MRI – From Basics to State-Of-The-Art Protocols:

TRANSLATING CLINICAL NEEDS INTO PROTOCOLS

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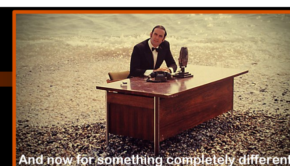
Introduction



- Physicists often asked to troubleshoot/optimize MR acquisitions
- 'MR protocols' much more than a collection of acquisitions
  - must address the complex nature of the patient management decision(s)
- MRI has unique contrasts for anatomy, physiology & function
  - multiparametric → myriad of potential protocol approaches for given indication
  - MR protocols tend to both vary more widely across different practices and change more frequently
    - constant performance feedback and evolving needs
    - persistent technological innovation in hardware, software and capabilities
- Physicists may benefit from developing a holistic, systems level knowledge of the process in addition to their solid knowledge of the modality & troubleshooting skills

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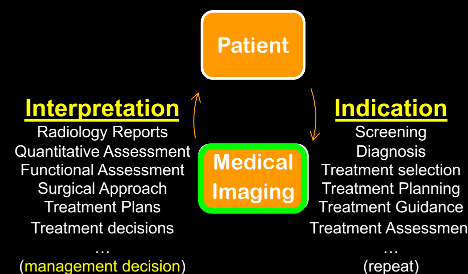
Medical imaging protocols

- Process begins and ends with the patient
  - Patient presents with indication
  - Examination prescribed & performed
  - Results interpreted, communicated and factored into patient management
- Value derived from safe & effective imaging that results in actionable patient management decisions
- Protocol quality management should therefore focus on making certain imaging is safe and effective for the intended purpose
  - *need feedback on performance of imaging test for intended purpose on patients, not just IQ as a surrogate*
  - *need to manage the full process to accomplish*



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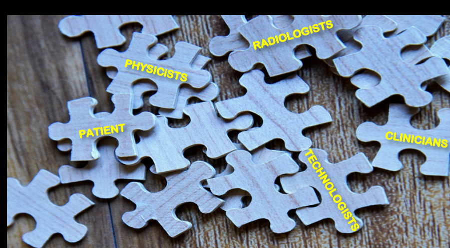
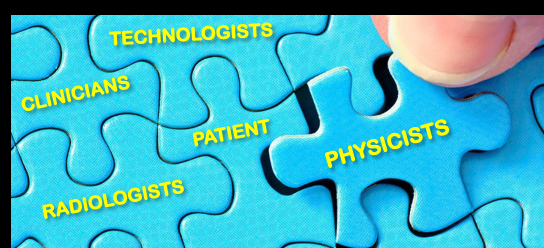
Protocol management needs an organized team effort





It's important to have all the right pieces working together!

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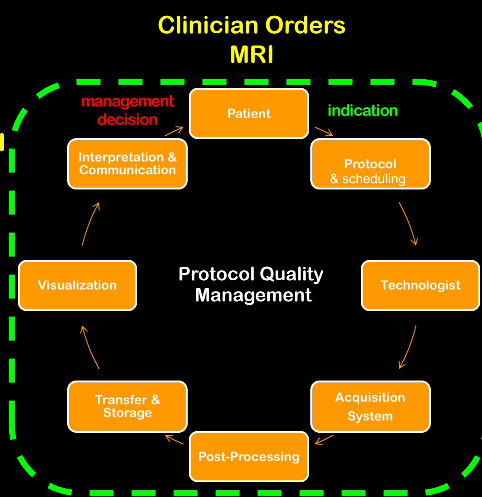
Holistic view of protocols as a process

- Physicists often focused on technical acquisition parameters and/or accreditation issues
- **Increased understanding and involvement in overall process facilitates physicists as more effective protocol 'team' members**
- This same knowledge makes the physicist more effective at troubleshooting protocol issues as well as development
- ACGME six dimensions of clinical competency
  - Patient Care
  - Medical Physics Knowledge
  - Practice-based Learning and Improvement
  - Interpersonal and Communication Skills
  - Professionalism
  - Systems-based Practice



