDER and Academic Center Contracts
- NCI: Imaging Response Assessment Team (IRAT) / MR Committee
- RSNA: Quantitative Imaging Biomarker Alliance MR Committee
- ISMRM: *Ad Hoc* Committee on Standards for Quantitative MR
- AAPM: Committee on Quantitative Imaging / Working Group for Standards for Quantitative MR Measures
- NCI: Quantitative Imaging Initiative (QIN)

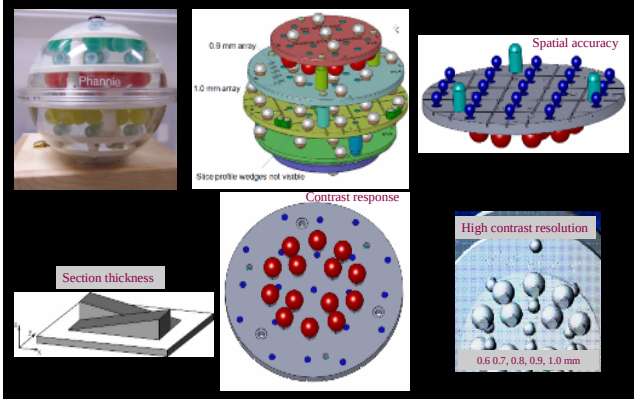
ISMRM Ad Hoc Committee

ISMRM: *Ad Hoc* Committee on Standards for Quantitative MR (SQMR)

- Membership includes MR physicists, technologists, radiologists, NIST staff, NCI/CIP staff, vendors, and pharma. Expertise in research trials using quantitative MR.
- Current status:
  - White paper on quantitative MR
  - Design specifications & construction of an "open source" MR system phantom (collaboration with and funding by NIST)
  - Initial multicenter / multivendor phantom pilot studies began in June 2010.

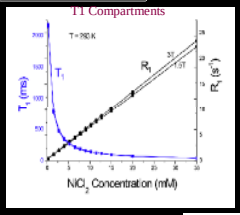
http://wiki.ismrm.org/twiki/bin/view/QuantitativeMR/

ISMRM SQMR System Phantom

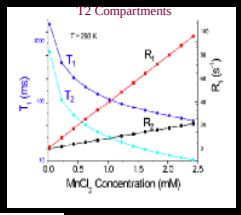


ISMRM SQMR System Phantom

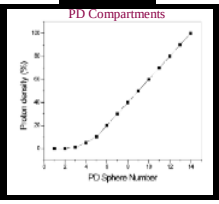
T1 Compartments



T2 Compartments

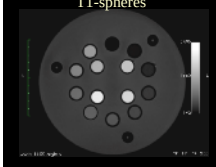


PD Compartments

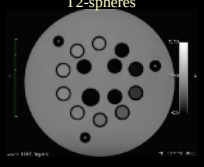


ISMRM SQMR System Phantom

T1-spheres



T2-spheres



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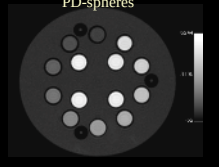
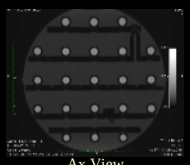
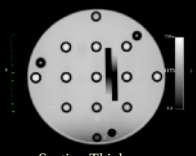




Ax View



Section Thickness

High Contrast Resolution

RSNA Quantitative Imaging Biomarker Alliance

RSNA QIBA: DCE-MRI Technical Committee

- Multiple subcommittees:
  - Phantom development / selection
  - Scan protocol / data analysis
  - Synthetic DCE-MRI test data
- Acquisition and phantom designed to mimic typical Phase I / II applications to liver using phased array receive coils
- Modified version of the ADNI MagPhan, as previously modified by IRAT MR Committee
- 1-cm fiducial spheres for spatial accuracy assessment
- Eight 3-cm contrast response spheres (same as IRAT modified version)

