Magnetic Resonance Curriculum

A Multi-organizational Curriculum Project Group produced this MR Curriculum.

Magnetic Resonance Curriculum

Introduction

This curriculum identifies the cognitive base of entry-level education in the practice of magnetic resonance (MR) technology. This document represents a collaborative effort involving representatives from the American Society of Radiologic Technologists (ASRT), the Association of Educators in Imaging and Radiologic Sciences (AEIRS) and the Section for Magnetic Resonance Technologists (SMRT) of the International Society for Magnetic Resonance in Medicine (ISMRM).

This curriculum document establishes national, standardized educational guidelines for MR, including clinical and didactic components. The curriculum is suitable for all programs in this discipline, including limited fellowships, certificate programs, and college-based education programs. The curriculum recognizes that the educational components are not static, but represent current practice and trends in the field. Educators are responsible for incorporating new concepts and trends in the curriculum as they occur.

The document contains an outline for an educational program including body areas defined by the ARRT examinations. The content is designed to assure quality patient care and production of quality diagnostic images.

The document is divided into two content areas: core and optional content.

- Core content: This content makes up the body of the document and reflects educational content the professional community supports as essential for preparation to enter the magnetic resonance field. Specific instructional methods were intentionally omitted to allow for programmatic prerogative as well as creativity in instructional delivery.
- Optional content: Content in this section will assist program planners wishing to enhance the curriculum with select topics of instruction intended to satisfy the mission of a given program or local employment market.

The guidance provided by this curriculum document will span the time period prior to and after the projected Jan. 1, 2015, start date for the minimum associate degree requirement for candidates seeking professional certification established by the American Registry of Radiologic Technologists (ARRT). The focus of this document is on core instructional content that will be expanded with institution-specific course content to fulfill metrics for receipt of an academic degree. This document does not outline administrative strategies for programs that are unable to award graduates an academic degree that complies with the ARRT 2015 degree requirement.

Advances in diagnostic imaging and employer expectations demand independent judgment by MR technologists. Consequently, the educational process must foster, develop and assess critical-thinking skills. Critical thinking is incorporated in multiple content areas, and faculty is expected to develop and implement critical thinking throughout the curriculum. In summary, the MR curriculum is based on data relevant to today's health care environment. The curriculum offers a foundation for lifelong learning that will serve MR technologists throughout their careers. In addition, it offers faculty the flexibility to develop curriculum designed to meet the needs of individuals preparing to perform diagnostic magnetic resonance imaging procedures.

Magnetic Resonance Curriculum

Table of Contents

Clinical Practice and Patient Management

Description

Content is presented as a progression in competency levels through clinical performance objectives and competency exams. Students can access the educational materials, examination facilities and personnel necessary to competently achieve content objectives. Objectives include demonstration and observation of an activity, after which the student assists in performing the activity. When a satisfactory degree of proficiency is apparent, the student can perform the activity under direct supervision. When both the student and instructor are satisfied with the student's proficiency, the student performs MR imaging procedures under indirect supervision to gain experience and expertise.

Objectives

1. Employ the code of ethics and professional behaviors.
2. Demonstrate professional communication with patients, staff members and the general public.
3. Demonstrate cultural competence.
4. Describe the role of health care team members.
5. Demonstrate proper scheduling and sequencing of imaging procedures.
6. Correlate the requested imaging procedure with clinical history and reported physical examination findings.
7. Demonstrate proper suite and equipment preparation.
8. Demonstrate patient assessment (e.g., screening, monitoring, etc.).
9. Demonstrate effective education to patients, family members and other health care professionals.
10. Demonstrate charting and documentation.
11. Employ infection control precautions to prevent disease transmission.
12. Employ safe cleaning of equipment and disposal of contaminated materials.
13. Describe communicable disease terminology and required transmission-based precautions.
14. Evaluate and respond to medical emergencies.
15. Differentiate the functions of tubes, catheters, lines and infusion devices.
16. Examine preprocedural considerations.
17. Employ proper setup of patient positioning, MR coils, equipment, table accessories and cushioning.
18. Apply national, organizational and departmental standards, protocols, policies and procedures regarding MR imaging and patient care.
19. Demonstrate image quality analysis.
20. Demonstrate storage and dissemination of images.
21. Explain the environmental considerations (e.g., gauss lines, radiofrequency (RF) shielding and magnetic shielding, etc.).
22. Employ safety practices for all patients, employees and staff entering the MR environment.

Content

I. Clinical Practice

A. Code of ethics and professional behavior
   1. Scope of practice
   2. Incident reporting mechanisms
   3. Standards for supervision
      a. Direct
      b. Indirect
   4. The patient care partnership: understanding expectations, rights and responsibilities

B. Professional communication and cultural competence
   1. Patient
   2. Patient's family and friends
   3. Health care team
   4. Confidentiality of patient records (Health Insurance Portability and Accountability Act, or HIPAA, compliance)

C. Role of health care team members
   1. Technical
   2. Professional

II. Procedural Performance

A. Scheduling and sequencing MR imaging procedures

B. Evaluate requisition and verify order

C. Suite and equipment preparation

D. Patient assessment and education
   1. MR screening documentation form
      a. Contraindications for MR imaging
      b. Laboratory results – normal ranges and values
         1) Blood urea nitrogen (BUN) test
         2) Blood creatinine level
         3) Hemoglobin test
         4) Red blood cell count (RBCs)
         5) Platelet count
         6) Oxygen (O_2) saturation
         7) Prothrombin time
         8) Part thromboplastin time
         9) Glomerular filtration rate calculation (GFR)
   2. Adult vs. pediatric considerations
   3. Patient monitoring – emergent and nonemergent
      a. Vital signs – normal ranges and values
         1) Temperature

a) Fahrenheit
b) Celsius
2) Pulse
3) Respiration
4) Blood pressure

b. Physiologic monitoring
1) Electrocardiogram (ECG)
2) Pulse oximetry
3) Capnography – end tidal carbon dioxide (ETCO2)
4) Invasive blood pressure and central venous pressure
5) Temperature changes

E. Protocol selection

F. Performance of imaging procedure

G. Charting and documentation
1. Medical reconciliation (The Joint Commission [TJC] requirement)
2. Surgical and medical history
3. Pain assessment

III. Infection Control

A. Centers for Disease Control and Prevention (CDC)
1. Purpose
2. Publications and bulletins

B. Occupational Safety and Health Administration (OSHA)
1. Purpose
2. Publications and bulletins

C. Cycle of infection
1. Infectious pathogens
2. Source or reservoir of infection
3. Mode of transmission
a. Direct
b. Indirect

D. Preventing disease transmission
1. Standard precautions
a. Hand washing
b. Personal protective equipment
2. Transmission-based precautions
a. Airborne (e.g., negative ventilation)
b. Droplet
c. Contact

3. Health care worker
    a. Immunization
    b. Titer – booster
    c. Postexposure protocols (prophylaxis)

E. Asepsis
1. Medical
    a. Definition
    b. Procedures
        1) Hand washing
        2) Chemical disinfectants
2. Surgical
    a. Definition
    b. Growth conditions for microorganisms
    c. Methods used to control microorganisms
        1) Moist heat
            a) Boiling
            b) Steam under pressure
        2) Dry heat
            a) Incineration
            b) Dry heat sterilized
        3) Gas
        4) Chemicals
    d. Procedures
        1) Opening sterile packaging
        2) Gowning and gloving
        3) Skin preparation
        4) Draping
        5) Dressing changes
    e. Packing
    f. Storage
    g. Rules for surgical asepsis

F. Safe cleaning of equipment and disposal of contaminated materials
1. Handling linens
2. Needles
3. Patient supplies
4. Scanner, bore, coils, ancillary equipment
5. Wound dressing care

G. Communicable disease terminology and required transmission-based precautions
1. Patient transportation
2. Disease-specific
3. Communicable
4. Infectious pathogens

5. Human immunodeficiency virus (HIV)
6. Hepatitis
    a. Hepatitis A virus (HAV)
    b. Hepatitis B virus (HBV)
    c. Hepatitis C virus (HCV)
    d. Hepatitis D virus (HDV)
    e. Hepatitis E virus (HEV)
7. Tuberculosis (TB)
8. Respiratory syncytial virus (RSV)
9. Hospital-acquired infection (HAI)
10. Methicillin-resistant *Staphylococcus aureus* (MRSA)
11. Vancomycin-resistant Enterococci (VRE)
12. *Clostridium difficile* (*C-diff*)
13. Influenza

H. Precautions for compromised patient (reverse isolation)
    1. Purpose
    2. Procedure

I. Psychological considerations

IV. Medical Emergencies

A. Terminology

B. Emergency equipment

C. Latex reactions

D. Signs, symptoms and precautions
    1. Shock
    2. Diabetic emergencies
    3. Respiratory and cardiac failure
    4. Airway obstruction
    5. Cerebral vascular accident (stroke)
    6. Syncope
        a. Nausea
        b. Postural hypotension
        c. Vertigo
        d. Vasovagal response
    7. Seizures
    8. Epistaxis
    9. Mental illness
    10. Neurological
        a. Head injuries
        b. Spinal injuries

11. Extremity fractures
12. Wounds
13. Burns
14. Reactions to contrast agents
15. Other

V. Tubes, Catheters, Lines and Infusion Devices

A. Terminology

B. Function of devices

C. Nasogastric and nasointestinal tubes

D. IVs, butterflies and angiocatheters

E. Power injectors

F. Infusion pumps

G. Suction

H. Tracheostomy

I. Chest (thoracostomy) tube

J. Central venous lines

K. Postoperative drains

L. Oxygen administration using MR-conditional equipment

M. Other
1. Ostomies
2. Urinary catheters
3. Prosthetics

VI. Imaging Procedures

A. Preprocedural considerations

B. Positioning

C. Protocol considerations
1. Imaging sequence
2. Imaging parameter adjustments

3. Postprocessing images (maxiumum-intensity projection [MIP], multiplanar reformatting [MPR])

D. Image quality analysis
   1. Signal-to-noise ratio (SNR)
   2. Window levels and widths
   3. Artifacts
   4. Anatomy

E. Image storage
   1. Digital imaging and communications in medicine (DICOM)
   2. Picture archival communication system (PACS)
      a. Legal requirements for image documentation and retention of storage media

F. Patient and personnel protection
   1. Screening: patient, personnel and general public
      a. Metallic objects
      b. Implants and pacemakers
      c. Sickle cell disease
      d. Renal disease
      e. Asthma
      f. Pregnancy
      g. Breast feeding
      h. Dialysis
      i. Claustrophobia
   2. Equipment and accessories
      a. Coils
      b. Emergency alarm call button
      c. Earplugs and headphones
      d. MR-conditional equipment:
         1) ECG leads
         2) Oxygen tanks
         3) IV pumps
         4) Anesthesia equipment and ventilators
         5) Pulse oximeters
         6) Blood pressure cuffs
         7) Suction
         8) Physiologic monitors
   3. Environment
         1) Gauss lines
         2) RF shielding and magnetic shielding
         3) Warning alarms and signs
         4) Safety zone 1-4
         5) Climate control
         6) Ferromagnetic metal detector

4. Biological Considerations
    a. RF field
    b. Static magnetic field
    c. Gradient fields

VII. ARRT Clinical Experience Requirements

A. Primary Pathway Eligibility Requirements: (https://www.arrt.org/pdfs/Disciplines/Competency-Requirements/MRI-Competency-Requirements-new.pdf)

B. Postprimary pathway (https://www.arrt.org/pdfs/Disciplines/Clinical-Experience/MRI-Clinical-Experience-new.pdf)

Computers in Imaging and Medical Informatics

Description

Content introduces knowledge in computing and information processing. It presents computer applications in the radiologic sciences related to image capture, display, storage and distribution. Additional content is designed to provide the basic concepts of patient information management. Medical records management, including privacy and regulatory issues, are examined. The role of the technologist is identified and discussed. In addition, this content imparts an understanding of the components, principles and operation of digital imaging systems found in MR, image data management, storage and data manipulation (postprocessing). Factors that impact image acquisition, display, archiving and retrieval are discussed.

Objectives

1. Describe computer fundamentals.
2. Examine the impact of regulations, laws and standards related to informatics on health care delivery.
3. Describe the evolution and role of health care informatics.
4. Explain the ethical concerns related to health care informatics.
5. Evaluate decision-making strategies used in informatics.
6. Compare and contrast different informatics applications in health care.
7. Describe digital imaging characteristics.
8. Apply digital imaging acquisition requirements.
9. Demonstrate imaging standard expectations (e.g., protocol and parameter selection, problem-solving, etc.).
10. Analyze the cause and correction of image artifacts.
11. Employ quality assurance.
12. Demonstrate postprocessing strategies (e.g., 3-D, MIP, Region of Interest, etc.).
13. Describe the methods of image display (e.g., monitor, film, digital, etc.).
14. Explain RIS, HIS and PACS applications as they relate to radiology.
15. Describe the procedural factors (e.g., image identification, documentation of ordered imaging procedure, artifacts and image evaluation).
16. Apply The Joint Commission/HIPAA standards regarding accountability and protection of patient information.