1999 Accreditation Council for Graduate Medical Education (ACGME)

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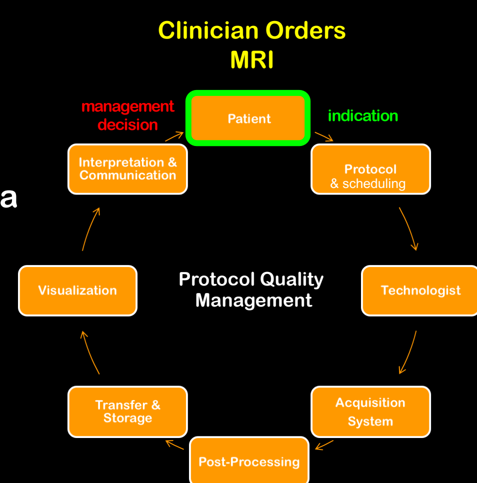
Patient considerations

- Patient condition
  - needs imaging exam to be safe & effective
  - is a special protocol needed to ensure?
- Example considerations that may require a specific alternate protocol design:
  - Age — Size
  - Body habitus — Size; Safety/ Artifacts
  - Medical implants — Safety/ Artifacts
  - Pregnancy status — Safety/ Contrast
  - Sedation and/or anesthesia — Compliance/ Motion
    - Mental state
    - Pain or emotional distress
    - Emergent



Size Example:
- Reduced FOV adaptations for pediatric
- Large FOV and/or SNR compensation for large patients

Compliance/Motion Example:
- 'Quick' vs 'motion' oriented protocol adaptations
- Series order in breast or prostate exams

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Patient considerations: Medical Implants & Artifacts

- Implants can often come with substantial susceptibility artifacts resulting in signal loss, distortion and fat suppression problems

Fat Suppression Techniques

Name	Type	B_0	B_1	Time	SNR	SAR	Notes
CHESS	CS	- -	- -	+	+	-	Routine chemically selective fat 'saturation'
Water Excitation	CS	-	+	-	+	-	Spatial spectral excitation
Dixon	CS	++	++	- -	+	+	Generates water, fat, in-phase, out-of-phase images; Swap artifacts
SPIR/SPAIR	IR/CS	-	+	-	+	-	Hybrid technique; Safe for T1+C
STIR*	IR	++	++	- -	- -	- -	Fat 'suppression'; *Nulls short T1 (fat) → NOT FOR T1+C

Metal Artifact Reduction

Approach	Time	SNR	SAR	Notes
Protocol				Standard approaches to susceptibility effect reduction
1.5T > 3.0T	-	-	+	
FSE > GRE	-	+	-	
Increase rBW	-	-	-	
Increase resolution	-	-	-	
Decrease TE	na	+	na	
Advanced				
VAT, SEMAC, MAVRIC	- -	-	-	Hybrids of all three exist

VAT=view Angle Tilting; SEMAC=Slice Encoding for Metal Artifact Correction; MAVRIC=Multi-Acquisition variable-resonance image combination

Del Grande F, et al, Radiographics. 2014 Jan-Feb; 34(1): 217–233.
Jungmann PM, et al, J Magn Reson Imaging. 2017 Oct;46(4):972-991.

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Patient considerations: Medical Implants & MR Safety Conditions

- In addition to artifacts, some implants have very restrictive acquisition MR safety conditions, such as low SAR and active scan time limitations at these SAR levels
- Physicists may need to adapt existing protocols to incoming patients with a variety of implants

SAR Management Strategies

Acquisition Modification	Potential Tradeoff
K-space view reduction	
reduced phase encodes	resolution loss
rectangular field of view	not amenable to all anatomy
parallel/compressed acquisition	SNR loss & potential artifacts;
RF pulses	
reduced flip angle excite and/or refocus	SNR loss & contrast changes
pulse amplitude/width modulation	SNR loss; sequence timing issues
saturation/suppression pulse reduction	contrast changes; artifacts
Time efficiency	
increase concatenations	longer acquisition times
reduce ETL; increase ESP and/or TR	longer acquisition times
reduce anatomical coverage	need for multiple acquisitions
increase slice thickness/spacing	slice resolution loss
Pulse sequence	
gradient vs spin echo or bSSFP	contrast & SNR considerations
RF coil selection or patient positioning	
smaller volume transmit coils	coverage, uniformity, availability

Example condition for full-body:

$SAR \leq 0.8$ W/kg or $B_{1\,rms}^{+} \leq 2.0\mu T$

Active Scan Time ≤ 30 min

Like MARS techniques, most SAR management strategies tend to increase acquisition times.