http://qibawiki.rsna.org/index.php?title=DCE-MRI

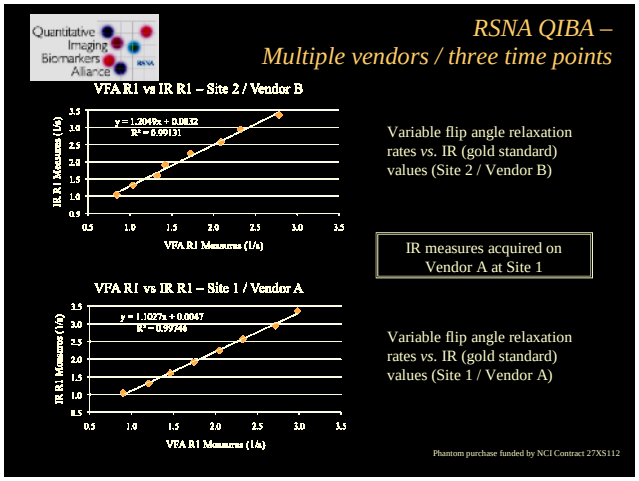
Phantom purchase funded by NCI Contract 27XS112

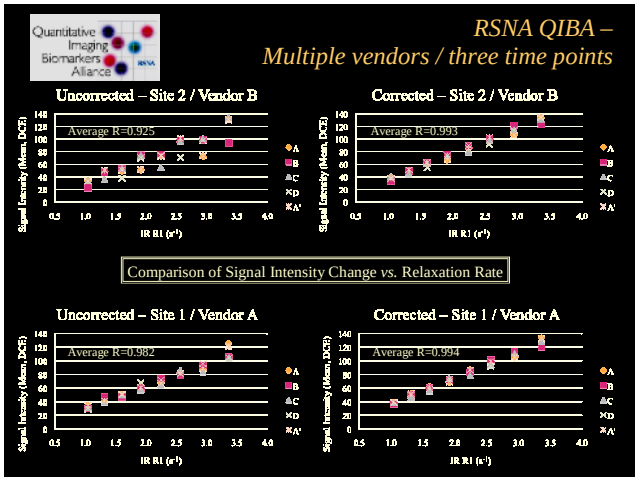
QIBA DCE-MRI Phantom v1 Studies

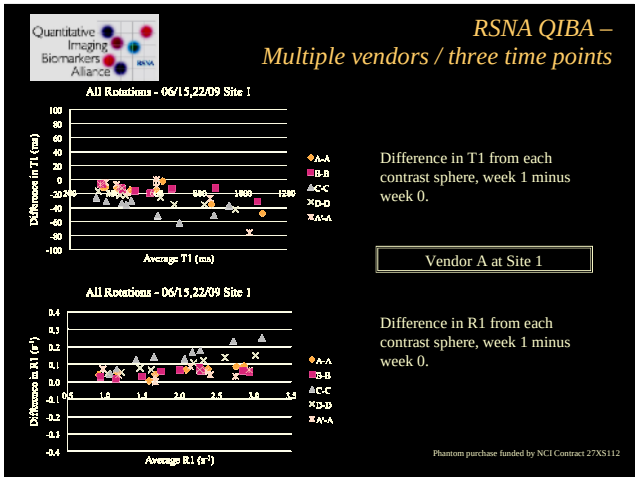
- Phantom measurements (overview):
  - Phased array acquisition
  - Body coil acquisition
  - SNR acquisition
  - Variable flip angle T1 measurement acquisition
  - DCE acquisition

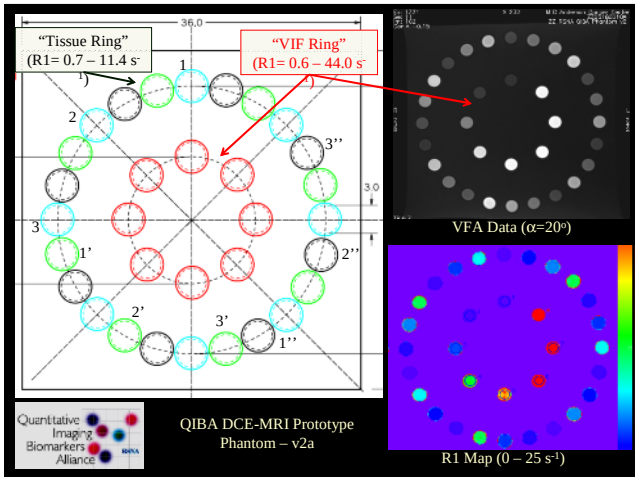
  } Ratio map correction for RF coil sensitivity characteristics
- Each of the above acquisitions repeated with phantom rotated by 90, 180, 270, and 360°
- All acquisitions repeated one week later
- Sites / vendors