Content

I. Computer Fundamentals

A. Terminology
   1. Analog
   2. Digital
   3. Binary

B. Types of computers
   1. Supercomputer/mainframe
   2. Minicomputer
   3. Microcomputer

C. Characteristics
   1. Memory
   2. Speed
   3. Capabilities

D. Capabilities
   1. Protocols
   2. Parameters
   3. Data manipulation

E. Array processor
   1. Fourier transform
   2. Half and partial Fourier

F. Configurations
   1. Thin client
   2. Thick client

II. Health Care Informatics

A. Definition

B. History

C. Theories

D. Databases

E. Ethics

III. Regulations, Laws and Standards

A. Licensure and/or certification

B. Accreditation

C. National and international standards

D. Federal laws

IV. Decision Making

A. Administrative

B. Clinical

C. Evidence-based medicine

V. Health Care Informatics Applications

A. Electronic health records

B. Patient care systems

C. Patient monitoring systems

D. Radiology imaging systems

VI. Digital Imaging

A. Digital image characteristics
   1. Picture elements – pixels
   2. Pixel size
      a. Field of view (FOV)
      b. Matrix
   3. Voxel size
      a. FOV
      b. Thickness
      c. Matrix
   4. Matrix size
   5. Image quality characteristics
      a. Spatial resolution
      b. Temporal resolution
      c. Image contrast
      d. Data size

B. Digital image acquisition
   1. MR image acquisition
      a. Protocol/parameter selection
         1) Resolution (FOV, thickness, matrix)
         2) Contrast – repetition time (TR), echo time (TE), inversion time (TI) and flip angle (FA)
         3) Other parameters

b. System requirements
    1) Hardware requirements
    2) Software requirements
c. Anatomical considerations
    1) Anatomy of interest
    2) Plane/baseline reference
    3) Anatomical variations
    4) Body habitus
    5) Pathology
d. Positioning aids
e. Special concerns
    1) Age
    2) Patient condition
    3) Positioning

2. MR image formation
    a. K-space
    b. Analog to digital converter
    c. Fourier transformation

C. Imaging standards
1. Protocol selections
2. Parameter selections
3. Problem-solving process
4. Role of the MR technologist

D. Artifacts
1. Determining the cause(s) of artifacts
2. Optimizing acquisition parameters
3. Nonoperator controlled

Ethics and Law in the Imaging Sciences

Description
Content provides a fundamental background in ethics. The historical and philosophical basis of ethics and the elements of ethical behavior are discussed. The student examines a variety of ethical issues and dilemmas found in clinical practice.

An introduction to legal terminology, concepts and principles also is presented. Topics include misconduct, malpractice and legal and professional standards. The importance of proper documentation and informed consent is emphasized.

Objectives
1. Discuss the origins of medical ethics.
2. Apply medical/professional ethics and moral reasoning.
3. Explain ethical considerations in health care delivery.
4. Identify specific situations and conditions that give rise to ethical dilemmas in health care.
5. Explain legal issue considerations that are embodied in the principles of patients' rights, the doctrine of informed (patient) consent and other issues related to patients' rights.
6. Explain the legal implications of professional liability, malpractice, professional negligence and other legal doctrines applicable to professional practice.
7. Identify information systems used to manage and transfer a patient's protected health information.
8. Identify standards used to secure and manage the compliance of protected health information.

Content

I. Ethics and Ethical Behavior

A. Origins of history of medical ethics

B. Moral and ethical reasoning

C. Professional behavior standards

D. Competence

E. Professional attributes

F. Standards of practice

G. Self-assessment and personal integrity

H. Code of professional ethics

I. Ethical concepts
   1. Ethics principles
   2. Violation process
   3. Solving ethical dilemmas

J. Ethical patient care data research and data discovery

II. Ethical Considerations in Health Care

A. Individual and societal rights

B. Cultural competence
   1. Organizational
   2. Interpersonal

C. Health care equity

D. Access to quality health care

E. Medical and health care research

F. End-of-life decisions

III. Legal Issues

A. The Joint Commission Standards
   1. Accountability for protecting patient information
      a. Information collection
      b. Information maintenance

c. Use of personally identifiable health information
d. Contractual agreements
e. Demonstrating and monitoring compliance

B. Consents
1. Informed
a. Patient and provider elements
2. Release of information
a. Purposes
b. Types of information released
c. Recipients of information

C. Education regarding policies, rights and responsibilities
1. Patient education
2. Provider education

D. Parameters of legal responsibility
1. Informed patient consent
a. Definition
b. Types
c. Condition for valid consent
d. Documentation of consent

E. Patient personal information
1. Patient's Bill of Rights
2. Health Insurance Portability and Accountability Act (HIPAA)
3. Confidentiality of patient information

F. Intentional misconduct

G. Negligence or malpractice
1. Definitions
2. Components of malpractice
3. Legal doctrines
4. Legal and professional standards
5. Medical liability
6. Sources of law
7. Civil and criminal liability

IV. Protected Health Information

A. Information systems
1. Hospital information system (HIS)
2. Radiology information system (RIS)
3. Picture archiving and communications system (PACS)

B. Standards
   1. Digital imaging and communication in medicine (DICOM)
   2. Health level standards (HL7)

C. Health information exchanges (HIE)

D. Methods of obtaining patient health information
   1. Coding and standardization

E. Physical or electronic health record content
   1. Elements of proper charting and documentation
   2. Legal ramifications of improper charting and documentation

V. Compliance

A. Accreditation

B. Federal and state regulations

C. Protected health information (PHI)

D. Noncompliance issue

Fundamentals of Imaging Science and Health Care

Description

Content provides an overview of the foundations in radiologic science and the practitioner's role in the health care delivery system. The principles, practices and policies of health care organizations are examined and discussed in addition to the professional responsibilities of the MR technologist.

Objectives

1. Identify other health science professions that participate in the patient's total health care.
2. Identify various health care continuum environments involved in the delivery of health care.
3. Discuss the role and value of a philosophy and mission statement to the operation of an institution.
4. Describe relationships and interdependencies of departments within a health care organization.
5. Discuss the responsibilities and relationships of all personnel and support systems in the radiology organization.
6. Discuss the responsibilities and relationships of radiologic science personnel.
7. Differentiate among different accreditation types.
8. Describe continuing education requirements evaluation mechanisms at the national, state and regional levels.
9. Describe the regulatory agencies relevant to the fundamentals of imaging science and health care.
10. Define credentialing, certification, registration, licensure and regulations.
11. Discuss the purpose, function and activities of professional organizations at the local, state, national and international levels.
12. Discuss professional development and advancement opportunities.
13. Identify the benefits of continuing education as related to improved patient care and professional enhancement.

Content

I. The Health Science Professions

A. Radiologic technology
1. Education
2. Diagnostic medical sonography
3. Magnetic resonance imaging
4. Management
5. Medical dosimetry
6. Nuclear medicine technology
7. PACS administration
8. Positron emission tomography (PET)
9. Radiation therapy
10. Radiography specialties
    a. Bone densitometry
    b. Cardiac-interventional radiography
    c. Computed tomography
    d. Diagnostic radiography
    e. Mammography
    f. Multiskilled
    g. Quality management
    h. Radiologist assistant
    i. Vascular-interventional radiography

B. Health care professions
1. Health information technology
2. Medical laboratory sciences
3. Nurse practitioner
4. Nursing
5. Occupational therapy
6. Pharmacy
7. Physical therapy
8. Physician assistant
9. Radiologist assistant
10. Respiratory therapy
11. Social services
12. Other

II. The Health Care Continuum

A. Health care systems
1. Hospitals
    a. Veterans Administration/military
    b. Not-for-profit
    c. For-profit
    d. System/network
2. Outpatient ambulatory care facilities

3. Mental health facilities
4. Long-term, residential facilities
5. Home health care
6. Hospice
7. Preventive care
8. Telemedicine

B. Payment and reimbursement systems
   1. Self pay
   2. Third-party payors

III. Hospital Organization

A. Philosophy

B. Mission
   1. Role within the community
   2. Commitment to education within the profession and community health

C. Administrative services
   1. Governing board
   2. Hospital administration
   3. Admissions
   4. Information systems
   5. Materials management
   6. Accounting
   7. Support services
   8. Human resources

D. Medical services
   1. Independent licensed practitioners (ILP)
   2. Clinical services
   3. Clinical support services
      a. Physical
      b. Spiritual
      c. Psychological
   4. Risk management

IV. Radiology Organization

A. Professional personnel
   1. Administrative director/chair
   2. Medical director/chair
   3. Safety officer/committee
      a. Radiation
      b. MRI
   4. Radiologists

5. Medical physicist
6. Radiologic technologists

B. Support personnel
   1. Administrative staff
   2. Medical billing
   3. Information technology
      a. EMR
      b. HIS/RIS
      c. PACS

C. Educational personnel
   1. Educational/program director
   2. Clinical coordinator
   3. Didactic instructor
   4. Clinical instructor
   5. Clinical staff

V. Accreditation

A. Definition

B. Programmatic accreditation

C. Institutional accreditation

D. Regional accreditation

VI. Continuing Education Requirements

A. National

B. State

C. Regional

VII. Regulatory Agencies

A. Federal

B. State

VIII. Professional Credentialing

A. Definition
   1. Certification
   2. Registration
   3. Licensure

B. Agencies
   1. National
      a. American Registry of Radiologic Technologists (ARRT)
      b. Nuclear Medicine Technology Certification Board (NMTCB)
      c. American Registry of Diagnostic Medical Sonographers (ARDMS)
      d. American Healthcare Radiology Administrators (AHRA)/Radiology Administration Certification Commission (RACC)
      e. American Registry of Magnetic Resonance Imaging Technologists (ARMRIT)
      f. State – licensure

IX. Professional Organizations

A. Purpose, function, activities

B. Local organizations

C. State organizations

D. International
   1. International Society of Radiographers and Radiological Technologists (ISRRT)
   2. International Society for Magnetic Resonance in Medicine (ISMRM)/Section for Magnetic Resonance Technologists (SMRT)

E. National organizations
   1. American Society of Radiologic Technologists (ASRT)
   2. American Healthcare Radiology Administrators (AHRA)
   3. Association of Collegiate Educators in Radiologic Technology (ACERT)
   4. Association of Educators in Imaging and Radiologic Sciences, Inc. (AEIRS)
   5. American Registry for Diagnostic Medical Sonographers (ARDMS)
   6. Nuclear Medicine Technology Certification Board (NMTCB)
   7. Magnetic Resonance Managers Society (MRMS)
   8. American College of Healthcare Executives (ACHE)

F. Related associations and organizations
   1. American Board of Radiology (ABR)
   2. American College of Radiology (ACR)
   3. Radiologic Society of North America (RSNA)
   4. American Medical Association (AMA)
   5. Intersocietal Accreditation Commission (IAC)

X. Professional Development and Advancement

A. Clinical experience requirements
   1. Primary certification
   2. Postprimary certification

B. Continuing education opportunities

1. Collegiate/educational programs
2. Self-learning activities
3. Professional conferences

C. Employment considerations
   1. Geographic mobility
   2. Economic factors
   3. Workforce needs

D. Advancement opportunities
   1. Education
   2. Administration
   3. Advanced practice
   4. Medical
   5. Physics
   6. Research
   7. Industrial
   8. Medical informatics
   9. Sales
   10. Applications training

MR Imaging Procedures

Description

This content provides the student with imaging techniques related to the central nervous system (CNS), neck, thorax, musculoskeletal system and abdominopelvic regions. The content covers specific clinical application, available coils and their use, considerations in the scan sequences, specific choices in the protocols (e.g., slice thickness, phase direction and flow compensation) and positioning criteria. Anatomical structures and the plane that best demonstrates anatomy are discussed as well as signal characteristics of normal and abnormal structures.

Objectives

1. Demonstrate proper patient screening.
2. Demonstrate effective communication skills with patients, their family members and staff.
3. Demonstrate MR safety and protective practices associated with MR imaging procedures.
4. Demonstrate proper use of MR-safe monitoring devices.
5. Power up and shut down the system.
6. Describe the coils available for MR and their specific applications.
7. Explain the use of contrast media in evaluating pathology.
8. State positioning criteria for different areas of the body.
9. State advantages and disadvantages of axial, sagittal, coronal and oblique images (i.e., which structures are best demonstrated from each projection).
10. Describe common pulse sequences used to evaluate the different areas of the body.
11. Describe considerations in designing an imaging protocol and state the application of protocols in specific situations.
12. Identify when to modify a protocol and successfully perform the modification.
13. Describe common artifacts that occur during imaging.
14. Demonstrate proper windowing levels and widths.
15. Describe the criteria for imaging windows for different areas of the body.
16. Identify the probable cause of image quality problems and recommend an appropriate solution.
17. Describe the differences between adult and pediatric pulse sequences in MR.
18. Describe the differences in tissue signal characteristics between adult and pediatric examinations.
19. Evaluate images for appropriate positioning, anatomy, pulse sequences and overall quality.
20. Identify the common indications and pathology for body systems in the adult and pediatric patient.
21. Describe normal MR tissue characteristics of anatomical structures of interest.
22. Describe the MR tissue characteristics of select pathological processes.
23. Identify procedure considerations for contrast studies.
24. List technical and practical considerations for special procedures including functional techniques and procedures requiring the use of patient sedation.