Reducing resolution via phase-view reduction and/or incorporating acceleration techniques may help with both SAR and active scan time limits.

Stafford RJ, Magn Reson Imaging Clin N Am. 2020 Nov;28(4):517-536.

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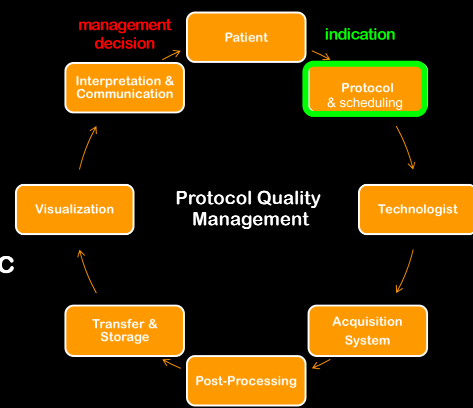
Protocoling & scheduling considerations

- Appropriate protocol(s) exist for indication & patient status considerations
- Written references to aid in protocoling
- Is protocol orderable and billable?
- Will there be a need to schedule to specific area and/or resource?
  - process for team notification outlined?
- Patient communication, education, preparation instructions



Examples:
- cardiologist evaluation and/or presence for MRI with CIED
- neuropsychologist evaluation and/or presence for fMRI
- specific post-processing required for billing
- patient preparation for exam (including implants)
- PHYSICIST SUPPORT!

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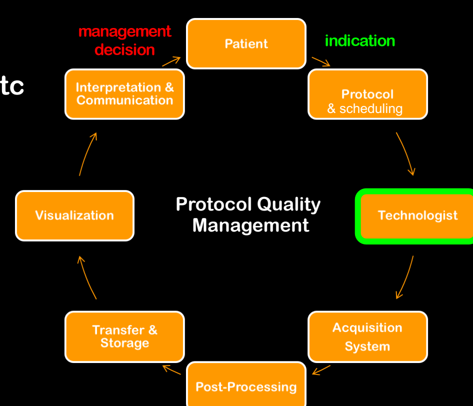
Technologist & Procedure Considerations

- Technologist education on protocol
- Written procedure guide(s)
  - Guidance on anatomical prescription, timing, etc
  - Help triage to appropriate system
  - Clarity on what to run, how and when
  - Who to contact for technical assistance
- Technologist skill & experience
  - Patient preparation & positioning
  - Prescription & execution
  - Niche team needed? Physics support?
- Consumables ordered and on-hand



Examples:
- most IQ events hit this bin
- various execution and setup errors
- rotating tech issues (familiarity/expertise on system
- manual post-processing and transfer errors
- failure to repeat failed acquisitions
- timing issues (contrast, breathing, gating, etc)

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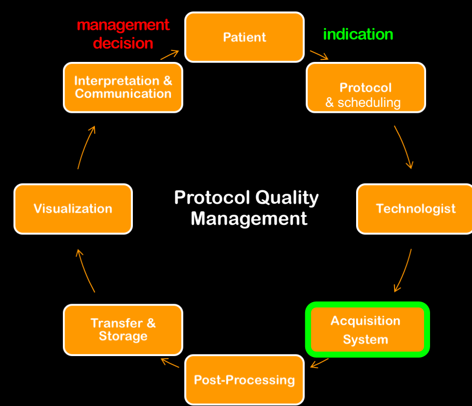
Acquisition system considerations

- Protocol translated & installed on system(s)
  - naming consistent across all systems and with online protocol references
  - up to date?
- Field strength adjustments
- Vendor & platform specific adjustments
- System hardware/software specifications
- 'Details'



Examples:
- Shimming, Partial Fourier, interpolation, SCIC, distortion correction, etc
- Missing licenses (fMRI, breast, Dixon, etc)
- Wide vs narrow bore performance considerations

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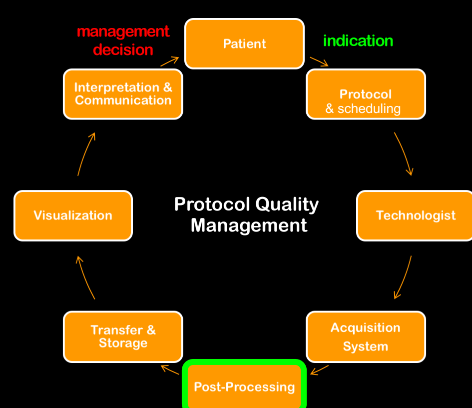
Post-processing considerations

