The History and Current Practice of Magnetic Resonance Imaging (MRI)

A White Paper presented by the American Registry of Magnetic Resonance Imaging Technologists

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The American Registry of Magnetic Resonance Imaging Technologists - ARMRIT, a New York State Not-for-Profit corporation, tax exempt under Internal Revenue Code Section 501(c)(6), is a certifying organization which was founded in 1991 to provide certification to the thousands of MRI Technologists who had been trained on the job since MRI became available in 1983. As an International Certifying Body, ARMRIT certifies MRI technologists who have met its established criteria, and who work in MRI facilities at Hospitals and private non-hospital facilities. To date it has certified technologists in 46 states, Puerto Rico, Guam, Canada, Britain, and in Asia and the Middle East. ARMRIT has adopted the slogan - "Because MRI is a Specialty".

Radiologic Science, in a strictly technical definition, has to do with the administration of ionizing radiation (X-Ray). MRI Technology has nothing to do with Radiologic Science. MRI Technology employs radio frequency transmission in a main magnetic field. The education and training of an MRI Technologist is distinct from any other medical imaging modality. The patient safety issues, especially, are specific to MRI which involves very strong magnetic fields that can affect medically implanted devices. This high magnetic field can cause ferromagnetic objects to become projectiles. Numerous MRI manufacturers, such as, Fonar Corporation, General Electric Healthcare, Bruker Biospin, Hitachi Medical Systems of America, Philips, Siemens, Varian and Toshiba Medical Systems, etc., produce different types of MRI units with differing designs, magnetic field strengths and imaging capabilities. These MRI scanners allow the patients to be imaged in various positions, for example, lying down on a table supine, sitting-up in a chair or standing, depending on the anatomical area of the body being imaged. The MRI Technologist must have a deep understanding of MR physics which involves electromagnetic fields and deciphering information from the hydrogen atoms in human body tissue. To insure high quality diagnostic images the MRI Technologist must have an extensive knowledge of the numerous and increasingly complex applications, protocols and parameters involved in quality imaging, patient care and safety techniques, the knowledge and ability to inject MRI specific contrast agents and most important, the safety requirements of patient care in the MRI suite.

MRI is an exceptionally safe imaging modality. No inherent adverse biological affect has ever been shown in MRI when performed correctly and carefully. MRI is a highly respected modality due to the flexibility and versatility of MRI Technology and modern medical preference to avoid ionizing radiation. MRI is however not without unique safety issues. Ferrous objects can fly into the magnet bore causing severe injury or death, radio-frequency burns could occur on the patient's skin without proper supervision, high-decibel acoustic noise to damage hearing and gadolinium-based IV-contrast agents while much safer than iodine based contrast agents can be harmful in patients with compromised kidney function. The MRI technologist is trained in preventing, and responding to, all possible MRI hazards.

The most horrific injuries that have occurred in conjunction with MRI were due to ferrous oxygen tanks and other ferrous items being allowed near the MRI machine which were drawn into the magnet bore with incredible levels of force. There have in fact been a number of MRI related fatalities and other serious injuries all of which occurred when a technologist failed to protect his/her patient~~s~~. Lack of proper MRI safety training is the cause. No MRI-related patient injury has ever been attributed to an ARMRIT-certified technologist.

MRI, like Ultrasonography uses no 'Ionizing Radiation', hence it does not necessarily fall under generally accepted regulations applicable to Radiography. Accordingly, there are no Federal regulations governing MRI Technologists specifically. The Centers for Medicare and Medicaid Services (CMS) has established accreditation requirements for providers of advanced medical imaging mandated by the Medicare Improvements for Patients and Providers Act of 2008 (MIPPA). Providers have been required to comply with the CMS requirement that all providers of CT, MRI, PET and Nuclear Medicine exams be accredited by a CMS recognized accrediting organization as of January 1, 2012 in order to be reimbursed. CMS has recognized four organizations as acceptable accrediting bodies: the American College of Radiology (ACR), the Inter-societal Accreditation Commission (IAC), the Joint Commission (formerly JCAHO), and RadSite. **ARMRIT is included in the MRI site accreditation standards of all four CMS recognized accrediting organizations.**

***O*NET Online*: in the fall of 2009, ARMRIT was contacted by Traci Davis of RTI International, Raleigh, North Carolina informing announcing that the U.S. Department of Labor was sponsoring research of 400 new careers and that MRI Technology was one of them. Ms. Davis requested a national database of MRI Technologists with at least five (5) years of MRI Clinical experience to participate in the project to collect occupational information on the career of MRI Technologist. In September 2013, Ms. Davis provided the materials to the MRI Technologists explaining the O*NET Occupational Expert Data Collection Program for review. On September 26, 2013, ARMRIT agreed to the process.