Content

I. Preprocedural Considerations

A. Evaluation of MR orders
1. Patient identification
2. Verification of procedure(s) ordered
3. Establish patient rapport
   a. Explain procedure
   b. Proper patient screening
      1) Screening for metal on patient
      2) Screening for metal inside of patient
      3) Screening for physical indications that might contraindicate the imaging procedure or hinder results
      4) Determine any contrast contraindications
4. Patient education
   a. Communication
      1) Types
      2) Barriers
      3) Methods for overcoming barriers
      4) Clinical situations
      5) Common MR safety issues and concerns
5. Patient Preparation
   a. Appropriate disrobing and gowning
   b. Remove items that are contraindicated in the MR suite that could cause artifacts
6. Room preparation
   a. Maintain a clean and organized environment
   b. Ensure necessary supplies and accessory equipment are available
7. Patient assistance
8. Patient monitoring
9. Image evaluation
10. Patient dismissal

II. Considerations for Routine MR Procedures

A. Preprocedural considerations

B. Patient instructions

C. Patient positioning

D. Part placement

E. Protocol considerations

F. Equipment and accessories

G. Coil type and selection

H. Localization

I. Use of contrast agents

J. Patient and personnel protection

K. Image quality analysis

L. Image storage

M. Special considerations
    1. Atypical conditions
    2. Anesthesia considerations
    3. Ancillary staff considerations
    4. Special needs patients
    5. Trauma

III. Imaging Considerations

A. Pulse sequences considerations
    1. Imaging planes
        a. Positioning criteria
        b. Axial, sagittal and coronal
            1) Movement and direction
                a) Orthogonal
                b) Oblique
        c. Anatomy best demonstrated
        d. Slice thickness
    2. Image weighting
        a. Proton density weighted
        b. T1-weighted
        c. T2-weighted
        d. Diffusion weighted
        e. Susceptibility weighted

B. Parameter considerations
    1. Timing
    2. Flow and motion effect
    3. Encoding direction
    4. Motion reduction
    5. Artifact reduction
    6. Spatial resolution
    7. Contrast resolution
    8. Bandwidth/sampling

C. Image viewing
    1. Windowing
    2. Proper orientation

IV. Positioning and Procedural Considerations for Adult and Pediatric Patients

A. Anatomic regions
    1. MR/Magnetic resonance angiography (MRA) of the central nervous system
        a. Clinical indications
            1) Vascular disease
            2) Trauma
            3) Neoplasia
            4) Infection and/or inflammation
            5) Anomalies
            6) Myelination patterns
            7) Development anomalies and/or congenital malformations
        b. Anatomic locations
            1) Brain
                a) Head trauma
                b) Brain for stroke
                c) Brain for Multiple Sclerosis
                d) Brain for seizure
                e) Brain for cerebrospinal fluid (CSF) flow
                f) Pediatric brain
                g) Pituitary
                h) Angiography
                i) Spectroscopy
            2) Vertebral column
            3) Spinal cord
                a) Brachial plexus
                b) Sacrum/coccyx
            4) Neck
                a) Soft tissue
                b) MRA
    2. MR of the musculoskeletal system
        a. Clinical indications
            1) Degenerative disease
            2) Infection and/or inflammation
            3) Vascular
            4) Trauma
            5) Neoplasia
            6) Developmental anomalies, congenital malformations
            7) Implants
        b. Anatomic locations
            1) Temporomandibular joint
            2) Orbit

3) Internal auditory canal (IAC)
4) Shoulder
5) Elbow
6) Hands and fingers
7) Thumb
8) Hip
9) Ankle
10) Knee
11) Forefoot and hindfoot
12) Long bones
    a) Humerus
    b) Forearm
    c) Femur
    d) Lower leg
13) Arthrography
14) Angiography
15) Sacroiliac joints
16) Sternoclavicular joints
17) Sternum
18) Bony pelvis

3. MR/MRA of the thorax, abdomen and pelvis
   a. Clinical indications
      1) Infection and/or inflammation
      2) Vascular
      3) Trauma
      4) Neoplasia
      5) Anomalies
      6) Developmental anomalies and/or congenital malformations
   b. Anatomic locations
      1) Mediastinum
      2) Chest and thorax
      3) Cardiac
      4) Breast
      5) Abdomen
         a) Liver, spleen
         b) Pancreas
         c) Alimentary canal (enterography)
         d) Magnetic resonance cholangiopancreatography (MRCP)
      6) Retroperitoneum
         a) Kidney
         b) Adrenals
      7) Pelvis, male and female
         a) Soft pelvis: Bladder, rectum, anus
         b) Uterus, cervix, ovaries, vagina

c) Prostate, testes
d) Angiography: iliac and run-off

4. Special imaging procedures
   a. MRA/MRV
      1) Flow dynamics
      2) Time-of-flight
      3) Phase contrast
      4) Contrast enhanced
      5) Fluorotriggering
      6) Timing bolus
      7) Automatic bolus
      8) Extremity MR angiography
   b. Functional techniques
      1) Diffusion
      2) Perfusion
      3) Spectroscopy
      4) Functional MRI (fMRI)
   c. Dynamic imaging
   d. Image postprocessing

V. Procedural Considerations for Contrast Studies

A. Equipment and materials needed

B. Contrast media
   1. Purpose
   2. Types
      a. Intravenous
      b. Oral
      c. Endocavitary

VI. Procedural Considerations for Special Studies

A. Age-related

B. General anesthesia

C. Moderate sedation

D. Monitoring of conditional devices

MR Parameters, Imaging Options and Quality Assurance

Description
Content provides the student with knowledge of the parameters and imaging options used to create MR images. In addition, the content introduces quality assurance measures used in maintaining image quality.

Objectives
1. Identify imaging parameters that determine image contrast.
2. Describe imaging parameters that relate to spatial resolution on MR images.
3. Describe the imaging parameters involved in MR image formation.
4. Apply MR imaging parameters in the clinical setting.
5. Define imaging options used to optimize image quality.
6. Explain how to apply parameters and imaging options in order to minimize image artifacts.
7. Discuss how to acquire high-quality MR images with the aid of routine quality assurance practices.

Content

I. MR Imaging Parameter and Sequence Selections

A. Pulse sequence selections

1. Spin echo
   a. Types
      1) Single echo
      2) Multiecho
      3) Rapid acquisition relaxation enhancement (RARE)
         a) Fast spin echo (FSE)/Turbo-spin echo (TSE)
         b) Fast-recovery fast spin echo (FRFSE)
      4) Single-shot fast spin echo (SSFSE)/Half-Fourier single-shot turbo spin-echo (HASTE)
      5) Radial blade for motion correction
   b. Weighting
      1) T1
      2) T2
      3) Proton Density (PD)
      4) Diffusion-weighted imaging (DWI)
2. Gradient echo
   a. Types
      1) GRE
      2) Echo Planar Imaging EPI
      3) Steady state
   b. Weighting
      1) T1
      2) T2
      3) T2*
      4) PD
      5) DWI
         a) Apparent diffusion coefficient (ADC)
         b) Exponential apparent diffusion coefficient (EADC)
         c) Diffusion tensor imaging (DTI)
      6) Susceptibility-weighted imaging (SWI)
3. DTI
   a. Number of eigenvectors
   b. Fiber tracking
4. Inversion recovery
   a. Short tau inversion recovery (STIR)
   b. Spatial inversion recovery selected inversion recovery (SPIR)
   c. Spectral selected attenuation inversion recovery (SPAIR)
   d. Fluid-attenuated inversion recovery (FLAIR)
   e. T1 FLAIR
   f. Types
      1) Spin-echo inversion recovery (SE IR)
      2) Fast spin-echo inversion recovery (FSE-IR)

3) Gradient-echo inversion recovery (GRE-IR)

5. Flow studies

B. Image contrast parameters
   1. Extrinsic contrast parameters (user selectable parameters)
      a. TR – repetition time
         1) Image influencers
      b. TE – echo time
         1) Image influencers
         2) TE settings for FSE
      c. TI – Inversion time (tau)
         1) STIR
         2) FLAIR
         3) T1 FLAIR
         4) Double inversion recovery (DIR)
         5) Triple inversion recover (TIR)
      d. Flip angle
      e. "B" value
      f. Velocity encoding (VENC) value
   2. Intrinsic contrast parameters (determined by tissue characteristics)
      a. T1 recovery time
      b. T2 decay time
      c. Proton/spin density
      d. Physiologic motion
         1) Periodic motion
         2) Aperiodic motion
   3. Extrinsic contrast influences (contrast media)
      a. T1 agents
         1) Gadolinium
            a) IV agent
            b) Dose
            c) Effects on images
         2) Organ-specific and blood pool-specific
         3) Manganese (historical)
      b. T2 agents
         1) Gadolinium (perfusion)
         2) Iron oxide (historical)
      c. Oral agents
         1) Bulk gastrointestinal (GI) expansion agents
            a) Cellulose-containing
            b) whole milk
         2) negative contrast agent (e.g., blueberry juice, barium sulfate)
      d. Off-label applications

C. Resolution parameters

1. Voxel size
    a. Voxel size parameters
        1) FOV
        2) Slice thickness
        3) Matrix
    b. Affect on Quality
        1) Affect on SNR
        2) Affect on resolution
        3) Affect on scan time
2. Sampling parameters
    a. Sampling parameters
        1) Number of signals averaged (NSA)
        2) Receiver bandwidth
        3) Number phase encodings (matrix)
        4) Echo Train Length (ETL)/turbo factor
        5) Slices in a 3-D (volume) acquisition
        6) Parallel imaging
    b. Effect on quality
3. Dimensionality (mode)
    a. 2-D
    b. 3-D
    c. 4-D/time resolved
    d. Slice thickness/gap
    e. Slice order

II. Imaging Options

A. Saturation pulses
    1. Spatial presaturation band
    2. Spectral saturation
    3. Chemical saturation

B. Signal suppression and/or separation techniques
    1. Fat suppression
        a. Fat saturation (chemical saturation)
        b. STIR
    2. Water suppression
    3. Silicone suppression
    4. Dixon techniques

C. Gradient moment nulling (flow compensation)

D. Physiologic gating and triggering
    1. Respiratory gating
        a. Mechanical
        b. Chemical shift

2. Pulse gating
    a. Cardiac gating
    b. Peripheral gating
3. Navigator pulse

E. Magnetization transfer

F. Phase/frequency orientation

G. In/out of phase

H. Antialiasing

III. Quality Assurance

A. Artifacts, cause, appearance and compensation
1. Physics artifacts
    a. Dielectric effect
    b. B1 inhomogeneity
    c. Chemical shift
        1) Types
        2) Cause
        3) Compensation
    d. Susceptibility
        1) Metal
        2) Tissues with dissimilar chemical compensation
2. Sampling artifacts
    a. Aliasing
    b. Cross-talk
    c. Parallel imaging
    d. Gibbs truncation
3. Motion artifacts
    a. Voluntary
    b. Involuntary
    c. Ghosting
    d. Blurring
4. Technical errors
    a. Improper centering
    b. Coil selection
5. Hardware artifacts
    a. Moiré
    b. Corduroy
    c. Shading
    d. RF leak

B. Cause and appearance

C. Compensation

D. Operator-adjustable parameters

E. Quality assurance (QA)
   1. Electronic measurements
   2. Nuclear magnetic resonance (NMR) measurement
   3. Archival QA
   4. QA of display and multiformat cameras
   5. Record keeping
   6. Cryogen level and pressure
   7. Room temperature
   8. Slice thickness
   9. Spatial resolution
   10. Contrast resolution
   11. Signal-to-noise ratio
   12. Center frequency
   13. Transmit gain
   14. Geometric accuracy
   15. Equipment inspection

MR Pathology

Description
Content familiarizes the student with the common pathologies found in magnetic resonance imaging and the appearance of these pathologies in various imaging protocols. Content covers a broad spectrum of commonly-imaged body systems and areas.

Objectives
1. Cite common pathologies seen in MR.
2. Describe signal characteristics displayed by abnormal tissues during various pulse sequences and imaging modes in illustrating pathological processes.
3. Recognize and explain changes in sizes and shapes of anatomical structures that can indicate pathology.
4. Describe the effect of contrast agents on visualizing common pathologies.

Content

I. Central Nervous System

A. Brain

1. Neoplastic disorders
    a. Intra-axial
        1) Astrocytoma
        2) Glioblastoma
        3) Ependymoma
        4) Ganglioma
        5) Neuroblastoma
        6) Metastases
        7) Lymphoma
        8) Medulloblastoma
        9) Hemangioblastoma
    b. Extra-axial
        1) Meningioma
        2) Epidermoid
        3) Dermoid
        4) Lipoma
        5) Pituitary adenoma
        6) Pineal gland tumors and cysts
2. Infections and inflammatory disorders
    a. Meningitis
    b. Cerebral abscess
    c. Encephalitis
    d. HIV and associated infections
    e. Sarcoidosis
    f. Multiple sclerosis
    g. Fungal, bacterial and viral infections
3. Vascular disorders
    a. Stroke
        1) Types
            a) Ischemic
            b) Hemorrhagic
        2) Acute
        3) Subacute
        4) Brain hypoxia
    b. Venous sinus occlusion
    c. Arterial origin
        1) Aneurysm
        2) Vascular malformation
        3) Nontraumatic hemorrhage
        4) Arteritis
4. Congenital and hereditary disorders
    a. Aqueductal stenosis

    b. Chiari malformations
    c. Dandy-Walker syndrome
5. White matter disorders
6. Trauma
    a. Skull fracture
    b. Hematomas
    c. Shearing injury
    d. Contusion
    e. Hemorrhage
    f. Child abuse
    g. Arterial dissection
7. Other (e.g., aging, metabolic, idiopathic, iatrogenic, phakomatoses, etc.)

B. Spine and spinal cord
1. Tumor and tumor-like disorders
    a. Metastases (vertebral body and spinal cord)
    b. Spinal cord astrocytoma
    c. Spinal cord ependymoma
    d. Spinal meningioma
    e. Hemangioma
    f. Bone and/or spinal cord cyst
    g. Chordoma
    h. Paget disease
    i. Syringomyelia (syrinx)
2. Inflammatory disorders
    a. Spondylitis
    b. Discitis
    c. Abscesses
3. Vascular disorders
    a. Arteriovenous malformation
    b. Cavernous angioma
    c. Infarctions
4. Trauma
    a. Fractures
    b. Hematomas
    c. Syringomyelia (syrinx)
5. Degenerative spine
    a. Herniated disc
    b. Free herniated disc fragment
    c. Postsurgical fibrosis and arachnoiditis
    d. Spondylolysis and spondylolisthesis
    e. Ossified ligaments
6. Brachial Plexus
    a. Masses
    b. Malignancy

c. Trauma
7. Other (e.g., congenital anomalies, demyelinating disorders, etc.)

