Magnetic Resonance Curriculum

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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 Society for MR Radiographers & Technologists (SMRT), a Section of the International Society for Magnetic Resonance in Medicine (ISMRM).

This curriculum document establishes 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, with main body areas defined by the ARRT examinations. The content is designed to assure quality patient care and the production of quality diagnostic images.

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

- Core content: content in this section reflects educational content the MR 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 focus of this document is on core instructional content that will be expanded with institution-specific course content to fulfill the requirements for an academic degree. This document is not intended for programs that are unable to award graduates an academic degree in compliance with the ARRT associate degree requirement.

Advances in diagnostic imaging and increasing employer expectations demand independent judgment by MR technologists. Consequently, the educational process must foster critical-thinking skills. Critical thinking is incorporated in multiple content areas, and faculty are expected to develop critical thinking opportunities throughout the curriculum. 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 flexibility to develop a curriculum that will meet the needs of individuals preparing to perform diagnostic MRI procedures.

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Fundamentals of Imaging Science and Health Care

Description

Content provides an overview of the foundations of medical imaging and radiation therapy, 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. Recognize various health care continuum environments.
3. Discuss the value of a philosophy and mission statement to the operation of health care institutions.
4. Explain the relationships and interdependencies of departments within a health care organization.
5. Discuss the responsibilities and relationships of personnel and support systems in the medical imaging organization.
6. Differentiate between accreditation types.
7. Describe continuing education requirements and evaluation mechanisms at the national, state and regional levels.
8. List the regulatory agencies relevant to the imaging sciences and health care.
9. Define credentialing, certification, registration, licensure and regulations.
10. Discuss the purpose, function, and activities of professional organizations at the local, state, national and international levels.
11. Identify professional development and advancement opportunities.
12. Explain the patient care and professional enhancement benefits of continuing education.

Content

I. The Health Science Professions

A. Radiologic technology

1. Diagnostic radiography
2. Fluoroscopy
3. Mammography
4. Bone densitometry
5. Computed tomography
6. Positron emission tomography (PET)
7. Magnetic resonance imaging
8. Diagnostic medical sonography
9. Nuclear medicine technology
10. Cardiac-interventional
11. Vascular-interventional
12. Radiologist assistant
13. Radiation therapy (photon and proton therapy)
14. Medical dosimetry
15. Quality management
16. PACS administration
17. Education
18. Management

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

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. Support services
7. 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. Radiology nursing
6. Medical physicist
7. Radiologic technologists

B. Support personnel
1. Administrative staff

2. Medical billing
3. Transport staff
4. Information technology
5. Other

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

C. Institutional

D. Regional

VI. Continuing Education Requirements

VII. Regulatory Agencies

VIII. Professional Credentialing

A. Definition
1. Certification and registration
2. Licensure

B. Agencies
1. National
2. State

IX. Professional Organizations

A. Purpose, function and activities

B. Local organizations

C. State organizations

D. International organizations
1. International Society of Radiographers and Radiological Technologists (ISRRT)
2. International Society for Magnetic Resonance in Medicine (ISMRM)/Society for MR Radiographers & 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. Society of Diagnostic Medical Sonographers (SDMS)
   6. Nuclear Medicine Technology Certification Board (NMTCB)
   7. Magnetic Resonance Managers Society (MRMS)
   8. American College of Healthcare Executives (ACHE)
   9. Association for Radiologic & Imaging Nursing (ARIN)

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

Clinical Practice and Patient Management

Description

Content is presented as a progression in competency levels through clinical performance objectives and competency exams. The content assumes students can access the educational materials, examination facilities, and personnel necessary to competently achieve content objectives. Objectives begin with observation of activities, 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. Describe the code of ethics and professional behaviors.
2. Communicate professionally with patients, staff members and the general public.
3. Demonstrate cultural competence.
4. Explain the role of health care team members.
5. Demonstrate proper scheduling and sequencing of imaging procedures.
6. Correlate requested imaging procedures with clinical history and reported physical examination findings.
7. Assess patients (e.g., screening, monitoring, etc.).
8. Educate patients, family members, and other health care professionals.
9. Demonstrate charting and documentation.
10. Apply infection control precautions to prevent disease transmission.
11. Describe communicable disease terminology and required transmission-based precautions.
12. Evaluate and respond to medical emergencies.
13. Differentiate the functions of tubes, catheters, lines and infusion devices.
14. List preprocedural considerations.
15. Position and setup patients, MR coils, equipment, table accessories and cushioning.
16. Apply national, organizational and departmental standards, protocols, policies and procedures regarding MR imaging and patient care.
17. Analyze image quality.
18. Store and disseminate images.
19. Explain environmental considerations (e.g., gauss lines, radiofrequency (RF) shielding and magnetic shielding, etc.).
20. Apply safety practices to protect 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: (i.e., expectations, rights and responsibilities)