- Written post-processing protocol
- On scanner or remote workstation
  - automated, semi-automated, manual
  - licenses and compatibility with acquisitions

    Example: In prostate MRI protocols, a synthetic DWI with b≥1400 sec/mm^2 may be a desirable alternative to achieving a high b-value DWI since the focus is on conspicuity.
    However, are there licenses for this on all systems you run prostate on?
- Who performs the task(s)
  - time needed vs expected turn-around time
  - is workflow disruptive
- Quality assurance and commissioning



Examples:
- ADC, synthetic DWI, parametric maps, etc
- Reformats, MIP, multi-station composing, etc
- fMRI, DTI, liver iron concentration, spectroscopy, perfusion

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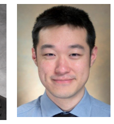
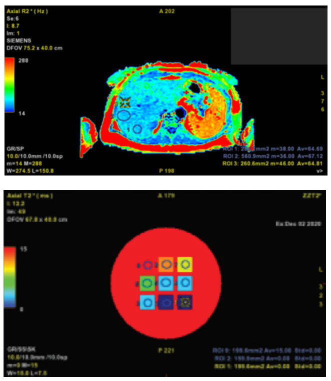
R2*-based liver iron calculation

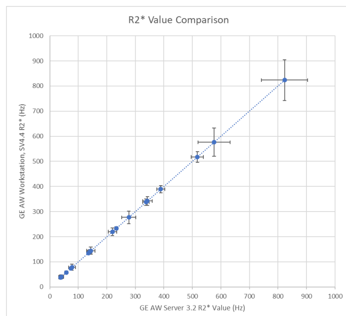
Brian Taylor



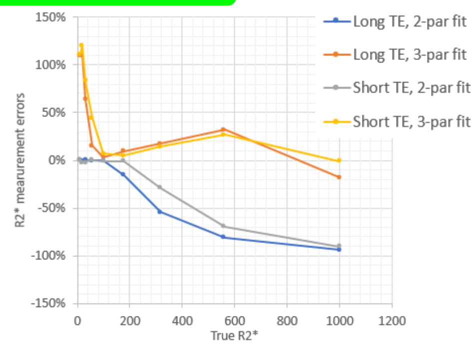
Henry Chen

- Clinical indication: Multiple blood transfusions for cancer/hematology Treatment
  - Linear relationship between R2* with liver iron measurements
  - R2* can be measured using multi-gradient echo MRI with post-process fitting.
- Role of physicists:
  - Protocol: Range of TE, SNR
  - Post-processing: Development & oversight; QA of quantitative imaging software





Consistency between software (patient data)

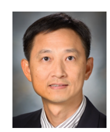


Accuracy per protocol (DRO data)

Presurgical *f*MRI/DTI

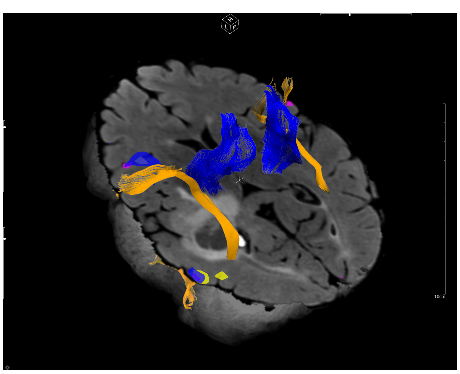
Mu-Lan Jen

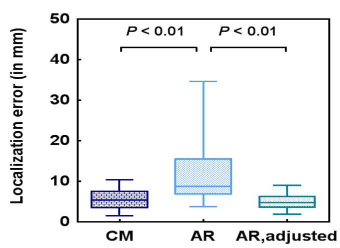
Ping Hou



Ho-Ling Liu

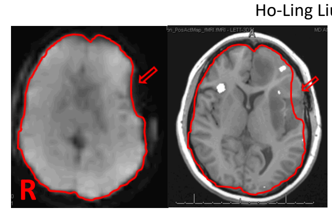
- Clinical indication: Map eloquent brain areas and critical fiber tracts
  - Minimize post-operative deficits and maximize tumor resection
  - Guide intra-operative functional mapping
- Role of physicists:
  - Protocol: Balance SNR & resolution by considering scan time and patient performance
  - Post-processing: Strict QA for detection & localization considering lesion effects
  - Provide consultation to radiologist and neurosurgeon