II. Head and Neck

A. Eye and orbital contents
1. Persistent hyperplastic primary vitreous
2. Retinopathy
3. Retinoblastoma
4. Hemangioma
5. Melanoma
6. Tumors
7. Optic neuritis
8. Severe ophthalmopathy
9. Sarcoidosis
10. Abscess
11. Orbital trauma

B. Paranasal sinuses, pharynx (nasal and oral) and larynx
1. Ostiomeatal unit obstruction
2. Cysts and polyps
3. Sinusitis
4. Malignancy
5. Mucocele
6. Papilloma

C. Temporal bone and temporal mandibular joint (TMJ)
1. Tumor and tumor-like disorders
a. Cholesteatoma
b. Cholesterol granuloma
2. Fractures
3. Dislocated TMJ
4. Meniscal pathology

D. Ear, cranial nerves, and posterior fossa
1. Tumors
a. Acoustic neuroma
b. Schwannoma
2. Conditions
a. Bell's palsy
b. Trigeminal neuralgia
c. Meniere's disease
d. Tinnitus

E. Neck
1. Masses

a. Nasopharyngeal space
b. Parapharyngeal space
c. Parotid space
d. Retropharyngeal space
e. Oropharyngeal space
f. Masticator space
g. Buccinator space
h. Carotid space
i. Laryngeal
j. Angiofibroma
k. Hemangioma
l. Hygroma
m. Thyroid
n. Glomus jugulare

2. Metastases
3. Cysts
4. Sialolithiasis
5. Trauma

III. Thorax

A. Mediastinum

1. Thyroid masses
2. Thymoma
3. Thymic hyperplasia
4. Duplication cysts
5. Lymph node enlargement
6. Lymphoma
7. Teratoma
8. Neurogenic
9. Pancoast tumors
10. Aneurysms
11. Esophageal tumors

B. Chest wall

1. Malignant processes
2. Inflammatory lesions

C. Respiratory system

D. Cardiac and aorta

1. Aneurysm
2. Dissection
3. Coarctation
4. Thrombus
5. Ischemic disease

a. Infarction
b. Viability

6. Hypertrophic cardiomyopathy
7. Pericardial disease
8. Sarcoidosis
9. Amyloidosis
10. Intracardiac masses
    a. Myxoid tumor
    b. Myosarcoma
11. Valvular heart disease
12. Hemochromatosis
13. Congenital heart conditions
14. Arrhythmogenic right ventricular cardiomyopathy (ARVC)

E. Breast

1. Dysplasia
2. Cysts
3. Benign tumors
4. Inflammatory conditions
5. Carcinomas
6. Post surgery or radiation
7. Implant rupture

IV. Abdomen

A. Liver

1. Hemangioma
2. Cysts
3. Abscesses
4. Carcinoma
    a. Hepatocellular
5. Hepatic metastases
6. Venous thrombosis
7. Hemochromatosis
8. Cirrhosis
9. Fatty liver (steatosis)
10. Transplant
11. Gall bladder anomalies

B. Pancreas

1. Pseudocyst
2. Cystic fibrosis
3. Pancreatitis
4. Transplants
5. Adenocarcinoma
6. Islet cell tumors

7. Lymphoma
8. Metastases

C. Biliary system
   1. Ductal anomalies
   2. Biliary carcinoma
   3. Biliary stone

D. Kidneys
   1. Polycystic kidney disease
   2. Renal cell carcinoma
   3. Transitional cell carcinoma
   4. Metastatic disease
   5. Wilms' tumor
   6. Nephroblastoma
   7. Infarction
   8. Infection
   9. Transplant
   10. Hydronephrosis

E. Adrenal glands
   1. Adenoma
   2. Metastasis
   3. Pheochromocytoma
   4. Neuroblastoma
   5. Hemorrhage

F. Spleen and lymphatics
   1. Infections
   2. Benign focal lesions
   3. Hodgkin's and nonHodgkin's lymphoma
   4. Vessel complications

G. Gastrointestinal (GI) tract
   1. Colon polyps
   2. Tumors
   3. Congenital anomalies
   4. Crohn's Disease
   5. Fistula
   6. Inflammatory bowel disease (IBD)

H. Vascular disorders
   1. Renal artery stenosis
   2. Vasculitis
   3. Abdominal Aortic Aneurysm (AAA)

4. Dissection
5. Thrombus
6. Congenital vascular anomalies
7. Portal hypertension

V. Pelvis

A. Female reproductive organs (e.g., uterus, ovaries, vagina and associated structures)
   1. Neoplastic disorders
      a. Leiomyoma
      b. Endometrial polyps
      c. Endometrial carcinoma
      d. Cervical carcinoma
      e. Adenocarcinoma
      f. Vaginal carcinoma
      g. Ovarian carcinoma
      h. Dermoid/teratoma
      i. Fibroma
   2. Inflammatory disorders
      a. Pelvic inflammatory disease
      b. Salpingitis and oophoritis
   3. Endometriosis
   4. Ovarian cysts
   5. Other
      a. Congenital anomalies and hereditary disorders
      b. Traumatic disorders

B. Male reproductive organs (e.g., prostate, seminal vesicles and associated structures)
   1. Neoplastic disorders
      a. Benign prostatic hyperplasia
      b. Prostatic carcinoma
   2. Inflammatory disorders
      a. Prostatitis
      b. Orchitis and epididymitis
   3. Other
      a. Congenital anomalies and hereditary disorders
      b. Traumatic disorders

C. Urogenital
   1. Neoplastic disorders
   2. Obstructions
   3. Inflammatory disorders
   4. Other
      a. Congenital anomalies and hereditary disorders
      b. Traumatic disorders

VI. Musculoskeletal

A. Skeletal system
   1. Traumatic injury
   2. Bone fracture union
   3. Bone neoplasms and tumor like lesions
      a. Cartilage lesions
      b. Fibrous lesions
      c. Osteoid osteoma
      d. Tumor-like lesions
      e. Malignant tumors
      f. Metastases
   4. Inflammatory disorders
      a. Osteomyelitis
      b. Periprosthetic infections
   5. Other
      a. Congenital abnormalities
      b. Osteonecrosis and bone infarcts
      c. Avascular necrosis
      d. Contusion/hematoma

B. Soft tissues
   1. Neoplastic disorders
      a. Lipomatous tumors
      b. Vascular lesions
      c. Synovial lesions and sarcoma
      d. Fibrous tumors
      e. Peripheral nerve sheath tumors
      f. Benign vs. malignant lesions
   2. Inflammatory disorders
      a. Infections and abscesses
      b. Myositis
      c. Bursitis
      d. Tenosynovitis
      e. Osteomyelitis
      f. Cellulitis
      g. Compartment syndrome
      h. Fluid extravasation

C. Joints
   1. Fibrocartilage disorders
      a. Articular cartilage injuries
      b. Cartilage status
      c. Degenerative joint disease
   2. Ligament and tendon tears
      a. Rotator cuff tear

b. Anterior/posterior cruciate tear
c. Patellar tendon tear
d. Collateral ligament tear
e. Achilles tendon tear
f. Labral tears

3. Inflammatory disorders
   a. Infections and abscesses
   b. Myositis
   c. Bursitis
   d. Tenosynovitis
   e. Osteomyelitis
   f. Overuse synovitis
   g. Ganglion and bursal cysts
   h. Rheumatoid and seronegative arthritides
4. Meniscal Disorders
   a. Meniscal tears
      1) Bucket handle
      2) Anterior horn
      3) Posterior horn
   b. Meniscal cysts
   c. Discoid lateral meniscus
5. Other
   a. Trauma
   b. Congenital anomalies and hereditary disorders
   c. Bone marrow abnormalities

VII. General Vascular Disorders

A. Atherosclerosis

B. Post radiation injury

C. Dissections

D. Aneurysms

E. Graft patency

F. Venous mapping

G. Vena caval tumor invasion

H. Vasculitis

MR Instrumentation and Imaging

Description
Content provides a comprehensive overview of the instrumentation associated with MR imaging. The subjects are formatted in individual outlines and can be sequenced according to level of knowledge desired. Topics include: magnetism, properties of magnetism, MR system components, MR magnets (e.g., permanent, resistive, superconducting, hybrid), radiofrequency (RF) systems, gradient systems, shim systems and system shielding.

Objectives
1. Describe magnetism and magnetic properties.
2. Define gauss (g), Tesla (T) and the electromagnetic spectrum.
3. Describe the three basic types of commercially available clinical magnets, citing advantages and disadvantages of each.
4. Describe field strength in relation to image quality (e.g., image contrast, SNR and artifacts).
5. State the main function of the radiofrequency system in MR imaging.
6. Explain the functionality of the gradient system in MR imaging.
7. Describe the importance of the shim system in MR imaging.
8. Demonstrate the use of ancillary equipment in MR imaging.

Content

I. Magnetism

A. Magnetic properties
1. Diamagnetism
   a. Principles
      1) Electron configurations
      2) Effects of externally applied magnetic fields
   b. Materials
      1) Examples of materials (e.g., wood, glass, gold, etc.)
      2) Nonmagnetic
2. Paramagnetism
   a. Principles: slightly magnetic
      1) Electron configurations
      2) Effects of externally applied magnetic fields
   b. Materials
      1) Gadolinium
      2) Others
3. Superparamagnetism
   a. Principles: slightly higher than paramagnetic
   b. Materials
      1) Hemosiderin
4. Ferromagnetism
   a. Principles: highly magnetic
   b. Materials
   c. Permanent magnets

B. Magnetic field strength (units of measure)
1. Gauss (g)
2. Tesla (T)

II. Magnets

A. Types of magnets and magnet configurations
1. Permanent
   a. Characteristics
      1) Field strength (low field)
      2) Configuration
      3) Magnetic field direction
      4) Maintenance considerations
   b. Ferromagnetic materials
      1) Iron
      2) Other materials
2. Resistive
   a. Characteristics
3. Superconductive
   a. Characteristics

b. Maintenance considerations
    1) Cryogens
    2) Quench/emergency rundown
4. Hybrid
    a. Characteristics

B. Field configuration
1. Static magnetic field (B_0)
2. Fringe field
3. Exclusion zone
4. Safety considerations

C. Field strengths and imaging systems

D. Field strengths and imaging considerations
1. SNR and field strength
2. Image contrast and field strength
    a. T1 relaxation and field strength
    b. T2 relaxation and field strength
    c. T2* and field strength
3. Artifacts and field strength
    a. Susceptibility
    b. Chemical shift
    c. Dielectric effect
    d. Other artifacts and field strength

E. Field strengths and safety considerations
1. FDA regulations
2. Forces
    a. Translational force
        1) Spatial gradient magnetic field (dBz/dz)
    b. Rotational force
3. Bioeffects
    a. Magnetohemodynamic effect
    b. Magnetohydrodynamic effect
    c. Elevated/inverted T-wave (T-swell)
4. Implanted medical devices (cardiac pacemaker, nontitanium intracranial aneurysm clips, etc.)
5. Ancillary equipment
    a. MR-safe
    b. MR-conditional
    c. MR-unsafe
6. Safety screening
    a. Patients
    b. Others

7. Other safety considerations

F. Magnetic field shielding
   1. Regulations
      a. 5 gauss
      b. Shielding
   2. Mechanisms for magnetic field shielding
      a. Passive shielding
      b. Active shielding

G. Magnetic field function
   1. Align nuclei in a magnetic field
      a. Magnetic moments
      b. Vectors
      c. Alignment

H. Magnetic field production
   1. Power supply (for resistive)
   2. No power for superconducting
      a. Power to ramp up
   3. No power for permanent magnets

III. Shim Systems

A. Types of shim systems
   1. Passive shimming
   2. Active shimming

B. Shim function
   1. Maintain homogeneity
      a. Units of measurement
   2. Performed by
      a. Technologists
      b. Service engineers
      c. Physicists

C. Shim field production
   1. Power supply

IV. Radiofrequency Systems

A. Types of RF coils and RF configurations
   1. Transmit coils
      a. Linear
      b. Quadrature
      c. Multichannel
   2. Receive-only coils

a. Linear
    1) Single coil
    2) Helmholtz pair
    3) Maxwell pair
b. Quadrature
    1) Birdcage coil
    2) Saddle coil
c. Phased array
    1) Linear array
    2) Volume array
    3) Multichannel

3. Transmit/receive
    a. Linear
    b. Quadrature
    c. Multichannel

B. RF field configuration
1. B1
2. Oscillating field
3. Safety considerations for RF fields

C. RF field production
1. Power supply
2. Amplifiers and preamplifiers
3. Receivers

D. Resonance and RF frequencies
1. Precession
    a. Spin alignment
    b. Precessional frequency
2. Larmor equation
3. Larmor frequency
    a. Related to field strength (B0)
    b. Related to chemicals
        1) Gyromagnetic ratio
        2) Spin angular momentum
        3) Magnetic moment
4. Units of measurement
    a. MHz (megahertz)
    b. Hz (hertz)
5. Energy level (radiation)
    a. Electromagnetic spectrum
    b. Nonionizing radiation vs. ionizing radiation
    c. Low energy
    d. Electromagnetic radiation

1) Magnetic component (B_1)
2) Electric component

6. RF excitation pulses

E. Signal induction
1. Faraday's law of induction
a. MR signal induction

F. RF and field strengths

G. RF fields and safety considerations
1. FDA guidelines
2. Specific Absorption Rate (SAR)
3. Bioeffects
4. Other safety considerations

H. RF field shielding
1. Regulations and recommendations
2. Mechanisms for RF field shielding
a. Faraday cage
1) Copper
2) Steel

I. RF coil function
1. Transmit
2. Receive
3. Transmit/receive

V. Gradient Systems

A. Types of gradients and gradient configurations
1. Wire configurations determine gradient slope
a. Characteristics
b. Gradient slope
c. Polarity

B. Gradient characteristics
1. Strength and amplitude
2. Rise time
3. Amplitude and rise time
a. Slew rate
b. Tesla per meter per second (T/m/sec)
4. Duty cycle
a. Percent of time that the gradient can work
b. Gradient heating

C. Gradient fields and safety considerations
    1. Bioeffects
        a. Peripheral nerve stimulation
        b. Acoustic noise
    2. FDA guidelines
        a. Faraday's Law
        b. Until a patient feels discomfort
    3. Other safety considerations
        a. No skin-to-skin contact
        b. Burns

VI. Ancillary Equipment

A. Gating
    1. ECG leads for gating
    2. Peripheral gating
    3. Respiratory bellows for respiratory triggering

B. Power injectors
    1. Syringes
    2. Tubing

C. Patient monitoring

D. Gas cylinders (oxygen tanks)
    1. Patient transportation
    2. Intravenous supplies
    3. Step stools
    4. Other MR-safe supplies

E. Remote workstations (imaging manipulation)
    1. Window width and level
    2. ROI
    3. Annotations
    4. Postprocessing
    5. Archiving and data storage media
    6. Other functions

VII. Operational Flow

A. Image and system selection

B. Site selection

C. Facility design

D. Government regulations, certificate of need

E. Ancillary equipment

F. Staffing and staff training (when required and where applicable)

VIII. Scanning System Maintenance

A. Maintenance contracts

B. Preventive maintenance

C. Repairs

D. Quality assurance (testing)

MR Pulse Sequences, Image Formation and Image Contrast

Description
Content is designed to provide the student with a comprehensive overview of MR pulse sequences, image formation and image contrast. Pulse sequences include spin echo, fast spin echo, gradient echo, inversion recovery, echo planar, parallel imaging and spectroscopy. In addition, tissue characteristics, contrast agents and postprocessing techniques are covered.