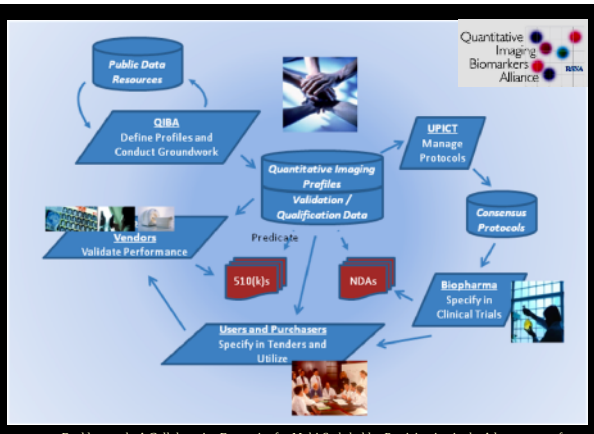
– MDACC	Site 1 / Vendor A, B
– UPenn	Site 2 / Vendor B
– Univ Chicago	Site 3 / Vendor C
– Duke Univ	Site 4 / Vendor C
– Univ CA Davis	Site 5 / Vendor A


Quantitative Imaging Biomarkers Alliance
RSNA QIBA –
Multiple vendors / three time points
VFA R1 vs IR R1 – Site 2 / Vendor B
y = 1.2049x + 0.0832
R² = 0.99131
IR R1 Measures (1/s)
VFA R1 Measures (1/s)
Variable flip angle relaxation rates vs. IR (gold standard) values (Site 2 / Vendor B)
IR measures acquired on Vendor A at Site 1
VFA R1 vs IR R1 – Site 1 / Vendor A
y = 1.1027x + 0.0047
R² = 0.99748
Variable flip angle relaxation rates vs. IR (gold standard) values (Site 1 / Vendor A)
Phantom purchase funded by NCI Contract 27XS112


Quantitative Imaging Biomarkers Alliance
RSNA QIBA –
Multiple vendors / three time points
Uncorrected – Site 2 / Vendor B
Average R=0.925
Corrected – Site 2 / Vendor B
Average R=0.993
Signal Intensity (Mean, DCE)
IR R1 (s⁻¹)
Comparison of Signal Intensity Change vs. Relaxation Rate
Uncorrected – Site 1 / Vendor A
Average R=0.982
Corrected – Site 1 / Vendor A
Average R=0.994


Quantitative Imaging Biomarkers Alliance
RSNA QIBA –
Multiple vendors / three time points
All Rotations - 06/15,22/09 Site 1
Difference in T1 (ms)
Average T1 (ms)
Difference in T1 from each contrast sphere, week 1 minus week 0.
Vendor A at Site 1
All Rotations - 06/15,22/09 Site 1
Difference in R1 (s⁻¹)
Average R1 (s⁻¹)
Difference in R1 from each contrast sphere, week 1 minus week 0.
Phantom purchase funded by NCI Contract 27XS112


"Tissue Ring"
(R1= 0.7 – 11.4 s⁻¹)
"VIF Ring"
(R1= 0.6 – 44.0 s⁻¹)
VFA Data (α=20°)
R1 Map (0 – 25 s⁻¹)
Quantitative Imaging Biomarkers Alliance
QIBA DCE-MRI Prototype
Phantom – v2a



Buckler, *et al.*, *A Collaborative Enterprise for Multi-Stakeholder Participation in the Advancement of Quantitative Imaging*, submitted, *Radiology*

Imaging - Cancer Imaging Program
RIDER

NCI RIDER

NCI Cancer Imaging Program **RIDER**

– Reference Image Database to Evaluate Response*

Collaborative project for development and implementation of a caBIG public resource

Data and meta analyses made publically available through NBIA (phantom and anonymized human subject data, including DCE-MRI, diffusion-weighted, and diffusion tensor MRI)