CM: Coordinate matching
AR: Automated registration
AR_{adj}: AR with QA adjustment

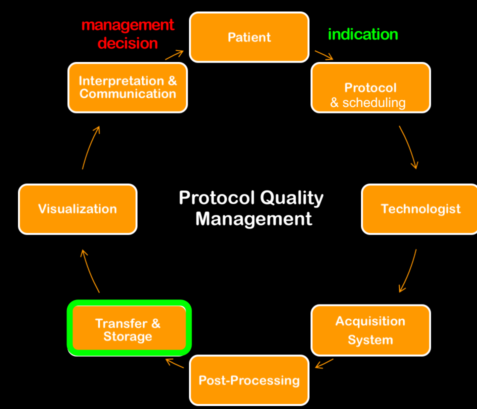
Jen, Med Phys, 2018



Susceptibility artifact from previous surgery can lead to false negative fMRI.

Transfer & storage considerations

- What items sent, not sent and to what locations?
  - automated transfer or manual?
  - exam size and transfer delay considerations
  - raw-data support structure
  - real-time transfer and display
- PACS issues
  - preservation of header
  - delete erroneous images
  - units for making measurements
    - DWI/DTI/ADC
- Our #1 radiologist IQ issue lives here:
  - "Please send missing images …"



Examples:
- Certain fMRI series sent to processing (size vs time)
- Automatic forwarding from PACS to workstation
- MR temperature imaging for real-time guidance

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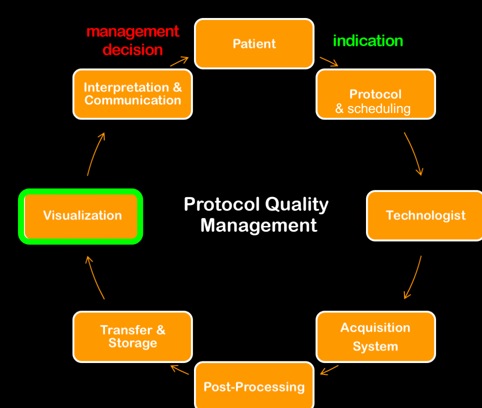
Visualization considerations

- Hanging protocol compliance
  - appropriate/approved naming
  - human and computer recognition
    - identification of priors
  - important tool for managing resistance to new protocols with increased series
- DICOM header information
- Post-processing, measurements and reports for interpretation
- Image stacking
- Window/level settings



Examples:
- Send extra series (i.e., Dixon Fat, source images, etc) to the back of the stack
- Post-processing => automated naming schema
- Embed protocol name in localizer series descript

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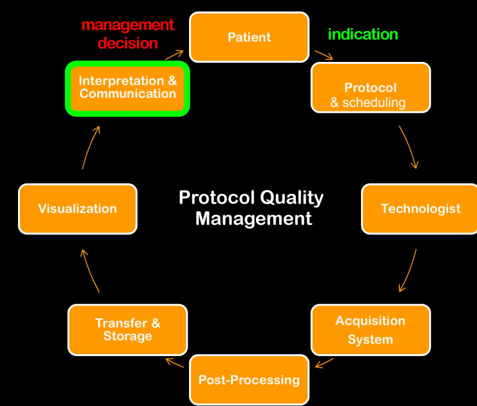
Interpretation & communication considerations

- Communication of findings
  - timely actionable results & identify limitations
- Structured reporting
- Quantitative assessments
- Standardization/repeatability for longitudinal assessment
- Follow-up imaging
- Feedback from clinician & radiologists



Want to make sure the protocol is designed to provide the information expected safely, with high quality and reliability.

To do this, may need to pay attention to failures or limitations as noted in the reports

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Value Based Imaging: a useful heuristic

Appropriateness
Quality & Effectiveness
Patient/decision management

Safety & Harm
Discomfort, Pain, Injury
Short/long term effects

$$\text{Value} = \frac{\text{Outcome}}{\text{Cost}} = \frac{\text{Benefit} - \text{Risk} \pm \text{PE}}{\text{Cost}}$$

Patient Experience

Patient, Payer
Institution, Resources
Efficiency

useful heuristics → useful KPI/metrics → a new space for innovation

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Value Based Imaging: high reliability