In December 2013, Ms. Davis sent an email for distribution to the MRI Technologists in the database, which included an extensive Occupational Questionnaire. Upon submission of the questionnaires and completion of the Occupational Expert Data Collection Program, Magnetic Resonance Imaging (MRI) Technologist was described as a distinct and separate career by the U.S. Department of Labor with the O*NET Code: **29-2035.00** Rapids Code: **1115.**

On the State level, at this time, only three States, North Dakota, Oregon and West Virginia, have licensing requirements for MRI Technologists. ARMRIT certification is a criterion for licensure in all three states. A fourth state, New Mexico is currently in the process of drafting licensing for all medical imaging modalities. The **New Mexico Medical Imaging & Radiation Therapy Act Committee (MIRTAC) draft** has included ARMRIT certification as a requirement to be eligible for a license to practice MRI Technology. In all other states, certification in the specialty is required or highly recommended however by insurance providers and required by most MRI employers.

ARMRIT is the first MRI Registry certifying body that required specific MRI education, in-depth clinical training, and hands-on experience. All applicants for Certification must meet the criteria to be eligible to sit for the ARMRIT certification examination, which are: 1) Graduate of an approved MRI Technologist Program; 2) Cross-Trained from an Allied Health Field with at least one-thousand (1000) hours of documented MRI Clinical experience; 3) Equivalency Clause, which is On-The-Job Training with at least four years of documented full-time clinical experience. Applicants who are qualified as Cross-Trained or the Equivalency Clause must be documented and signed off by a practicing board certified Physician. All eligible applicants must sit and successfully pass the ARMRIT MRI Technologist examination.

Once certified, ARMRIT Technologists are required to perform a minimum of 24 Continuing Medical Education credits specifically in the topic of MRI for every three-year renewal period. ARMRIT established an annual meeting and seminar, offering MRI Technologists twelve hours of lecture in MRI subjects by leaders in the MRI field nationally and internationally. For example, in 2010 Raymond Damadian, MD, inventor of the modern MRI scanner was the featured speaker at the ARMRIT Annual Meeting & Seminar.

The examination for ARMRIT Certification is administered by PSI Computer Testing. PSI has over 1000 testing sites nationally and internationally. Exams are graded and a hard copy of results is made available immediately to each candidate upon completion of the exam. PSI also provides evaluation of the on-going psychometric data used by the ARMRIT examination committee.

Moreover, the genesis of ARMRIT is to offer an alternative venue to qualified MRI Technologists who opted to train specifically in MRI technology without undergoing a Radiology/Radiography oriented background. Parenthetically, there are individuals who have radiation-phobia, whether justified or not, especially among women of child bearing age. That said ARMRIT does not preclude ARRT technologists to take the Registry certification exam, provided the ARMRIT criteria for said candidates are met. In fact a significant number of its current certificants are of ARRT background.

The Commission on Accreditation (COA) of the American Registry of Magnetic Resonance Imaging Technologists was created in response to a growing interest in the accreditation of MRI programs and in order to comply with federal and state regulatory requirements and of any national or international body. The voluntary application process assures that any MRI program accredited by the COA is committed to quality education. The sponsoring institution of the MRI program must formally apply to the COA for accreditation. Upon approval of the submitted application a site visit of the institution is scheduled. Accreditation is required for all campuses and at the conclusion of the accreditation period a renewal of accreditation is required.

Safety and Imaging Complexity Implications of MRI

Used properly and with care MRI is extremely safe. **No inherent adverse biological effects from MRI have ever been shown. Moreover, MRI and Ultrasound are the only two imaging modalities deemed safe for imaging a human fetus.** However, the MRI process poses significant dangers. Aside from rare and extreme allergic reactions from IV contrast agents in other modalities, **MRI is the only modality that has resulted in the death of a patient at the time of the exam. MRI is the only imaging modality that can kill instantly.**

The complexity of the MRI process is unparalleled in medical imaging. For example, the decision tree for selecting the Imaging Options in Radiography (X-Ray) is 4, Computed Tomography is approximately 6, Ultra-sonography including Echo is approximately 35, Nuclear Medicine including PET is approximately 6. **Contrast these with the number of imaging parameters controlled by an MRI Technologist which is no less than 70.**

There is no imaging modality like Magnetic Resonance Imaging. Like Ultrasonography, MRI utilizes a completely different branch of physics. There is no other imaging modality that is at the same time so safe and so **potentially** dangerous. It is understandable that the general public is not aware of the vast differences between MRI and every other imaging modality. What is unfortunate is that so many in the medical imaging field are equally unaware.

Magnetic Resonance Imaging as Compared to Other Imaging Modalities

Can there be any argument that Radiography and Ultrasonography (U/S) are two completely different imaging modalities? That they are both used in industrial and medical imaging is their only similarity. Nuclear Medicine (NM) and Radiography both share the same unit of energy: ionizing radiation. But again, here the similarities stop. Is it any surprise then that the fields of medical Ultrasonography and Nuclear Medicine have separate registries from medical radiography?

