

A. Basic underlying MR safety principles

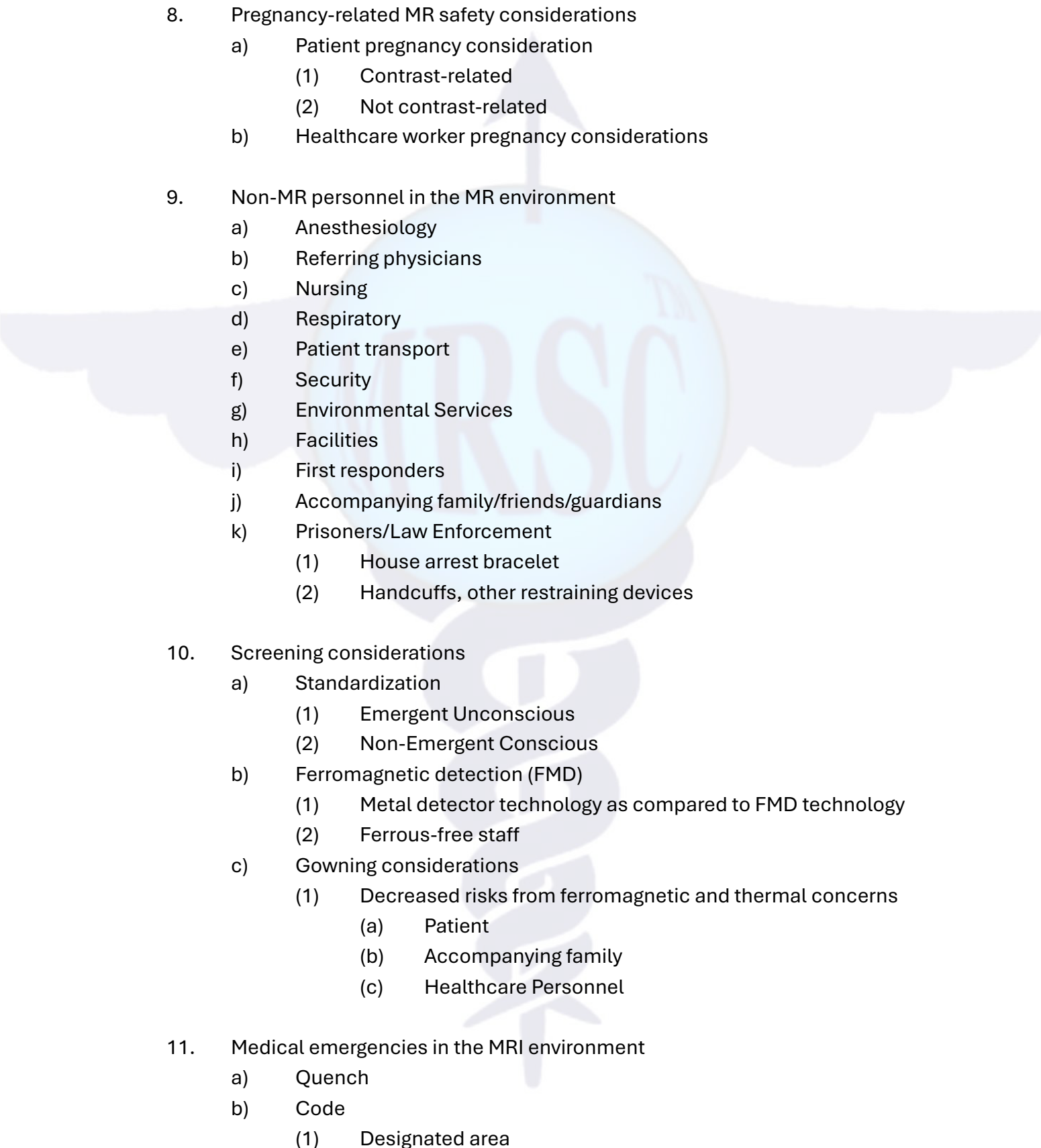
1. Three magnetic fields

- 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 of 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

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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) Breach 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