Objectives
1. List intrinsic contrast characteristics and describe their impact on image quality.
2. List extrinsic contrast characteristics and describe their impact on image quality.
3. Construct pulse sequence diagrams based on specific timing of RF pulses and gradient applications.
4. Determine the appropriate pulse sequence for specific clinical applications based on the desired image contrast.
5. Explain the process of MR image formation.
6. Identify the various postprocessing techniques used in MR.
7. Discuss the use of contrast media in MR including different types, dosing, mechanism of action, effects in images and safety characteristics.

Content

I. Intrinsic Contrast Characteristics (Tissue Characteristics)

A. Longitudinal regrowth (T1 recovery)

B. Transverse decay (T2 Decay)

C. Spin density
   1. Actual proton density (total number of mobile water protons)
   2. Relative proton density (spin excess during thermal equilibrium)

D. Flow and motion
   1. Orders of motion
   2. Flow characteristics
      a. Laminar flow
      b. Vortex flow
      c. Turbulent flow
      d. Stagnant flow

E. Diffusion
   1. Restricted diffusion
   2. Unrestricted diffusion

F. Magnetization transfer

II. Extrinsic Contrast Characteristics (User-selection Parameters for Image Contrast)

A. TR – repetition time
   1. Time constant
      a. SE, FSE sequences
      b. GRE, EPI sequence
      c. IR sequences
   2. Effects on image quality
      a. T1 information on MR images
      b. Scan time
      c. SNR
      d. Number of slice locations

B. Echo Time (TE)
   1. Time constant (time to echo)
      a. For spin echo (SE)
      b. For gradient echo (GRE)
   2. Effects on image quality
      a. T2 information on MR images
      b. SNR
      c. Number of slice locations
      d. Susceptibility artifact

C. Inversion time (TI)
    a. IR
    b. STIR
        1) Fat suppression
    c. Fluid-attenuated inversion recovery (FLAIR)
    d. SPIR
2. Effects on image quality

D. Flip angle – degree of angulation of the net magnetization
1. RF pulse
    a. Duration of RF pulse
    b. Power deposition
2. Effects on image quality
    a. SNR (Ernst angle)
    b. Image contrast (T1 information)

E. Imaging options for MR image contrast
1. PC-MRA
    a. Velocity encoding (VENC) value – certain flow velocities bright
    b. Flow direction
2. Diffusion imaging
    a. Shots
    b. "b" value
3. Flow imaging
    a. Saturation pulses
        1) Spatial presaturation
        2) Spectral saturation
    b. Gradient moment nulling

III. Pulse Sequences

A. Pulse sequencing diagrams
1. RF pulse timing (image contrast manipulation)
    a. TR
    b. TE
    c. TI
2. Gradient pulse timing
    a. Logical gradients
        1) Z – Slice selection
        2) Y – Phase encoding
        3) X – Frequency encoding
    b. Physical gradients
        1) Z, Y, X

B. Pulse sequence configurations

1. Partial saturation and saturation recovery sequence
2. Spin echo
3. Inversion recovery
    a. Types of IR sequences
        1) Spin echo IR
        2) Fast spin echo (FSE) – IR
        3) Double IR (driven equilibrium)
        4) Gradient echo – IR
    b. IR sequence image contrast
        1) STIR
        2) FLAIR
        3) SPAIR
4. Rapid acquisition recalled echo (RARE)
    a. Types
        1) FSE
        2) Turbo-spin echo
5. Gradient echo
    a. Steady-state coherence (SSC)
    b. Spoiled gradient recall (SPGR)
    c. Rapid gradient echo – echo planar sequences (EPI)
        1) Susceptibility sequences (T2*)
        2) Diffusion
        3) Perfusion
            a) Contrast-enhanced (dynamic susceptibility weighted sequences)
            b) Spin-tagged suppression
        4) Blood oxygenation-level dependent (BOLD)
6. Spectroscopy sequences
    a. Single voxel
    b. Multivoxel

IV. Image Contrast Characteristics

A. T1-weighted image
    1. Spin echo
    2. Gradient echo
    3. Gradient echo (spoiled sequences for flow)
        a. Time of flight-magnetic resonance angiography (TOF-MRA)
        b. Dynamic contrast-enhanced MRA

B. T2-weighted image
    1. Conventional spin echo
    2. Gradient echo
    3. Gradient echo (steady state sequences for flow)
        a. Phase contrast magnetic resonance angiography (PC MRA) – flow velocity and flow direction
        b. Cine PC – dynamic cardiac and vascular imaging

4. Gradient echo (EPI sequences)
    a. Diffusion – for stroke
    b. Perfusion – for stroke and for tumors
    c. BOLD – for brain function

C. PD image
    1. Spin echo
    2. Gradient echo

V. MR Contrast Media

A. Types

B. Mechanism of action

C. Effects on images
    1. T1 & T2 shortening

VI. MR Image Formation

A. Gradients
    1. Z
    2. Y
    3. X

B. Spatial localization
    1. Slice selection
        a. Imaging planes
        b. Slice thickness
    2. Phase encoding
        a. FOV (gradient amplitude)
        b. Matrix (phase encoding steps)
        c. Scan time
        d. Resolution
    3. Frequency encoding
        a. FOV
        b. Matrix
        c. Readout gradient
            1) Nyquist theorem

C. Gradient refocusing

VII. Postprocessing

A. Measurements

B. Reconstruction and reformatting
    1. Multiplanar reconstruction (MPR)

2. 3-D reformats
3. Volume reconstruction (VR)

C. MRA reformats and reconstructions
1. Maximum-intensity pixel (MIP)
2. Shaded surface display (SSD)

MR Safety

Description

The content in this section provides information on the principles of MR safety and concepts that relate to the safety of MR equipment. Because the MR environment poses unique risks to patients and personnel, screening questionnaires (both verbal and written) must be completed by all individuals entering the MR suite. Education of patients and personnel is essential to preventing MR incidents. The ACR has developed guidelines for safe MR practices, http://www.acr.org/~/media/ACR/Documents/PDF/QualitySafety/MR%20Safety/InterrelatingSentinelEventAlert38.pdf. This section also discusses handling patient and magnet-related emergencies within the MR environment, the reporting of incidents to an MR Safety Officer, and safe administration of contrast media.

Objectives

1. List MR safety organizations and identify the role of each organization in MR safety.
2. Define the three different magnetic fields associated with MR imaging and analyze the safety concerns associated with each one.
3. Identify and discuss the various components of MR safety screening for patients and personnel.
4. Describe the process of reporting MR safety incidents.
5. Identify and discuss the various components of MR safety screening for equipment.
6. Recognize emergencies that can occur in MR imaging, and explain appropriate actions required of the technologist.

Content

I. Introduction

A. Magnetic fields in MR
1. Main static field – aligns spins
2. Radio frequency field – flips spins
3. Gradient field is used for spatial encoding of the image

B. MR safety concerns
1. Force and torque on magnetic materials from the static magnetic field
2. Heating caused by the RF magnetic field used to flip spins
3. Nerve stimulation caused by gradient magnetic fields used for spatial encoding
4. Implanted medical devices affected by the static magnetic field, RF magnetic field and gradient magnetic fields

C. MR safety organizations
1. International Electrotechnical Commission (IEC)
2. U.S. Food and Drug Administration (FDA)
3. National Electrical Manufacturers Association (NEMA)
4. American Society for Testing and Materials (ASTM)
5. American College of Radiology (ACR)
6. International Society for Magnetic Resonance in Medicine (ISMRM) Safety Group
7. Institute for Magnetic Resonance Safety Education and Research (IMRSER)
8. The Joint Commission
9. Intersocietal Accreditation Commission IAC

II. Static Magnetic Field

A. Potential dangers
1. Translational
   a. Projectiles
2. Rotational
3. Spatial gradient
   a. Force vs. distance from magnet
   b. Long bore vs. short bore magnets
   c. field strength and design
4. Magnetic shielding
   a. Active
   b. Passive

B. Designing MR guidelines for safety
1. Written safety policies and procedures
2. Controlling access to the MR suite to trained MR personnel/non MR personnel/levels of training (annual safety training)
3. ACR guidelines regarding MR suite safety zones I through IV
4. Lock MR suite door when trained MR personnel are absent

5. Provide safety education to all staff who could potentially work near the magnet, including the local fire department
6. Warning signs citing examples of potentially dangerous projectiles

C. Field strength relevance to safety

D. Status of high-field MR safety studies

III. Radio Frequency (RF) Magnetic Field

A. Theory of RF heating in MR
1. Potential bioeffects

B. Regions with high resistance can cause focal heating

C. RF heating in clinical MR
1. Using SAR to estimate temperature increase
2. SAR = absorbed power/mass (e.g., watts/kg)
3. Concerns for core (whole body) and localized heating

D. Responsibilities of technologist concerning patient safety in avoiding RF heating
1. Patient positioning
2. Positioning of monitoring equipment
3. Screen patients for electronically conducting jewelry, tattoos, cosmetics, medication patches, etc.
4. Monitor patients who are unable to dissipate heat because of physiological conditions
5. Monitor patients who are unable to respond because of sedation or mental status
6. Limit pregnant individuals' presence in the RF field

E. How a scanner estimates SAR
1. Scanner calibration routine
2. Determines energy needed to get a 90° flip and 180° flip
3. Whole body SAR calculation

F. IEC/FDA limits for whole-body heating
1. Normal mode limit
2. First level controlled mode

IV. Gradient Magnetic Fields

A. Gradient coils and current waveforms
1. Linear magnetic fields for spatial encoding
2. Echo planar imaging pulse train

B. Effects on patients
1. Nerve stimulation

a. Orientation of field gradient with respect to the body
b. Location in the body
c. Duration of the gradient pulse
d. FDA limits on dB/dT

C. Hearing damage caused by dangerously loud sound pressure levels (OSHA)

D. Hyperbolic relationship between pulse duration and stimulation threshold
1. Nerve stimulation
2. Variations in patient response to nerve stimulation

V. Patient and Personnel Safety Screening in MR (Technologist Responsibilities)

A. Obtain screening documentation
1. Reviewed by two trained personnel
a. Written
b. Verbal
2. MR safety screening questionnaire completed by the patient or guardian or qualified personnel

B. Obtain any necessary special consent documentation for non-FDA approved MR scanning following ACR guidelines.
1. Pregnancy for contrast injection
2. NSF risk
3. Cardiac stress

C. Patient and personnel safety — contraindications for entering the MR suite
1. Implanted electronic devices
2. Implanted metallic objects at risk of deflection
3. Indications for plain film radiography for safety screening include intraocular foreign bodies, shrapnel and bullets in the body
a. The physician in charge should be consulted in each instance and approve of the patient entering the MR environment

D. Reporting of MR safety incidents

E. Claustrophobia/anxiety disorder

F. Monitoring patients
1. Two forms of patient monitoring

G. Laser and alignment light (eye safety)

VI. Equipment Safety Screening in MR Environment (Technologist Responsibilities)

A. Screen all equipment before allowing entrance to the MR suite

B. Properly label MR-safe equipment

C. Keep all MR-conditional and MR-unsafe equipment clear of the MR suite and anteroom

D. Recognize table stop and emergency shut-down switches that control electricity to the scanner, and quench or magnet run-down switch

E. Monitor, record and report cryogen levels

F. Monitor the cryogen exhaust vent line for blockages

G. Monitor the cryogen fill line for ice blockages

H. Maintain awareness and marking of gauss lines in MR area

I. Display warning signs prominently

J. Display signage that prohibits items and implants
   1. Implants susceptible to electromagnetic fields
   2. Open flame
   3. Electronic media
   4. Ferrous objects
   5. Credit cards

VII. Monitoring of Ancillary Equipment

A. Perform quality measurement of the RF coils

B. Perform quality measurement of software

C. Perform and report cryogen levels

D. Perform checks on pulse receptor, ECG cables and disposable electrodes

E. Measures to take if phantom fluid spills
   1. First aid in case of contact with phantom fluid
   2. Mandatory reporting to local fire department of phantom fluid contents in case of fire
   3. Disposal as special waste
   4. Gauss lines and their relationship to electronic equipment

VIII. Emergencies in the MR Environment Requiring Technologist Action

A. Emergency code (e.g., code blue)
   1. Emergency plan of action
   2. Follow-up documentation

B. Fire emergency
   1. Evacuate patients and others
   2. Suspend all electricity to the MR scanner
   3. Follow institution's fire emergency procedure
   4. Employ MR-safe fire equipment
   5. Local fire department should be trained by MR personnel
   6. Follow procedures when the fire cannot be contained

C. Metallic items pinned to the magnet
   1. If a person is in immediate danger
   2. If equipment only is pinned to the magnet

D. Quench
   1. Causes
   2. Procedure for evacuation
   3. Remove patient and staff from MR suite
   4. Establish a procedure for gaining entry to the MR suite in case positive pressure is pinning the door to the MR suite (if the door opens inward)
   5. Maintain the room
   6. Notify in-house maintenance personnel
   7. Notify vendor service of quench
   8. Risks of cryogen boil-off during quench

IX. Safety in MR Contrast Administration

A. Patient history

B. Preparation

C. Contrast administration
   1. Administration by hand
   2. Administration by power injector

D. Adverse reactions
   1. Local events
   2. Treatment and follow-up guidelines
   3. Systemic events

E. Gadolinium-based MR contrast and NSF
   1. ACR Manual on Contrast Media – Version 9, 2013 Nephrogenic Systemic Fibrosis http://www.acr.org/~/media/ACR/Documents/PDF/QualitySafety/Resources/Contrast%20Manual/2013_Contrast_Media.pdf/#2013_Contrast_Media_Manual.indd:.27752:10188
   2. ACR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Abdomen (Excluding the Liver) http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/MRI_Abdomen.pdf

Pharmacology and Drug Administration

Description
Content provides basic concepts of pharmacology. This section covers the theory and practice of basic techniques of venipuncture and administration of diagnostic contrast agents and/or intravenous medications. The appropriate delivery of patient care during these procedures is emphasized.