Computed Tomography (CT) is often thought to have much in common with Magnetic Resonance Imaging (MRI), yet nothing could be further from the truth. Other than having similar looking machines and consoles they have virtually nothing in common. In fact, CT has far more in common with X-ray Radiography. In the simplest sense, CT is just an X-ray tube that goes around in a circle while energized. MRI, like U/S and NM, is a completely different imaging modality. **A comparison of MRI to other medical imaging modalities (see pages 3-8) is therefore useful.**

In Conclusion:

1) MRI already plays a major role in modern medicine which will continue to grow with expanded clinical and research applications and advanced imaging techniques.

2) The patient safety need to reduce exposure to ionizing radiation will lead to the continuing growth of MRI and the reduction of future use of CT Scan.

3) At present, **the vast majority of MRI Technologists, as much as 90%, in the Unites States were trained on the job.** Since its inception, ARMRIT has advocated for distinct MRI Technologist training verses MRI training as an addendum to Radiologic Science, (X-Ray) School or any other allied health education.

4) The essential elements to the growth of MRI are highly trained technologists and maintaining the high level of patient safety that properly trained technologists brings to MRI.

5) ARMRIT continues to be the world leader in the certification of highly trained, educated, and certified MRI Technologists.

A Comparison of MRI to Other Medical Imaging Modalities.

RADIOGRAPHY **(X-Ray)**

Unit of Energy: Ionizing X-Radiation.

Principle Contrast Mechanism: Electron Density.

Approximate Exams/Year: Over 100 Million.

Main Applications: Bony detail, lung disease, 1^{st} level screening, breast (mammography).

Short-term potential for patient harm: **Low** Typically low radiation dose.

Long-term potential for patient harm: **Medium-High**. Cumulative radiation dose linked to increased cancer risk later in life.

Imaging Options for an X-Ray Tech (RT)

1) Peak kilovolts 2) Amperage 3) Distance 4) Time

A Comparison of MRI to Other Medical Imaging Modalities (continued)

COMPUTED TOMOGRAPHY (CT)

Unit of Energy: Ionizing X-Radiation.

Approximate Exams/Year: 70 Million.

Principle Contrast Mechanism: Electron Density.

Main Applications: Bony detail, lung disease, 2^{nd}-$3rd^{st}$ level screening, brain, angiography, large bowel, 1^{st} level coronary screening.

Short-term potential for patient harm: **Medium.** Higher radiation dose than radiography. Misuse of system can lead to over radiating the patient.

Long-term potential for patient harm: **Medium-High.** Cumulative radiation dose shown to increase cancer risk later in life through over-use.

Imaging Options for an CT Tech (RT)

1) Kvp 2) Milli Amps 3) Time 4) Slice thickness 5) Pitch (table speed) 6) FOV

ULTRASONOGRAPHY (U/S)

Unit of Energy: High Frequency Sound Energy.

Approximate exams/year: 90 Million.

Principle contrast mechanism: Tissue Sound (Reflection and Scattering) Absorption.

Main Applications: Abdomen, Echocardiography, Obstetrics/GYN, Ophthalmic, Musculoskeletal, Neuro-Sonology, Vascular, Color Flow and Tissue Doppler.

Short-term potential for patient harm: **Extremely low.** In extreme circumstances, cavitation and/or tissue heating may occur.

Long-term potential for patient harm: **Extremely low.** None shown to date.

Imaging Options for an Ultrasonographer

- Application Type Selection
- Transducer Type Selection
- Frequency Selection
- Imaging mode selection:
  - 2D Imaging
  - M-mode
  - Color Flow Doppler
  - PW or CW Doppler
  - Tissue Doppler
  - Contrast Harmonics

- Strain Imaging
- 3D Imaging

- Imaging Window and Imaging Plane Selection
  - Abdominal (Sagittal, Coronal)
  - Pelvic (Sagittal, Coronal)
  - Cardiac: Parasternal (Long Axis, Short Axis), Apical (4-chamber, 5-chamber, 2-chamber, Long Axis), Subcostal (Long Axis, Short Axis, IVC), Suprasternal (Long Axis, Short Axis), Right Parasternal.
  - Vascular (Long Axis, Cross-section)
  - Ophthalmic, Musculoskeletal, Neurosonology (Sagittal, Coronal)
- Image Optimization Decisions:
  - Depth
  - Gain
  - Pre-processing
  - Post-processing
  - TGC
  - Persistence
  - Dynamic Range
  - Focus
  - PRF
  - Doppler baseline
  - Doppler velocity scale
  - Doppler gain
  - Doppler transmit
- Measurements:
  - Distance
  - Circumference
  - Surface Area
  - Volume
  - Velocity
  - VTI
  - Time Intervals

NUCLEAR MEDICINE (NM)

Unit of Energy: Ionizing Isotope Radiation.