Series of manuscripts in *Translational Oncology* in Dec 2009

RIDER: https://wiki.nci.nih.gov/display/CIP/RIDER
NBIA: https://imaging.nci.nih.gov/ncia/login.jsf

Imaging - Cancer Imaging Program
RIDER

NCI RIDER

3.1 ACADEMIC SITE COLLECTIONS: Focus on methods for data analysis

MSKCC

Download on NBIA by searching Collection name: RIDER Lung CT

- Repeat CT Measurements: Human subjects: Lung
- Download the related lesion notes: MSKCC RepeatCT Lesion notes for RIDER.xls
- Download the related publication: Zhao-RepeatCT Radiology2009.pdf

UNIVERSITY OF WASHINGTON

Download on NBIA by searching Collection name: Phantom

- Repeat measurements: PET/CT phantoms

Download on NBIA by searching Collection name: RIDER Lung PET CT

- Longitudinal PET/CT Human studies: Lung

DUKE UNIVERSITY

Download on NBIA by searching Collection name: RIDER Neuro MRI

- Repeat human subject studies: Neuro
- Dynamic Contrast Enhanced studies: DCE MRI:
- Diffusion weighted imaging: DWI MR
- Diffusion tensor imaging: DT MRI.

UNIVERSITY OF MICHIGAN

Download on NBIA by searching Collection name: RIDER Breast MRI

- Repeat measurements: Human subjects: Breast
- DCE MRI
- SUMMF 2009 poster demonstrates how each of the "coffee break" exams were used as an estimate of each patient's null hypothesis, i.e. distribution associated with no change, and thus supports the estimate of the null's 97.5 percentile for subsequent estimation of early response to neoadjuvant chemotherapy on an individual patient basis.

MDACC

Download on NBIA by searching Collection name: RIDER Phantom MRI

- Repeat measurement: Phantom studies
- DCE MRI
- RIDER_MR_Phantom_Data_Summary.pdf provides a summary of the images in this collection.
- RIDER_PhantomMR_Key.pdf provides a key for understanding their presentation in NBIA.

AAPM Committee

- AAPM: *Ad Hoc* Committee on Quantitative Imaging (Science Council)
  - Charge
    - To assess the role of AAPM and its members in the growing field of quantitative imaging as, e.g., it relates to imaging biomarkers, assessing disease states and/or response to therapy.
    - To determine mechanisms for clarifying quantitative imaging, CAD, and quantitative image analysis.
    - To determine mechanisms for promoting AAPM and medical physics activities in QI in basic science research, translational research, clinical trials, and ultimately clinical practice (*e.g.*, at annual meeting, in the MEDICAL PHYSICS journal [guest editorial], etc.).
    - To further advance the field by interacting with other organizations (such as RSNA, ACR, etc.)

AAPM Working Group

- AAPM: Working Group for Standards for Quantitative MR Measures
  - Charge
    - Development of quantitative MR phantoms and acquisition techniques / parameters specific to a given quantitative measure. Obtaining repeat measures on each phantom at multiple centers and using current high-field scanners from all major vendors.
    - Develop signal response characteristic standards for relevant pulse sequences. These response characteristic standards will allow ongoing QC at individual centers on a given platform (across upgrades) and comparisons between vendor platforms (and hardware/software versions.
    - Develop sets of annotated test data that can be publicly distributed (via the NBIA, for example) and used to validate image analysis software tools.

AAPM Task Group

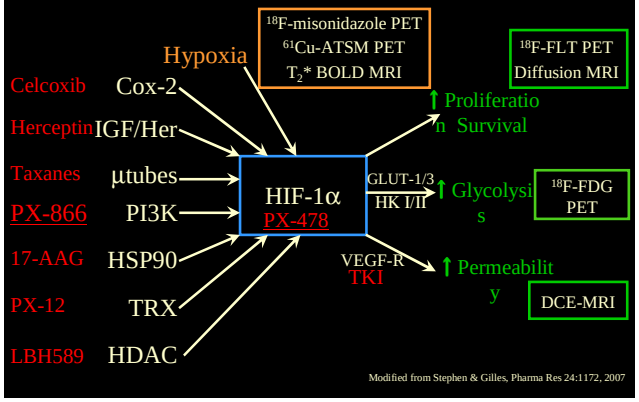
- AAPM: TG189: Validation of software tools for quantification of DCE MRI data
  - Charge
    - To provide to the community:
      - A robust validation methodology for testing DCE MRI-based quantification strategies.
      - Analysis of existing methods.
      - Guidelines for image acquisition.
      - A conceptual framework for generalized analysis of models based on dynamic MRI data

