A. Basic underlying MR safety principles

1. Three magnetic fields
    a) B0/static magnetic field/main magnetic field
        (1) Core concepts
        (2) Quantities and units
            (a) Gauss lines
            (b) Static magnetic field map/fringe field
        (3) Biological effects
            (a) Magnetophosphenes
            (b) Magnetohydrodynamic effect
            (c) ECG perturbations
            (d) Movement through static field
                (i) Vertigo, dizziness, nausea, nystagmus
        (4) Mechanical forces
            (a) Translational forces (missile effect)
                (i) Magnetic spatial gradient exposure (dB/dx)
                (ii) Static field exposure – FDA age limits
                (iii) Location of maximum translational force
                (iv) Force product
            (b) Rotational forces (Torque)
                (i) Location ox maximum rotational force
                (ii) Field orientation
                    (a) Horizontal
                    (b) Vertical
            (c) Lenz Forces
                (i) Dependence on:
                    (a) Static field B0
                    (b) Size of conductor
                    (c) Orientation of conductor
                    (d) Speed of motion of conductor
                    (e) Conductivity of metal
                (ii) Implants/devices
        (5) Magnetic properties of matter
    b) Radiofrequency magnetic field
        (1) Core concepts
            (a) Faraday’s Law of Induction
            (b) E-field

(c) Near and far field
(d) Tissue properties
(i) Conductivity
(ii) Dielectric constant
(2) Quantities and units
(3) Biological effects
(a) Potential thermal concerns
(i) SAR and energy deposited
(a) SAR modes
(i) Normal
(ii) First level controlled
(iii) Second level controlled
(ii) B1+rms
(iii) Rate of exposure
(iv) Route of exposure
(v) Transmitting RF coil
(a) Proximity of patient issue/device to transmitting RF coil
(b) Induced current loop
(c) Orientation of induced current loop relative to transmitted RF power
(d) Induced voltages/currents
(i) Leads, wires, devices with sharp edges/point
(ii) Field strength/transmitted RF wavelength relative to object
(iii) 'Hot spots"
(iv) Resonant conditional/critical length relationship to field strength/frequency
(e) Presence/absence of heat sink
(f) Use of padding/insulation
(i) Between patient and bore
(ii) Skin to skin contact – large caliber induced loops
(4) Mechanical forces

c) Time-varying Gradient Magnetic Field
(1) Core concepts
(2) Quantities and units

(3) Biological effects
(a) Acoustic/auditory considerations
(b) Direct neuromuscular stimulation potential
(c) Movement/motion within the static magnetic field
(4) Mechanical forces

2. Gadolinium based contrast agents (GBCA)
a) Short term adverse effects
(1) Non-allergic type: nausea, emesis, headache, local injection site adverse reactions, etc.
(2) Allergic type: hives, sneezing, swelling, etc.
(3) Anaphylaxis/anaphylactoid reactions
(4) Risk assessment
(a) Previous adverse event with GBCA
(b) Previous adverse event with iodinated agents
(c) History of allergies of allergic respiratory disorders
b) Long term effects
(1) Nephrogenic Systemic Fibrosis
(2) Retained gadolinium
(3) Anthropogenic gadolinium

3. Cryogen safety considerations
a) Quench vent pathway considerations
b) Hypothermia
c) Frostbite
d) Asphyxia
e) Explosive risk
f) Flammable risk
g) Pressure-related risk – quench vent pathway failure
(1) Ruptured eardrums
(2) Pressure “locking” of doors/access

4. Claustrophobia/Anxiety

5. Monitoring
a) MR environment effects on ability to accurately monitor
b) Effects of the monitoring device(s) on MR imaging/artifacts
c)

6. General implant/device safety considerations
    a) Maximum spatial gradient
        (1) Clinical application and decision making
        (2) Location of system maximum spatial gradient
    b) Thermal
        (1) Clinical application and decision making
    c) Induced voltages

7. Specific implant/device safety considerations
    a) Patient implant/devices
        (1) Ferromagnetic risk
            (a) Magnetic implants – dental, breast implants, ICP monitors, etc.
            (b) Intraocular or adjacent to other critical tissue/organs
            (c) Artifact considerations
        (2) Active implants/devices
            (a) Multiple active implants
            (b) MR fields interfering with implanted device function
            (c) Pacemakers
                (i) Legacy devices, one or more leads
                (ii) Newer intracardiac devices, leadless
            (d) ICD's
            (e) Neurostimulators
            (f) Deep brain stimulators
            (g) Bone growth stimulators
        (3) Passive implants/devices
            (a) Wires/leads/sutures
            (b) Foreign bodies
                (i) Bullets, shrapnel, BB's, etc.
            (c) Foil backed medication patches
            (d) Multiple adjacent or contiguous implants
                (i) Skin staples, multiple dermal anchors, piercings
    b) Healthcare worker implants
    c) Device labeling and proper use of terminology
        (1) MR Safe
        (2) MR Unsafe
        (3) MR Conditional

8. Pregnancy-related MR safety considerations
    a) Patient pregnancy consideration
        (1) Contrast-related
        (2) Not contrast-related
    b) Healthcare worker pregnancy considerations

9. Non-MR personnel in the MR environment
    a) Anesthesiology
    b) Referring physicians
    c) Nursing
    d) Respiratory
    e) Patient transport
    f) Security
    g) Environmental Services
    h) Facilities
    i) First responders
    j) Accompanying family/friends/guardians
    k) Prisoners/Law Enforcement
        (1) House arrest bracelet
        (2) Handcuffs, other restraining devices

10. Screening considerations
    a) Standardization
        (1) Emergent Unconscious
        (2) Non-Emergent Conscious
    b) Ferromagnetic detection (FMD)
        (1) Metal detector technology as compared to FMD technology
        (2) Ferrous-free staff
    c) Gowning considerations
        (1) Decreased risks from ferromagnetic and thermal concerns
            (a) Patient
            (b) Accompanying family
            (c) Healthcare Personnel

11. Medical emergencies in the MRI environment
    a) Quench
    b) Code
        (1) Designated area

(a) Location
(b) Events/steps to execute

12. 4 Zone concept
    a) Site access restriction for:
        (1) Staff/patients/family members
        (2) Ferrous devices/objects
            (a) Ancillary equipment in Zone IV
    b) Site access restrictions
        (1) MR magnet room
        (2) Quench vent exhaust port
    c) Signage
        (1) Relative to the MR magnet room
        (2) Relative to the quench vent exhaust port
    d) Authority and responsibility for enforcement

13. Infection control
    a) Cleaning between patients

B. Medicolegal implications in MR safety
    1. Legal foundation and building blocks
        a) Standard of care
            (1) Expectation of how another similarly trained individual would have behave in the same clinical situation
            (2) Defined by the patient's expectation
        b) Medical malpractice
            (1) Breach of standard of care = negligence
            (2) Breath of the standard of care was a proximate cause of an injury
        c) "Captain of the ship" doctrine for medical malpractice in the U.S.
        d) There can be multiple parties responsible /liable for an injury
        e) Vicarious liability
            (1) NOT determined by who hires/fires the employee
            (2) Vicarious actions and liabilities