Principle Contrast Mechanism: Tissue Uptake.

Approximate Exams/year: 18 Million.

Main Applications: 2^{nd} level cardiac, cancer staging (Includes PET).

Short-term potential for patient harm: **Low.** Rapid Half-Lives pose little if any short term harm.

Long-term potential for patient harm: **Low.** Theoretical risk of increased cancer risk but no link has been shown yet due to the lack of over-use.

Imaging Options for a Nuclear Medicine Tech

1) Height 2) Weight 3) Dose 4) Collimator 5) Scope (head/body) 6) Dynamic vs. Non-dynamic

MAGNETIC RESONANCE IMAGING (MRI)

Unit of Energy: Radio Frequency Transmission in a Large Main Magnetic field.

Principle Contrast Mechanism: Tissue Equilibrium Rates.

Approximate Exams/Year: 30 Million.

Main Applications: Cancer staging, Central Nervous System (Brian/spine), Musculoskeletal, 3rd level breast, 2nd-3rd level cardiac.

Short-term potential for patient harm: High. If improperly employed, RF burns are the most common injury. Instant death can occur due to magnetic or ferrous objects. Several deaths have been documented.

Long-term potential for patient harm: Low. No adverse effects from MRI even with multiple and repeated use has ever been shown.

Imaging Options for an MRI Tech

- Imaging Mode Decisions:
  2D acquisition, 3D acquisition, 4D acquisition
- Surface Coil Selection
- Plane: Axial, Sagittal, Coronal, Oblique
- Pulse Sequence Decisions
  - Spin Echo
  - Inversion Recovery
    - STIR
  - Fast (Turbo) Spin Echo
    FSE-IR, FSE Fast Recovery, Phase-sensitive IR, Single Shot FSE (HASTE)
  - FLAIR: T2 FLAIR, T1 FLAIR
  - Gradient Echo
    - GRE
    - Fast (Turbo) GRE (SPGR)
    - Spoiled GRE
    - Fast (Turbo) Spoiled GRE
    - In/Out of Phase GRE
  - Echo Planar Imaging (EPI)
    - GRE-EPI
    - SE-EPI
    - IR-EPI
    - Multi-shot EPI
    - Single Shot EPI
    - MS-IR-EPI
    - SS-IR-EPI
    - Susceptibility-weighted
    - Diffusion-weighted
    - Diffusion-Tensor: # of directions
  - Vascular
    - Time-of-Flight
    - Phase Contrast (PC)

        - CINE
        - CINE PC
        - TOF-GRE
        - TOF-SPGR
        - CE MRA
- Acquisition Timing Decisions
    - Time-to-Echo (TE)
      Min TE, Min Full TE, Number of echoes
    - Repetition Time (TR)
    - Inversion Time (TI)
    - Number of Excitations (NEX) or Number of Single Averages (NSA)
    - < than 1 Fourier Transform steps (0.5, 0.75. etc)
    - Receive Bandwidth
    - Echo-Time Length (ETL)
    - Flip Angle
- Image Resolution Decisions
    - Field of View
    - Slice Thickness
    - Inter-slice skip factor
    - Phase Encoding steps
    - Frequency Encoding Steps
    - Phase/Frequency direction
- General Imaging Options
    - Spatial RF Saturation pulse
      Default, Placement, Thickness
    - Gradient Moment Nulling
      Frequency Direction, Slice direction, Both
    - Magnetization Transfer
    - Sequential slice ordering
    - Interleaved slice ordering
    - Parallel Imaging
        - Acceleration factor
    - Anti-Aliasing
    - Respiratory Compensation
      Resp re-ordering, Resp-triggering
    - Cardiac Gating
        - R-R interval
        - Delay Time
        - Trigger Window
        - ECG gating vs. Peripheral
        - Views per Segment
    - Vascular
        - Contrast Bolus detection
            - Manual timing
            - Computer-assisted
            - Real-time “Fluoro-triggering”
            - Time-Resolved Kinetics (IE:TRICKS)
    - Fat Suppression
      Fat Saturation, Spectral Fat Suppression, 3pt Dixon
    - Local Field Shimming
      Auto, Selection Volume

A Comparison of MRI to Other Medical Imaging Modalities (continued)

- Image Prescription Decisions
  - Number of slices
  - Slice/Volume coverage
- Image Reconstruction Options
  - Zero-filling interpolation: In-plane, Through-plane
  - Surface Coil intensity correction
  - Auto-Image subtraction
  - Image Filtration
  - Image Add/Subtract
  - ADC Map
  - FA Map
  - Perfusion Maps
    rCBV, rCBF, rMTT
  - Auto-Reformation
  - Maximum-Pixel Intensity
  - Minimum-Pixel Intensity

END