Consistently HIGH → Benefit

Consistently LOW → Risk

$$\text{Value} = \frac{\text{Outcome}}{\text{Cost}} = \frac{\text{Benefit} - \text{Risk} \pm \text{PE}}{\text{Cost}}$$

Consistently Appropriate/reasonable → Cost

Consistently HIGH → PE

Value not measured 'per patient', but is a product of consistency.
Need to be wary of "theoretical benefits"
State of the art technology that fails to deliver consistent results is low value:

- risk vs benefit
- wasted effort
- wasted time
- wasted resources

useful heuristics → useful KPI/metrics → a new space for innovation

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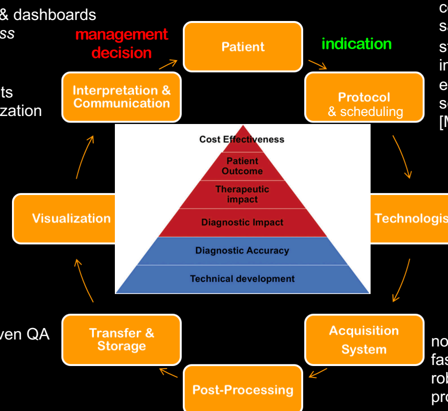
Incident Reporting Systems & Protocol Management

$$\frac{\text{Benefit} - \text{Risk} \pm \text{PE}}{\text{Cost}}$$

outcomes, radpath
stakeholder feedback
performance assessments
needs assessments
quality auditing & dashboards
cost effectiveness

develop – optimize – benchmark – manage
appropriate use criteria
continuity of care & patient experience
safety, efficiency, cost/comparative effectiveness
standards and expert consensus
individualized (body habitus, implants, etc)
elimination of 'vanity protocols'
scheduling & resource issues
[Maximize] access to [appropriate] care

structured reporting
quantitative assessments
protocol-report harmonization
OSF interpretations



hanging protocols
auto image-labeling
on-demand processing
AI driven CAD

equipment selection
patient preparation & positioning
protocol selection & execution
patient specific issues (coverage, timing, etc)
simplify/automate advanced procedure execution

data mining
automated, patient image-driven QA
automated protocol auditing
protocol harmonization
raw data storage
algorithm development

novel acquisition & reconstruction techniques
fast or abbreviated protocols (i.e., screening)
robust patient adaptive imaging
protocol optimization on modality
protocol harmonization across fleet
equipment performance assessment for QI

automation & in-line processing
quantitative imaging & biomarkers
actionable results
report generation
consistent and robust

J Am Coll Radiol 2019;16:810-813.
J. Magn. Reson. Imaging 2019;49:e40–e48.