B. Professional communication
   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

D. Cultural competence
   1. Diverse populations
   2. Health care team

II. Procedural Performance

A. Scheduling and sequencing of MR imaging procedures

B. Evaluate requisition and verify the 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) Temperature changes

E. Protocol selection

F. Performance of imaging procedure

G. Charting and documentation
1. Medical reconciliation
2. Surgical and medical history

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 (e.g., 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

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
6. Handling and disposal of toxic or hazardous material

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
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 (e.g., 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 (e.g., maximum-intensity projection [MIP], multiplanar reformatting [MPR])

D. Image quality analysis
   1. Signal-to-noise ratio (SNR)
   2. Artifacts
   3. 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 foreign body injuries
      b. External metallic objects
      c. Implants and pacemakers
      d. Renal disease
      e. Asthma
      f. Pregnancy
      g. Dialysis
      h. Claustrophobia
      i. Liver disease
      j. Chronic hypertension
      k. Diabetes
   2. Equipment and accessories
      a. Coils
      b. Emergency alarm call button
      c. Earplugs and headphones
      d. MR-conditional equipment:
         1) Patient monitoring devices
         2) Oxygen tanks
         3) Anesthesia equipment and ventilators
         4) Suction
   3. Environment
         1) Gauss lines
         2) RF shielding and magnetic shielding
         3) Warning alarms and signs
         4) Safety zones 1-4
         5) Climate control (temperature & humidity)
         6) Ferromagnetic metal detector
   4. Safety considerations
      a. RF field (B_1)
      b. Static magnetic field (B_0)
      c. Spatial magnetic field (dB/dx)
      d. Gradient fields (dB/dt)

VII. ARRT Clinical Experience Requirements

A. Primary Pathway Eligibility Requirements: https://www.arrt.org/arrt-reference-documents/by-document-type/didactic-and-clinical-competency-requirements

B. Postprimary pathway: https://www.arrt.org/arrt-reference-documents/by-document-type/clinical-experience-requirements

Pharmacology and Drug Administration

Description
Content provides basic concepts of pharmacology. This section covers the theory and practice 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 the administration of contrast media and intravenous medications vary by state and institution, these skills 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, educational programs have 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 verified before the student performs this task under indirect supervision.

Objectives

1. Distinguish between nonprescription drugs, prescription drugs and controlled substances.
2. Explain the process of reporting adverse reactions to the FDA.
3. List the six rights of drug administration.
4. Describe the various routes of drug administration.
5. Identify general drug actions, uses, adverse reactions, contraindications, precautions and interactions.
6. Discuss specific considerations of MR contrast administration.
7. Recall 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. The 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. Manual
   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
    a. Appropriate codes
    b. Emergency cart (crash cart)
    c. Emergency medications
    d. Accessory equipment
    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 complications/reactions

IX. MR Contrast Administration

A. Patient history
    1. Asthma
    2. Drug allergy
    3. Adverse reaction to contrast media
    4. Kidney function
    5. Cardiac function

B. Patient education
    1. Technologist's responsibility
    2. Standard procedure
    3. Distribution of GCBA medication guides

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

D. Contrast media preparation
    1. Proper dose
    2. Expiration dates

3. Vial retention (until patient release)
4. Aseptic technique
5. Venous access

E. Contrast administration
   1. Manual
      a. Integrity of venous access
      b. Extravasation monitoring
      c. Follow-up care
   2. Power injector
      a. Integrity of venous access
      b. Monitor angiocatheter gauge for rate of contrast media flow (angiocatheter manufacturer guidelines)
      c. Alternative access sites (e.g., venous access ports, central lines)
      d. Follow-up care