Considerations
Prior to introducing this educational content, students should have successfully completed patient care objectives (including CPR/BLS certification), as well as objectives related to anatomy and physiology of the circulatory and excretory systems.

Although regulations regarding administration of contrast media and intravenous medications vary in different states and institutions, the skill should be included in the didactic and clinical curriculum with demonstrated competencies of all appropriate disciplines regardless of the state or institution where the curriculum is taught.

In states or institutions where students are permitted to perform intravenous injections, the program has specific ethical and legal responsibilities to the patient and the student. The student shall be assured that:

- Legal statutes allow student MR technologists to perform this procedure.
- Professional liability coverage is adequate.
- Adequate supervision is provided.
- Appropriate, structured, laboratory objectives are identified.
- Competency is demonstrated and evaluated before the student performs this task under indirect supervision.

Objectives
1. Distinguish between nonprescription drugs, prescription drugs and controlled substances.
2. Discuss different types of drug reactions that can occur.
3. Explain the process of reporting adverse reactions to the FDA.
4. Identify the six rights of drug administration.
5. Diagram the various routes of drug administration.
6. Describe general drug actions, uses, adverse reactions, contraindications, precautions and interactions.
7. Discuss specific considerations of MR contrast administration to include:
   - Importance of patient history
   - Proper preparation and administration of contrast
   - Nephrogenic systemic fibrosis (NSF)
8. Analyze the current practice standards regarding contrast administration.

Content

I. Drug Nomenclature

A. Chemical name

B. Generic name

C. Trade name

II. Methods of Drug Classification

A. Chemical group

B. Mechanism/site of action

C. Primary effect

III. General Pharmacologic Principles

A. Pharmacokinetics

B. Pharmacodynamics

IV. Six Rights of Drug Safety

A. The right medication

B. The right dose

C. The right patient

D. The right time

E. The right location

F. Right documentation

V. Drug Categories of Relevance to MRI (Adverse Effects, Uses and Impacts on Medical Imaging)

A. Analgesics

B. Anticoagulant and coagulant drugs

C. Antihypertensive drugs

D. Anesthetic agents

E. Antiallergic and antihistamine drugs

F. Antianxiety drugs

G. Antiarrhythmic drugs

H. Antibacterial drugs

I. Antidepressants

J. Antiemetic drugs

K. Anti-inflammatory drugs

L. Antiseptic and disinfectant agents

M. Beta-adrenergic agonist

N. Bronchodilators

O. Cathartic and antidiarrheal drugs

P. Diagnostic contrast agents

Q. Diuretics

R. Sedative and hypotonic drugs

S. Vasodilators and vasoconstrictors

VI. Classification of Contrast Agents

A. Pharmacologic profile of contrast agents
   1. Chemical composition
   2. Absorption characteristics
   3. Distribution characteristics
   4. Metabolic characteristics
   5. Elimination characteristics
   6. Indications, actions and effects
   7. Interactions and contraindications
   8. Patient reactions

B. Dosage

C. Preparation

VII. Routes of Drug Administration

A. Systemic

1. Oral/sublingual
2. Rectal
3. Tube/catheter
4. Inhalation
5. Transdermal

B. Parenteral
1. Intravenous
2. Intra-arterial
3. Intrathecal
4. Subcutaneous
5. Intramuscular

VIII. Intravenous Drug Therapy

A. Purpose

B. Advantages
1. Delivery route
2. Onset action
3. Duration

C. Methods
1. Continuous infusion
2. Intermittent infusion
3. Direct injection
   a. Hand
   b. Mechanical/power injection
   c. Indirect injection

D. Sites of administration
1. Peripheral
2. Central

E. Complications
1. Infiltration
2. Extravasation
3. Phlebitis
4. Air embolism
5. Drug incompatibility
6. Low IV fluid level

F. Initiation of intravenous therapy
1. Intravenous infusion/venipuncture equipment
2. Patient identification, assessment and instructions
3. Informed consent

4. Dosage, dose calculations and dose-response
    a. Adults
    b. Pediatrics
5. Patient preparation
6. Application of standard precautions
7. Procedure for intravenous infusion/direct puncture
    a. Existing line
    b. Direct puncture
8. Site observation
9. Emergency medical treatment procedure
    a. Appropriate codes
    b. Emergency cart (crash cart)
    c. Emergency medications
    d. Accessory equipment
        1) Oxygen
        2) Suction
    e. Emergency medical treatment follow-up tasks
10. Discontinuation of intravenous therapy
    a. Equipment/supplies
    b. Patient preparation
    c. Application of standard precautions
    d. Withdrawal procedure
    e. Site observation
    f. Patient observation
    g. Postprocedural tasks
11. Documentation of administration
12. Documentation of a complications/reactions

IX. MR Contrast Administration

A. Patient history
    1. Sickle cell (in crisis)
    2. Severe asthma
    3. Drug allergy
    4. Adverse reaction to contrast media
    5. Kidney function

B. Patient education
    1. Technologist's responsibility
    2. Standard procedure

C. Patient preparation for examination
    1. Diet
    2. Bowel preparation
        a. Laxatives
        b. Enemas

D. Preparation of contrast media
    1. Proper dose
    2. Check for expiration date on contrast vial before administering
    3. Keep the vial until patient has been released
    4. Use aseptic technique in preparing lines, tubing and needles
    5. Obtain venous access

E. Contrast administration
    1. Administration by hand
        a. Care during the procedure
            1) Check for integrity of venous access
            2) Visualize access site during administration, watch for extravasation
        b. Follow-up care
    2. Administration by power injector
        a. Care during the procedure
            1) Check for integrity of venous access site
            2) Interpret the relationship between the gauge of the angiocatheter vs. the rate of contrast media flow and follow the guidelines of angiocatheter manufacturer
            3) Follow guidelines for contrast administration through alternative sites such as venous access ports, central lines, etc.
        b. Follow-up care

F. Adverse reactions
    1. Local events
        a. Stop contrast administration
    2. Treatment/follow-up guidelines
        a. Compress (as outlined by ACR)
        b. Written instructions for patient to follow after discharge
        c. Notify the physician in charge that the patient needs to be examined
        d. Document/report the extravasation
    3. Systemic events
        a. Stop contrast administration immediately if dose is not complete
        b. Remove patient from MR suite if treatment is required
        c. Assess patient for breathing difficulty
        d. Notify the physician in charge to examine the patient before he or she is released
        e. Treatment/follow-up guidelines:
            1) Appropriate health care provider to administer medications if necessary
            2) Give patient written instructions to follow after discharge
            3) Document/report the contrast reaction
        f. Emergency drugs to have available in the MR suite
        g. List of emergency contact phone numbers
        h. Location and use of an emergency code button or switch

G. Gadolinium-based MR contrast and NSF
    1. ACR guidelines regarding renal function and dialysis.
    2. FDA black box warning

H. Monitoring and care during invasive procedures
    1. Preparation for MR-compatible cardiac monitoring
    2. Electrocardiogram (ECG) rhythms
        a. Normal
        b. Abnormal

X. Current Practice Status

A. Professional standards
    1. Scope of Practice
    2. Practice Standards
    3. Professional liability and negligence

B. State statutes

C. Employer prerogative

Physical Principles of Magnetic Resonance Imaging

Description
Content provides the student with a comprehensive overview of MR imaging principles. The subjects are formatted in individual outlines and can be sequenced according to the level of knowledge desired. Topics include the history of MR, nuclear MR (NMR) signal production, tissue characteristics, pulse sequencing, imaging parameters/options and image formation.

Objectives
1. Discuss the roles of various scientists associated with the discovery and use of MR imaging.
2. Differentiate between MR active and nonactive nuclei.
3. Describe the production and detection of an MR signal.
4. Analyze the process of MR signal induction, sampling and conversion.
5. List and explain the functions of magnetic gradients in MR imaging.
6. Explain the concepts of resonance, excitation and relaxation.
7. Compare the image characteristics of spin echo and gradient echo pulse sequences.
8. Explain the role of parameter selection in MR weighting.

Content

I. History of MR

A. Scientific discovery of the principles of nuclear magnetic resonance (NMR)
   1. Felix Bloch (Bloch equations)
   2. Edward Purcell

B. Scientists associated with MR
   1. Nikola Tesla
   2. Jean Baptiste Fourier (Fourier transformation)
   3. Richard R. Ernst (Ernst angle)
   4. Joseph Larmor (Larmor equation)
   5. Michael Faraday (Faraday's Law of Induction)
   6. Charles Dumoulin (MRA)

C. MRI pioneers
   1. Raymond Damadian
   2. Paul Lauterbur
   3. Sir Peter Mansfield

II. Matter

A. Periodic table of elements
   1. MR active nuclei
      a. Hydrogen (1H)
      b. Phosphorous (31P)
      c. Other MR active chemicals (uneven mass number)
   2. Chemicals that are not MR active (even mass number)

B. Atom
   1. Nucleus
      a. Proton
      b. Neutron
   2. Electron
   3. Photon

III. Nuclear Magnetism

A. Definitions
   1. Approach/methodology
      a. Quantum
      b. Classical
   2. Frames of reference
      a. Laboratory frame of reference
      b. Rotating frame of reference

B. Nuclei in a magnetic field
   1. Nuclear alignment

a. Magnetic moment
b. Spin and charge
c. Vectors

2. Energy states
   a. Low energy state
   b. High energy state

IV. MR Signal Production

A. Thermal equilibrium
   1. Magnetization
      a. Longitudinal magnetization
      b. Transverse magnetization
      c. Net magnetization

B. Net magnetization vector precession
   1. Precessional frequency
   2. Larmor frequency (ωo)
      a. Hertz (Hz)
      b. Megahertz (MHz)
   3. Larmor equation
      a. Field strength (B_0)
      b. Gyromagnetic ratio

C. Resonance
   1. Excitation
      a. RF pulse (B1)
      b. Partial flip angle
         1) Heating power square of the flip angle
      c. NMR Signals
         1) Free induction decay (FID)
         2) Echoes
   2. Relaxation characteristics that relate to MR image contrast
      a. T1 relaxation
         1) Longitudinal recovery
         2) Spin-lattice
         3) T1 recovery
      b. T2 relaxation
         1) Transverse decay
         2) Spin-spin
         3) T2 decay
      c. Relaxation and contrast media in MR
         1) Enhanced T1 relaxation with contrast agents
            a) Gadolinium
         2) Enhanced T2* relaxation with contrast agents
            a) Gadolinium

b) Iron oxide

3. Tissue characteristics that relate to MR image contrast
   a. Proton density

V. MR Signal Induction/Sampling/Conversion

A. MR signal induction
   1. FID
   2. Echo/readout
   3. Nyquist theorem

B. MR signal conversion
   1. Fourier transformation
      a. Frequency domain (spectrum)
      b. Time domain (FID)
   2. Array processor

C. Spectroscopy
   1. Spectrum (1H)
      a. Chemical shift
      b. Field strength
   2. Spectrum of other MR active chemicals

VI. MR Image Contrast Characteristics

A. Weighting in MR imaging, parameters and image contrast characteristics
   1. T1 weighted images
   2. T2 weighted images
   3. T2* weighted images (GRE sequences)
   4. Relative Proton density (PD)
      a. Flow imaging
      b. Diffusion imaging
      c. Magnetization transfer
   5. Introduction to pulse sequences and image contrast
      a. Partial saturation/saturation recovery
      b. Spin echo
      c. T2* GRE
         1) Steady state (T2)/coherent
            a) PC MRA
            b) Steady-state dynamic cine
         2) Spoiled (T1)/incoherent
            a) Dynamic imaging
            b) In/out of phase imaging
            c) MRA
         3) Echo planar imaging
            a) Rapid imaging
            b) Perfusion

c) Diffusion
d) Functional (BOLD) imaging

d. Inversion recovery
1) Standard IR
2) FSE – IR

B. Image quality comparison of spin echo vs. gradient echo
1. T1 weighted images
a. T1 spin echo vs. T1 gradient echo
1) Comparison of SNR and susceptibility to artifacts
2. T2 weighted images
a. T2 spin echo vs. T2 gradient echo
1) Comparison of SNR and susceptibility to artifacts

VII. Introduction to MR Image Formation

A. Magnetic field gradients
1. Physical gradients, Z, Y, X
2. Logical gradients, Z, Y, X

B. Gradient functions
1. Image formation
a. Slice selection
b. Phase encoding
c. Frequency encoding
2. Gradient signal refocusing
a. Gradient echo
b. Gradient moment nulling
c. "b" value (diffusion sequence)
d. "Velocity encoding technique" (VENC) settings

VIII. Imaging Planes

A. Sagittal

B. Axial

C. Coronal

D. Oblique

IX. K-Space and Image Formation

A. Normal filling

B. Centric filling

C. Zero fill

D. Rectangular FOV

E. Parallel imaging

Sectional Anatomy

Description
Content is intended to develop a strong understanding of multiplanar images (axial, sagittal, coronal and orthogonal) of human anatomy created by modalities such as CT and MR that will aid in performing critical assessment of volumetric image renderings from these data sets.