NCI CQIE Program

Acknowledgements

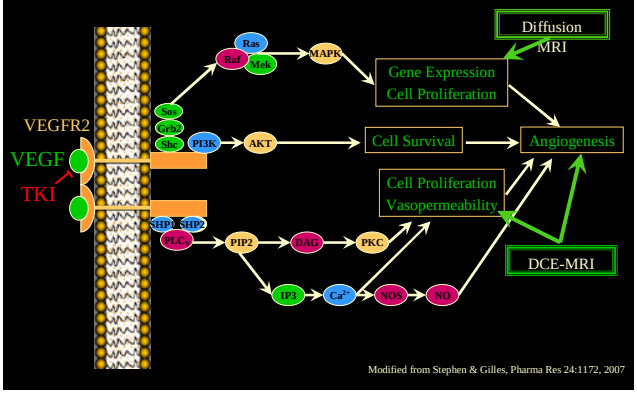
- NCI CIP RIDER SAIC Contract 27XS112
- RSNA QIBA Steering Committee and Quantitative MR Committee, especially Dan Sullivan, PhD, Andy Buckler, MS, Jeff Evelhoch, PhD, Gudrun Zahlmann, PhD, Sandeep Gupta, PhD
- Paul Kinahan, PhD and Mike McNitt-Gray, PhD
- John Boone, PhD and AAPM Science Council and MR Subcommittee
- Robert Jeraj, PhD and AAPM WGITA
- ISMRM *Ad Hoc* Committee on Standards for Quantitative MRI
- Steve Russek, PhD and colleagues at NIST Boulder (MR)
- Ryan Bosca, MS

Applications to HIF-1α targeted Rx



Modified from Stephen & Gilles, Pharma Res 24:1172, 2007

Applications to VEGFR targeted Rx

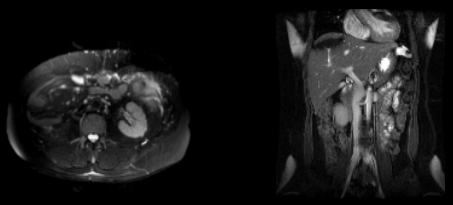


Modified from Stephen & Gilles, Pharma Res 24:1172, 2007

B_o homogeneity

In general: Larger B_0 => higher signal-to-noise

B_0 inhomogeneity yields spatially variant signal intensities in general and spatially variant fat suppression when chemically selective saturation methods are utilized.

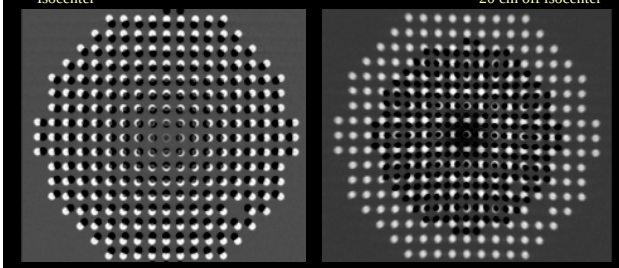


Gradient field nonlinearity effects

20 cm FOV, white: w/correction, black: w/o correction

Isocenter

20 cm off isocenter



$Error_{max}$ with correction: < 1 mm @ ± 10 cm
$Error_{max}$ w/o correction: ~ 4.5mm @ ± 10 cm

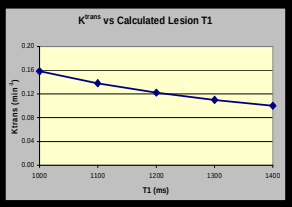
$Error_{max}$ with correction: < 2 mm @ ± 10 cm
$Error_{max}$ w/o correction: ~ 5.5cm @ ± 10 cm