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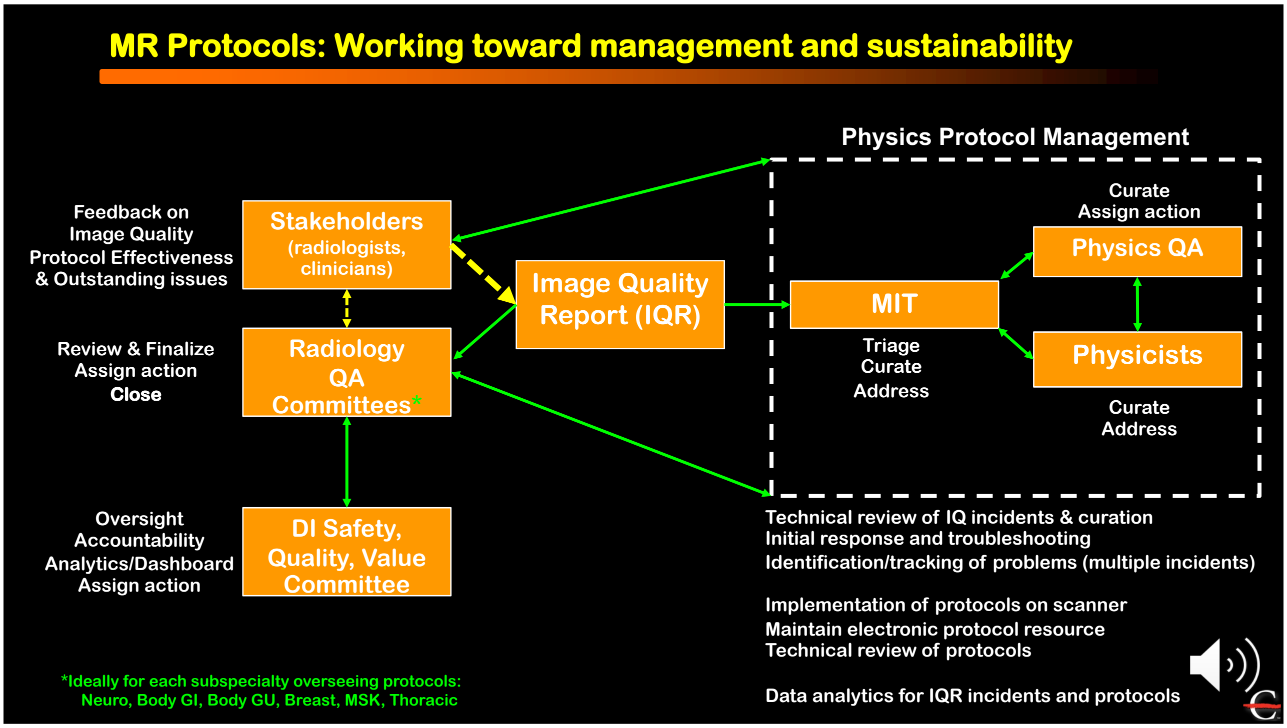
MR Protocols: Working toward management and sustainability
Physics Protocol Management
Feedback on
Image Quality
Protocol Effectiveness
& Outstanding issues
Stakeholders
(radiologists, clinicians)
Image Quality Report (IQR)
Review & Finalize
Assign action
Close
Radiology QA Committees*
Oversight
Accountability
Analytics/Dashboard
Assign action
DI Safety, Quality, Value Committee
MIT
Triage
Curate
Address
Curate
Assign action
Physics QA
Physicists
Curate
Address
Technical review of IQ incidents & curation
Initial response and troubleshooting
Identification/tracking of problems (multiple incidents)
Implementation of protocols on scanner
Maintain electronic protocol resource
Technical review of protocols
Data analytics for IQR incidents and protocols
*Ideally for each subspecialty overseeing protocols:
Neuro, Body GI, Body GU, Breast, MSK, Thoracic

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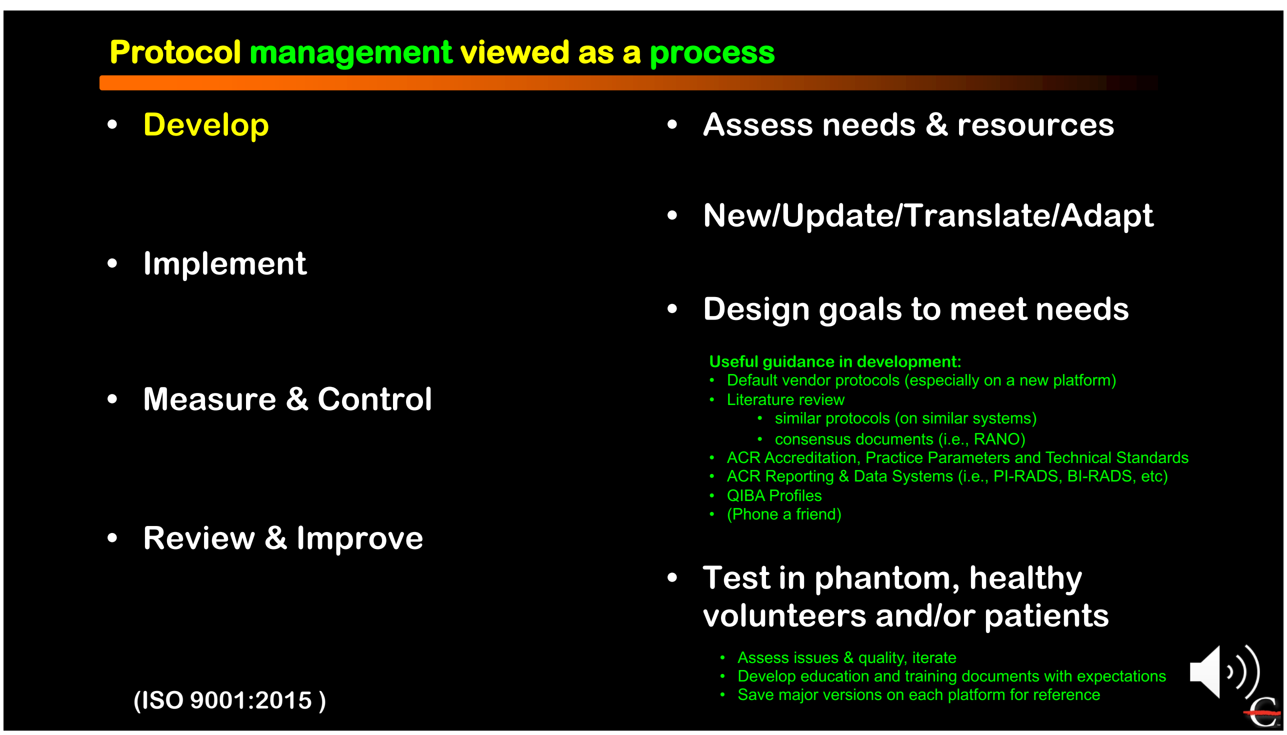
Protocol management viewed as a process
• Develop
• Implement
• Measure & Control
• Review & Improve
(ISO 9001:2015)
• Assess needs & resources
• New/Update/Translate/Adapt
• Design goals to meet needs
Useful guidance in development:
• Default vendor protocols (especially on a new platform)
• Literature review
• similar protocols (on similar systems)
• consensus documents (i.e., RANO)
• ACR Accreditation, Practice Parameters and Technical Standards
• ACR Reporting & Data Systems (i.e., PI-RADS, BI-RADS, etc)
• QIBA Profiles
• (Phone a friend)
• Test in phantom, healthy volunteers and/or patients
• Assess issues & quality, iterate
• Develop education and training documents with expectations
• Save major versions on each platform for reference