Objectives
1. For each body section listed below, locate anatomical structures on CT and MR images in the transverse, coronal, sagittal and orthogonal imaging planes.
   a. Head
   b. Neck
   c. Thorax
   d. Abdomen
   e. Pelvis
   f. Upper extremity
   g. Lower extremity
2. Translate anatomical structures from their 2-D planar image appearance into their appearance within multiplanar, curved planar and 3-D volumetric reformations.
3. Manipulate 3-D volumetric data sets to enhance the appearance of select anatomical structures.

Content

I. Head and Brain

A. Cranial bones
1. Frontal
2. Ethmoid
   a. Nasal conchae (turbinates)
   b. Nasal septum
3. Parietal
4. Sphenoid
   a. Lesser wings
      1) Tuberculum sellae
      2) Sella turcica
      3) Dorsum sellae
      4) Anterior and posterior clinoid process
      5) Optic canals
   b. Greater wings
      1) Foramen rotundum
      2) Foramen ovale
         a) Foramen spinosum
5. Occipital
   a. Foramen magnum
   b. Internal and external occipital protuberance
   c. Jugular foramen
6. Temporal
   a. Zygomatic process
   b. External auditory meatus (EAM)
   c. Internal auditory canal
   d. Bones and structures of inner ear
   e. Mastoid process
   f. Petrous portion or ridge

B. Facial bones
1. Mandible
2. Maxillae
3. Zygomas
4. Nasal bones

C. Sinuses
1. Frontal
2. Maxillary
3. Ethmoidal
4. Sphenoidal

D. Facial muscles
1. Masseter

2. Frontalis
3. Temporalis

E. Surface anatomy of the brain
   1. Fissures (sulci)
      a. Longitudinal cerebral
      b. Lateral (Sylvian)
      c. Central (of Rolando)
   2. Convolutions (gyri)
      a. Precentral
      b. Postcentral

F. Lobes of the brain and midline cerebral hemisphere structures
   1. Frontal
   2. Parietal
   3. Occipital
   4. Temporal
   5. Insula (island of Reil)
   6. Cerebellum
   7. Corpus callosum (genu, rostrum, body and splenium)
   8. Septum pellucidum
   9. Sella turcica
   10. Pineal gland
   11. Falx cerebri
   12. Septum pellucidum

G. Cranial nerves
   1. Olfactory
   2. Optic
   3. Oculomotor
   4. Trochlear
   5. Trigeminal nerve
      a. Mandibular nerve
      b. Inferior alveolar nerve
   6. Abducens
   7. Facial
   8. Vestibulocochlear
   9. Glossopharyngeal
   10. Vagus
   11. Accessory
   12. Hypoglossal

H. Brainstem and adjoining structures
   1. Diencephalon
      a. Thalamus

b. Hypothalamus
c. Optic chiasm
d. Optic tracts
e. Infundibulum (pituitary stalk)
f. Pituitary gland
g. Mammillary bodies
h. Pineal gland

2. Midbrain
3. Pons
4. Medulla oblongata
    a. Spinal cord

I. Arteries (circle of Willis)
1. Vertebral
2. Basilar
3. Internal carotid
4. Anterior and posterior communicating
5. Anterior and posterior cerebral
6. Posterior inferior cerebellar artery
7. Middle cerebral

J. Venous structures
1. Venous sinuses
    a. Superior sagittal sinus
    b. Vein of Galen
    c. Straight sinus
    d. Confluence of sinuses (torcular herophili)
    e. Transverse sinus
    f. Sigmoid sinus
2. Internal jugular

K. Ventricular system
1. Lateral ventricles (anterior, body, posterior, inferior or temporal and trigone or atrium)
2. Interventricular foramen (of Monro)
3. Third ventricle
4. Cerebral aqueduct (of Sylvius)
5. Fourth ventricle
6. Foramen of Luschka
7. Foramen of Magendie
8. Choroid plexus
9. Cerebrospinal fluid

L. Meninges
1. Dura mater

a. Extensions of the dura mater
    1) Falx cerebri
    2) Falx cerebelli
    3) Tentorium cerebelli
    4) Diaphragma sellae
2. Arachnoid
3. Pia mater

M. Basal ganglia
1. Caudate nucleus
2. Putamen
3. Globus pallidus
4. Claustrum
5. Internal capsule
6. External capsule
7. Extreme capsule

N. Orbit
1. Globe
2. Lens
3. Optic nerve
4. Lacrimal gland
5. Lateral rectus muscle
6. Medial rectus muscle
7. Superior rectus muscle
8. Inferior rectus muscle
9. Superior oblique muscle
10. Inferior oblique muscle
11. Orbital fat
12. Ophthalmic artery
13. Retinal vein

O. Anatomical structures of calvarium and brain
1. Diploe
2. Subcutaneous soft tissue
3. Superior sagittal sinus (anterior and posterior)
4. Central sulcus
5. Interhemispheric fissure
6. Falx cerebri
7. Centrum semiovale
8. Corpus callosum (genu, rostrum, body and splenium)
9. Septum pellucidum
10. Fornix
11. Sylvian fissure
12. Insula

13. Lentiform nucleus (putamen and globus pallidus)
14. Caudate nucleus (head)
15. Internal capsule (anterior, body and posterior sections)
16. External capsule
17. Claustrum
18. Hippocampus
19. Cerebral peduncles
20. Mammillary bodies
21. Tentorium cerebelli
22. Petrous portion or ridge
23. Cerebellar tonsil
24. Internal auditory canal (IAC)
25. Nasal septum
26. External auditory canal (EAC)
27. Clivus
28. Mastoid air cells

P. Lines of angulation (imaging baselines)
1. Supraorbitomeatal line
2. Orbitomeatal line
3. Infraorbitomeatal line

Q. Anatomical landmarks
1. Glabella
2. Nasion
3. Acanthion
4. Mental point
5. External auditory meatus (EAM)

II. Neck

A. Bones
1. Cervical vertebrae
   a. Parts of vertebrae
   b. Arteries in cervical spine

B. Organs
1. Pharynx
2. Larynx
3. Esophagus
4. Trachea
5. Salivary glands
6. Thyroid gland
7. Parathyroid glands
8. Lymph nodes

C. Vasculature and neurovasculature
    1. Carotid arteries
    2. Vertebral arteries
    3. Jugular veins
    4. Carotid sheath

D. Musculature
    1. Anterior triangle
    2. Posterior triangle
    3. Sternocleidomastoid
    4. Sternohyoid
    5. Scalene
    6. Trapezius

III. Chest and Mediastinum

A. Situs
    1. Solitus
    2. Inversus
    3. Ambiguus
        a. Asplenia (right sidedness)
        b. Polysplenia (left sidedness)

B. Bony thorax
    1. Thoracic vertebrae
        a. Arterial supply to spine
        b. Parts of vertebrae
    2. Sternum
    3. Ribs
    4. Costal cartilages
    5. Scapulae
    6. Clavicles

C. Pulmonary
    1. Apices (lung)
    2. Diaphragm
    3. Angles
    4. Hilum
    5. Lobes (lungs)
    6. Trachea
    7. Carina
    8. Primary (mainstem) bronchi
    9. Secondary bronchi

D. Mediastinum
    1. Thymus gland

2. Heart
    a. Coronary vessels
        1) Arteries
        2) Veins
            a) Coronary sinus
        3) Variant coronary artery anatomy
    b. Chambers
        1) Atria
            a) Atrial appendages
            b) Left lateral ridge left atrium
        2) Ventricles
        3) Interatrial and ventricular septum
        4) Papillary muscles
    c. Valves
3. Cardiovascular blood flow – pulmonary vessels
    a. Pulmonary arteries
    b. Pulmonary veins
        1) Anatomical variations
        2) Drainage patterns lung lobes
4. Aorta and branches
    a. Ascending aorta
    b. Aortic arch
    c. Branches of the aortic arch
        1) Anatomical variations
    d. Subclavian arteries
        1) Internal thoracic/mammary arteries
    e. Descending (thoracic) aorta
        1) Bronchial arteries
        2) Intercostal arteries
            a) Artery of Adamkiewicz
5. Veins
    a. Superior vena cava (SVC)
    b. Inferior vena cava (IVC)
    c. Azygos vein
    d. Hemiazygos vein
    e. Innominate veins
    f. Subclavian veins
6. Esophagus

E. Breasts

F. Lymphatic structures
    1. Thoracic duct
    2. Lymph nodes
    3. Lymph node stations

G. Musculature
    1. Pectoralis major/minor
    2. Serratus anterior
    3. Latissimus dorsi
    4. Rhomboideus

IV. Abdomen

A. Diaphragm and openings
    1. Aortic hiatus
    2. Caval hiatus
    3. Esophageal hiatus

B. Surface landmarks and regions
    1. Quadrants
        a. Upper left
        b. Upper right
        c. Lower left
        d. Lower right

C. Addison's planes (regions)
    1. Left hypochondriac
    2. Epigastric
    3. Right hypochondriac
    4. Left lumbar
    5. Umbilical
    6. Right lumbar
    7. Left iliac
    8. Hypogastric
    9. Right iliac

D. Abdominal organs and structures
    1. Bony structures
        a. Lumbar vertebrae
    2. Abdominal cavity
        a. Peritoneum
        b. Peritoneal space
        c. Retroperitoneum
        d. Retroperitoneal space
    3. Liver
        a. Hepatic arteries
        b. Portal venous system
        c. Liver segments
            1) Liver lobes
            2) Couinaud classification

d. Variant vascular anatomy of living related liver donors
4. Gallbladder and biliary system
5. Pancreas
   a. Pancreatic ducts
   b. Parts of pancreas
6. Spleen
7. Adrenal glands
8. Urinary system and tract
   a. Kidneys
      1) Cortex
      2) Medulla
      3) Renal pelvis
   b. Ureters
   c. Variant vascular anatomy of living related kidney donors
9. Stomach
10. Small intestine
11. Colon
12. Musculature
    a. Rectus abdominis
    b. Internal/external obliques
    c. Transversus abdominis
    d. Psoas
    e. Gluteus
13. Lymph nodes

E. Branches of the abdominal aorta
   1. Anterior visceral branches
      a. Celiac axis
         1) Left gastric
         2) Splenic
         3) Hepatic
            a) Gastroduodenal artery
      b. Superior mesenteric
         1) Jejunal and ileal
         2) Inferior pancreaticoduodenal
         3) Middle colic
         4) Right colic
         5) Ileocolic
         6) Replaced right hepatic
      c. Inferior mesenteric
         1) Left colic
         2) Sigmoid
         3) Superior rectal
   2. Lateral visceral branches
         1) Suprarenal

2) Renal
a) Accessory renal
3) Testicular or ovarian
3. Parietal branches
a. Inferior phrenics
b. Lumbars
c. Middle sacral
4. Terminal branches
a. Common iliacs

F. Tributaries of the inferior vena cava
1. Anterior visceral
a. Hepatic veins
2. Lateral visceral
a. Right suprarenal
b. Renal veins
1) Left gonadal vein
2) Left suprarenal vein
c. Right testicular or ovarian
3. Tributaries of origin
a. Common iliacs
1) Median sacral

G. Tributaries of the portal vein
1. Splenic
a. Inferior mesenteric
2. Superior mesenteric
3. Right gastric
4. Cystic
5. Left gastric

V. Pelvis

A. Bony structures
1. Proximal femur
2. Ilium
3. Ischium
4. Pubis
5. Sacrum
6. Coccyx
7. Acetabulum

B. Pelvic vasculature
1. Arterial
a. Common iliacs
b. Internal iliacs

c. External iliacs
d. Ovarian/testicular

2. Venous
   a. External iliacs
   b. Internal iliacs
   c. Common iliacs

C. Pelvic organs
1. Urinary bladder
   a. Ureter
   b. Urethra
2. Small intestine
   a. Terminal ilium and ileocecal valve
3. Colon
   a. Ascending
   b. Descending
   c. Sigmoid
   d. Rectum
   e. Vermiform appendix
4. Female reproductive organs
   a. Vagina
   b. Cervix
   c. Uterus
   d. Fallopian tubes
   e. Ovaries
5. Male reproductive organs
   a. Testes/scrotum
   b. Prostate gland
   c. Seminal vesicles
   d. External to pelvis
      1) Penis

VI. Musculoskeletal

A. Upper extremities
1. Shoulder
   a. Bony anatomy
      1) Clavicle
      2) Scapula
      3) Humerus
      4) Acromioclavicular joint
   b. Muscles and tendons
      1) Deltoid
      2) Supraspinatus
      3) Infraspinatus
      4) Teres minor

5) Subscapularis
6) Supraspinatus tendon
7) Biceps tendon

c. Labrum and ligaments
1) Glenoid labrum
2) Glenohumeral ligaments
3) Coracoacromial ligament
4) Coracoclavicular ligaments
5) Bursa (subacromial and subdeltoid)

d. Vasculature
1) Axillary artery
2) Thoracodorsal artery
3) Lateral thoracic artery
4) Subscapular artery
5) Thoracoacromial artery
6) Axillary vein