T1 measurements & impact on K^{trans}

Region	MDACC VFA 20090907*	MDACC VFA Flip + 5**	Average	Diff T1	
1	738.22	1124.59	931.41	386.37	
2	422.02	563.15	492.59	141.13	
3	556.35	770.53	663.44	214.18	
4	1356.10	1406.91	1381.51	50.81	
5	468.94	639.36	554.15	170.42	
6	704.67	1052.80	878.74	348.13	
7	955.35	1234.30	1094.83	278.95	
8	405.00	513.88	459.44	108.88	
9	490.49	659.58	575.04	169.09	
			781.24	110.936	<=stdev
			27.8	217.43	<=1.96*stdev
				207.55	<=mean difference

*Flip angles: 2, 5, 10, 15, 20, 25, 30 - per QIBA protocol

**Flip angles: 7, 10, 15, 20, 25, 30, 35



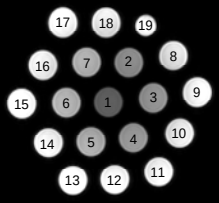
3D FSPGR TE=1ms, TR=5.1ms

T1 measurement "noise" is propagated into estimates of K^{trans} and other pharmacokinetic model parameters.

NCI RIDER DCE-MRI phantom data

Gel-filled compartments with varying T1 relaxation times

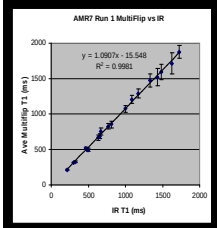
Eurospin TO5 – DiagnosticSonar, Ltd.

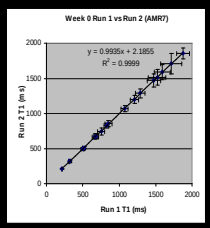


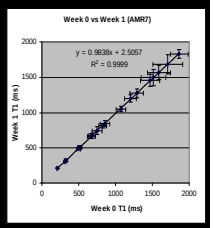
Compartment #	T1 IR (ms)
1	216.25
2	320.18
3	303.80
4	493.36
5	484.81
6	471.17
7	656.59
8	634.46
9	809.73
10	768.12
11	1001.62
12	1729.28
13	1086.39
14	1173.65
15	1331.32
16	1479.67
17	1432.01
18	1624.65
19	668.70

Funded by NCI Contract N01-CO-12400 and 27XS112

RIDER – Single vendor / multiple time points







Run 1 = baseline

Run 2 = 2 hrs post baseline

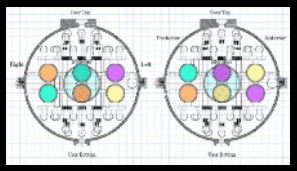
Week 1 = 1 week post baseline

Bosca & Jackson, AAPM 2009; Jackson *et al.*, *Trans Oncol*, Dec 2009

Funded by NCI Contract N01-CO-12400 and 27XS112

RSNA QIBA DCE-MRI Phantom v1

- Modified version of the ADNI MagPhan, as previously modified by IRAT MR Committee
- 1-cm fiducial spheres for spatial accuracy assessment unchanged
- Eight 3-cm contrast response spheres (same as IRAT modified version)
- T1 modifier: $CuSO_4$
- Flood fill solution of phantom and cuboid changed to 30 mM NaCl



Two matched phantoms were manufactured by The Phantom Laboratory (Salem, NY)

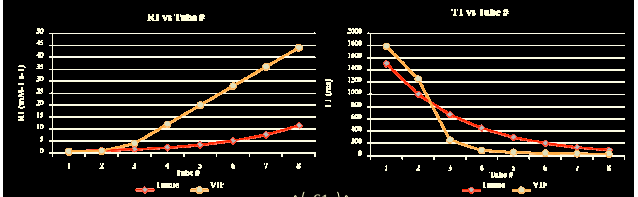
(Phantom purchase funded by NCI Contract 27XS112)