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Protocol management viewed as a process

- Develop
- Implement
- Measure & Control
- Review & Improve

(ISO 9001:2015)

- **Training plan for team(s)**
  - Provide an appropriate amount of communication and material
  - Have clearly written procedures to accompany protocol
  - Technologists, radiologists, clinicians, physicists and other staff
    - avoid "heroes" and single points of failure
  - "Train the trainers"
- **Add to online protocol resource page**
  - Protocol name, indications for use, contact(s)
  - Systems supported
  - Technical parameters & procedure
  - Expected outcomes and timing
- **Rollout to clinic**
  - Area by area, team by team
  - Provide adequate technical support
  - Feedback from stakeholders
    - pay careful attention to complaints
    - manage expectations
  - Back up final approved protocols to electronic database/storage
  - Update protocol page with areas/systems/personnel that support protocol

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Protocol management viewed as a process

- Develop
- Implement
- Measure & Control
- Review & Improve

(ISO 9001:2015)

- **Image quality incident reporting**
  - Report issues/concerns from any stakeholder
  - Curate and bin
  - Address major IQ concerns
  - Bundle and track related unresolved issues/problems
  - Document
- **Data analytics**
  - IQ incident tracking by bin
  - Active scan times & table times
  - Repeat analysis + root cause
- **QA committee**
  - Continuous quality improvement
  - Regular review of incidents
  - Regular review of protocol performance metrics
  - Periodic review of protocol(s)
    - updated needs/standards
    - performance improvement opportunities
    - means to sunset as well as improve
- **Restart process**

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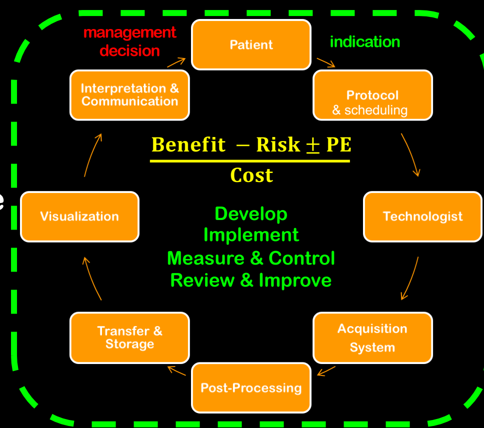
Closing thoughts

- A better understanding of the exam process can help physicists better develop, support and troubleshoot issues with protocols
- Developing a system for quality management can aid with control of these sprawling processes
- The value concept may provide teams with a useful heuristic to motivate and guide continuous process improvement and metrics of success

Protocol Quality Management



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THE UNIVERSITY OF TEXAS
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Thank you for your time!

Email: jstafford@mdanderson.org

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