2. Elbow
a. Bony anatomy
1) Humerus
2) Radius
3) Ulna

b. Muscles and tendons
1) Anterior group
2) Posterior group
3) Lateral group
4) Medial group

c. Ligaments
1) Ulnar collateral
2) Radial collateral
3) Annular

d. Neurovasculature
1) Brachial artery
2) Radial artery
3) Ulnar artery
4) Basilic vein
5) Cephalic vein
6) Median cubital vein
7) Ulnar nerve

3. Hand and wrist
a. Bony anatomy
b. Phalanges
c. Metacarpals
1) Carpal bones
2) Radius
3) Ulnar

d. Tendons
    1) Palmar tendon group
    2) Dorsal tendon group
    3) Triangular fibrocartilage complex
e. Neurovascular
    1) Ulnar artery
    2) Ulnar nerve
    3) Radial artery
    4) Median nerve
    5) Deep palmar arch
    6) Superficial palmar arch

B. Lower extremities
1. Hip/thigh
    a. Bony anatomy
    b. Labrum and ligaments
    c. Muscle groups
        1) Hamstring muscles
        2) Abductor/adductor
    d. Neurovasculature
        1) Femoral nerve
        2) Sciatic nerve
        3) Femoral artery
        4) Profunda artery
        5) Femoral vein
        6) Great saphenous vein
2. Knee
    a. Bony anatomy
    b. Menisci and ligaments
    c. Muscles
        1) Gastrocnemius
        2) Soleus
        3) Sartorius
        4) Tibialis anterior
    d. Vasculature
        1) Popliteal artery
        2) Anterior tibial artery
        3) Posterior tibial artery
        4) Fibular artery
        5) Variations in pedal arterial supply
3. Foot and ankle
    a. Bony anatomy
    b. Ligaments
    c. Tendons
    d. Muscles

1) Abductor hallucis/digiti

e. Vasculature
   1) Dorsalis pedis artery
   2) Lateral plantar artery
   3) Plantar arch

Optional Content

Cardiac MRI

Description

Content is designed to present a systematic approach to the techniques and procedures technologists use in the performance of select cardiac MRI procedures. Common to the discussion of all procedures will be the following:

- Anatomy and physiology.
- Pathology.
- Indications for the procedure.
- Contraindications.
- Required equipment and supplies.
- Patient preparation.
- Patient management during the imaging procedure.
- Contrast media use.
- Pharmacological stress.
- Free breathing technique adjustments (for sedated or very ill patients).
- Techniques for image capture and display.
- Postprocedure patient instructions.

Objectives

1. Identify equipment and supplies required for cardiac imaging.
2. Identify techniques for patient monitoring and communication during cardiac imaging.
3. List advantages and disadvantages of MR imaging vs. other invasive and noninvasive imaging modalities.
4. Identify normal anatomy of the heart and great vessels as seen on routine MR images.
5. Employ proper imaging techniques for demonstrating common pathologies.
6. Evaluate images for diagnostic quality.
7. Provide postprocedure patient instructions
8. Describe the benefits of postprocessing of digital images.

Content

I. Equipment Requirements for Cardiac Imaging

A. RF coils

B. Cardiac gating

C. Respiratory bellows

D. Patient monitoring

II. MR Advantages over other Imaging Modalities

A. Interventional angiography/cardiac catheterization

B. Nuclear medicine

C. Ultrasound/echocardiography

III. MR Presentation of Normal Cardiac Anatomy

A. Vertical axis

B. Horizontal axis

C. Short axis

D. Three and four chamber views

E. Aortic view

IV. Imaging Techniques

A. Steady-state free precession

B. Inversion recovery techniques
   1. Precontrast
   2. Postcontrast

C. Studies requiring the use of contrast media

D. ECG gating

E. Cine acquisitions

F. Myocardial tagging

G. Perfusion

H. T2*

I. T1 mapping

J. Phase contrast
   1. Velocity encoded gradient echo (VENC) imaging

K. MRA
   1. 3-D time-of-flight
      a. Postcontrast
      b. Breath hold
      c. Nonbreath hold
   2. 3-D steady-state free precession
      a. Breath hold
      b. Navigator imaging
      c. Pre- and postcontrast

V. Evaluating Common Errors

A. Patient preparation

B. Patient motion

C. Image artifacts

VI. Techniques for Demonstrating Common Cardiomyopathies

A. Viability assessment

B. Hypertrophic cardiomyopathy (HCM)

C. Dilated cardiomyopathy (DCM)

D. Restrictive cardiomyopathy (RCM)

E. Arrhythmogenic right ventricular cardiomyopathy (ARVC)

F. Myocarditis

G. Cardiac masses

H. Pericardial effusion

I. Valvular disease

J. Constricted cardiomyopathy

K. Infiltrative diseases
    1. Idiopathic
    2. Sarcoidosis
    3. Amyloidosis

VII. Techniques for Patient Monitoring and Communication

VIII. Patient Safety and Emergency Care

IX. Postprocedure Patient Instructions

Image Postprocessing

Description
Content is designed to establish a knowledge base in the fundamentals of digital image postprocessing that support guided skill development using clinical-based image workstations.

Objectives
1. Describe the benefits of postprocessing digital images.
2. Describe the requirements of the source data for each type of postprocessing technique.
3. Describe fundamentals of image data retrieval stored on Digital Imaging and Communications in Medicine (DICOM) enabled archive systems.
4. Describe techniques and procedures for saving postprocessed images and image sets.
5. Describe various methods for 3-D image viewing.
6. Describe the principles of correct ergonomics for workstation use.
7. Describe the principles, techniques and applications of:
   a. MPR.
   b. MIP.
   c. Subtraction.
   d. Diffusion.
   e. Perfusion.
   f. Spectroscopy.
   g. Elastography.
   h. fMRI.
   i. Fiber Tracking.
   j. Breast.
   k. Prostate.
   l. Fusion.
   m. 4-D.
8. Identify methods of acquiring quantitative data from a normal and temporal volumetric data set.
9. Identify sources of postprocessing image noise and image artifacts, as well as techniques to reduce their presence.

Content

I. Image Postprocessing

A. Definition/Key aspects involved

B. Types of postprocessing commonly performed in MR
1. MPR
2. MIP
3. Subtraction
4. Diffusion
5. Perfusion
6. Spectroscopy
7. Elastography
8. fMRI
9. Fiber Tracking
10. Breast
11. Prostate
12. Fusion
13. 4-D

C. Benefits to the observer

D. Source data requirements

E. How postprocessed images are generated

II. Retrieval and Exporting Image Data

A. Communication with configured DICOM devices
1. Query to retrieve study

B. Preview images as acquired by scanner
1. Identify proper series for postprocessing

C. Exporting/saving DICOM images

III. Viewing 3-D Images

A. 2-D screen captures
1. Proper window/level (W/L) display
2. Selecting anatomy of interest

B. 3-D viewing
1. Maximum-intensity projection (MIP)
2. Rotations
3. Temporal images

C. Transmission display

1. Computer monitor

D. Workstation ergonomics

IV. Postprocessing Techniques

A. Multiplanar reformation (MPR)
   1. Definition/description
   2. Defining the plane of image reformation
   3. Thick vs. thin MPR
      a. MIP
      b. Minimum-intensity projection (MinIP)
   4. MPR artifacts
      a. Dephasing
      b. False stenosis
   5. MPR applications
      a. 3-D isovoxel sets
         1) Multiple views from a single sequence
         2) Procedure time reduction
      b. Anatomical segmentation
      c. Noise reduction in standard displays

B. MIP and MinIP
   1. Principles
      a. Defining the volume of interest (VOI)
      b. Image contrast
      c. Viewing angle
      d. Cine loop to improve 3-D orientation
   2. Artifacts and pitfalls
      a. Depth perception
      b. Superimposition of structures
      c. Stents or graphs in vessels
   3. Applications
      a. MR angiography
         1) Vessel growing possible
      b. Intrahepatic bile ducts
      c. Pancreatic duct

C. Subtraction
   1. Pre- and postcontrast

D. Diffusion
   1. DWI
   2. DTI

E. Perfusion

F. Spectroscopy
    1. Single voxel
    2. Multi voxel

G. Elastography
    1. Automated color maps
    2. ROIs

H. fMRI

I. Fiber Tracking

J. Breast

K. Prostate

L. Fusion
    1. 3-D Fusion
    2. PET-MR

M. 4-D
    1. Time-resolved imaging

V. Quantitative Analysis

A. 2-D measurements
    1. Area
    2. Circumference
    3. Diameter
    4. Peak Flow
    5. Flow rations (e.g., Qp/Qs)
    6. Spectroscopic Values
    7. ADC Values

B. 3-D measurements
    1. Volume
        a. Ventricular volume
        b. Atrial volume
        c. Stroke volume
        d. Tumors
        e. Aneurysms

VI. Common Technical Errors that Lead to Postprocessing Artifacts

A. Noise

B. Segmentation misrepresentation

C. False stenosis

D. Wrap artifacts

E. Motion
   1. Voluntary
   2. Physiologic

F. Parallel imaging

G. Mismapping

H. Threshold levels

I. Aliasing of signal

Procedures for Image Postprocessing

Description

Content provides a framework of MR procedures that would benefit from the added value of postprocessing. Included are indications for the 2-D and 3-D procedures, proper patient preparation for the MR examination, patient history and assessment, contrast media use, selection of proper imaging tools and filming/archival of the images with picture archiving and communication system (PACS) integration. Images will be reviewed for quality and proper demonstration of anatomy and pathology. Procedures vary by facility and are dependent on the preference of the radiologist and referring physician.

Objectives

1. Describe the imaging protocol that best demonstrates anatomy and pathology for a given MR examination.
2. Differentiate both normal and diseased structures on the 2-D and 3-D images.
3. Describe the proper patient preparation to assure a successful postprocessed procedure.
4. Determine if contrast media would be indicated for each procedure.
5. Determine from patient history and prior imaging the key views to best demonstrate the patient's clinical concern.
6. Identify image artifacts and ways to avoid or alleviate them on the postprocessed images.

Content

I. Indications for 3-D Procedures

A. Value-added indicators

B. General types of studies that benefit from postprocessing

C. Patient history and assessment

II. Contrast Media Selection

A. Types of contrast media
   1. Extracellular
   2. Intravascular
   3. Other

B. Methods and routes of contrast introduction

III. Selection of Proper Imaging Tools

A. Appropriate use of:
   1. Multiplanar reformations (MPR)
   2. Maximum-intensity projections (MIP)

IV. Storage/Retrieval of Images

A. PACS integration with source images

V. Imaging Procedures

A. MR procedures
   1. Neuro
   2. Body
   3. Musculoskeletal
   4. Cardiovascular

B. PET-MR

C. Quantification
   1. Cardiac
      a. Ejection fractions
      b. Stroke volume
   2. Aortic root measurements
   3. Cardiovascular flow measurements
      a. Aorta
      b. Pulmonary artery
   4. MR vessel wall measurements
      a. Vessel widening
      b. Vessel narrowing
      c. Normal vessel diameter values

5. Volume measurements
    a. Organs
    b. Tumors

Quality Assurance in Image Postprocessing

Description

Content is designed to focus on the components of a quality assurance program for all aspects of postprocessing in MR, from initial MR scanning protocols through final reporting of findings. Postprocessing is dependent on the skills of the operator to effectively delineate anatomy and characterize pathology. Therefore, it is important to implement a quality assurance program to assure postprocessed images are error free on a consistent basis.

Objectives

1. Discuss the purpose and importance of quality assurance.
2. Discuss components of a quality assurance program.
3. Identify errors in acquisition of MR source images.
4. Identify common errors in imaging acquisition that influence postprocessing quality.
5. Identify causes of errors that influence postprocessing quality.
6. Identify methods for improving quality in postprocessing.

Content

I. Purpose of Quality Assurance

A. Definitions of quality assurance and quality control

B. Impact of imaging errors on patient care

II. Components of Postprocessing Quality Assurance Program

A. Methods for interdepartmental and intradepartmental communication
   1. Ensure proper requirements are met for MR source images
   2. Ensure all personnel are aware of protocol changes

B. Checklist of core competencies for novice technologists

C. Continuous training and updates for technologists

D. Consistent quality control measures integrated into workflow

E. Checks for interoperator and intraoperator variability

F. Checks for intermanufacturer and intramanufacturer variability

III. Common Errors in 3-D Images

A. Source image errors due to improper
   1. Slice thickness
   2. Image overlap
   3. Reconstruction algorithm
   4. Timing
      a. Timing run mismatch
      b. Automated bolus tracking
      c. Fluoro triggering
      d. Delayed images

B. Technical errors
   1. Segmentation
   2. Thresholding
   3. Annotation errors
   4. Improper choice of imaging protocol

C. Measurement errors
   1. Incomplete comparisons with prior measurements
   2. Improper measuring technique

D. Reporting errors
   1. Measurement data entry errors
   2. Improper documentation in procedure report

E. Image networking failures

IV. Causes of Errors in Postprocessing

A. Insufficient training or direction

B. Fatigue, distractions

C. Rushing, increase in workload

V. Quality Improvement in Postprocessing

A. Frequent image monitoring and quality control checks

B. Error rate measurement and documentation

C. Training and interventions and their effect on error rate

D. Documentation of 3-D department standard operating procedures

Resources

This list of magnetic resonance references can assist educators in sampling the pool of resources that pertain to medical imaging. The list should be viewed as a snapshot of available materials. Omission of any title is not intentional. Because the creation of literature and media related to the field is dynamic, educators are encouraged to search additional sources for recent updates, revisions and additions to this title collection.

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