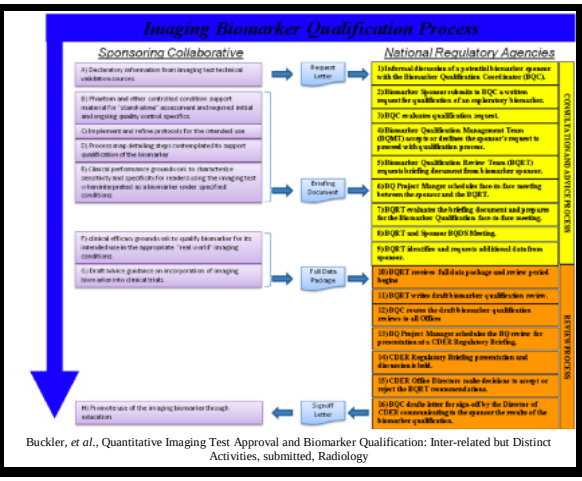
http://qibawiki.rsna.org/index.php?title=DCE-MRI

Phantom purchase funded by NCI Contract 27XS112

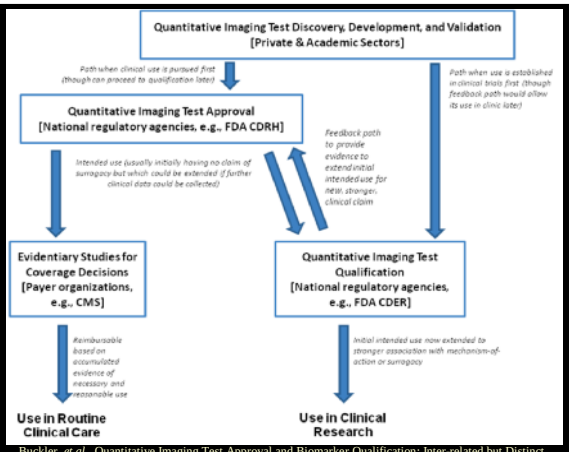
RSNA QIBA DCE-MRI Phantom v2

Tissue						VIF					
T1 (ms)	R1 (s-1)	Delta R1	[NiCl2] mM	NiCl2 mg/l	NiCl2 mg/40ml	R1 (s-1)	T1 (ms)	Delta R1	[NiCl2] mM	NiCl2 mg/l	NiCl2 mg/40ml
1500.0	0.67	0.00	1.075	139.35	5.57	0.56	1785.7	0.00	0.903	117.06	4.68
1000.0	1.00	0.33	1.613	209.03	8.36	0.80	1250.0	0.24	1.290	167.23	6.69
666.7	1.50	0.83	2.419	313.55	12.54	1.00	1000.0	0.44	1.613	209.03	8.36
454.5	2.21	1.54	3.629	470.32	18.81	1.25	800.0	0.69	2.016	261.29	10.45
296.3	3.38	2.71	5.444	705.48	28.22	1.67	600.0	1.11	2.903	376.13	15.05
197.5	5.06	4.40	8.165	1058.23	42.33	2.00	500.0	1.44	3.629	470.32	18.81
131.7	7.59	6.93	12.248	1587.34	63.49	2.50	400.0	1.94	4.839	627.10	25.08
87.8	11.39	10.72	18.372	2381.01	95.24	3.00	333.3	2.44	6.048	783.87	31.35
	Series 3		0.62 mM-1 s-1		274.57 mg NiCl2 per group of 8 vials						1215.40
					823.72 mg NiCl2 for 3 groups of vials						



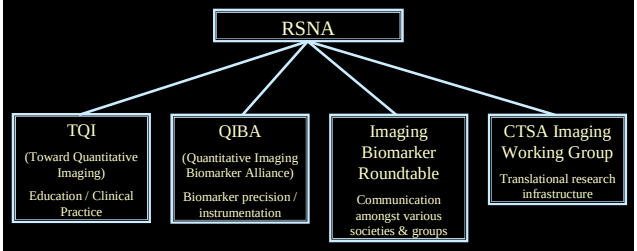


Buckler, *et al.*, Quantitative Imaging Test Approval and Biomarker Qualification: Inter-related but Distinct Activities, submitted, Radiology



Buckler, *et al.*, Quantitative Imaging Test Approval and Biomarker Qualification: Inter-related but Distinct Activities, submitted, Radiology

RSNA QI Initiatives



Based on information from Dan Sullivan, MD