F. Adverse reactions
   1. Local events
      a. Stop contrast administration
   2. Treatment/follow-up guidelines
      a. Compress (outlined by ACR)
      b. Written patient discharge instructions
      c. Physician notification
      d. Documentation and reporting
   3. Systemic events
      a. Stop contrast administration
      b. Remove patient from MR suite
      c. Assess for breathing difficulty
      d. Physician notification
      e. Treatment/follow-up guidelines:
         1) Health care provider to administer medications
         2) Written patient discharge instructions
         3) Documentation and reporting
      f. Availability of emergency medications
      g. Emergency contact phone numbers
      h. Emergency code buttons or switches

G. Gadolinium-based MR contrast and NSF
   1. Gadolinium retention
   2. ACR guidelines regarding renal function and dialysis
   3. FDA guidelines

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

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 is also presented. Topics include misconduct, malpractice, and legal and professional standards. The importance of proper documentation and informed consent is emphasized.

Objectives
1. Apply medical professional ethics and moral reasoning.
2. Explain ethical considerations in health care delivery.
3. Identify specific ethical dilemmas in health care.
4. Explain legal issues related to patients' rights, the doctrine of informed consent and other concerns related to patients' rights.
5. Explain the legal implications of professional liability, malpractice, professional negligence and other legal doctrines applicable to professional practice.
6. Identify standards used to secure and manage the compliance of protected health information.

Content

I. Ethics and Ethical Behavior

A. Moral and ethical reasoning

B. Professional behavior standards

C. Professional attributes

D. Standards of practice

E. Self-assessment and personal integrity

F. Code of professional ethics

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

H. 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. Accountability for protecting patient information
   1. Information collection
   2. Information maintenance
   3. Use of personally identifiable health information
   4. Contractual agreements
   5. Demonstrating and monitoring compliance

B. Consents

1. Informed
    a. Definition
    b. Types
    c. Patient and provider elements
    d. Condition for valid consent
    e. Documentation of consent
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. Patient personal information
1. Patient's Bill of Rights
2. Health Insurance Portability and Accountability Act (HIPAA)
3. Confidentiality of patient information

E. Intentional misconduct (e.g., battery, assault, libel, slander, etc.)

F. 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

G. Information systems

IV. Compliance

A. Accreditation

B. Federal and state regulations

C. Protected health information (PHI)
1. Physical or electronic health record content
    a. Elements of proper charting and documentation
    b. Legal ramifications of improper charting and documentation

D. Noncompliance issue

Computers in Imaging and Medical Informatics

Description

Content introduces principles of 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. Explain how regulations, laws, and standards related to informatics affect health care delivery.
3. Describe the evolution and role of health care informatics.
4. Recognize the ethical concerns related to health care informatics.
5. Evaluate the decision-making strategies used in informatics.
6. Compare and contrast different informatics applications in health care.
7. Describe digital imaging characteristics.
8. Assess digital imaging acquisition requirements.
9. Demonstrate imaging standard expectations (e.g., protocol and parameter selection, problem-solving, etc.).
10. Analyze and correct the cause of image artifacts.
11. Demonstrate postprocessing strategies (e.g., 3-D, MIP, Region of Interest, etc.).
12. Describe the methods of image display (e.g., monitor, digital, etc.).
13. Explain RIS, HIS and PACS.
14. Identify information systems and standards used to manage and transfer a patient's health information.
15. Identify 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

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

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

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

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. 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

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. Image acquisition
   1. Protocol/parameter selection
      a. Resolution (FOV, thickness, matrix)
      b. Contrast (e.g., repetition time [TR], echo time [TE], inversion time [TI] and flip angle [FA])
      c. Other parameters
   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. Non-operator controlled

MR Safety

Description

The content 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 prevent MR incidents. The ACR has developed guidelines for safe MR practices. 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 different magnetic fields associated with MR imaging and list the safety concerns associated with each one.
3. Apply safety measures to reduce the risk of safety incidents.
4. Identify and discuss the various components of MR safety screening for patients and personnel.
5. Describe the process of reporting MR safety incidents.
6. Discuss the various components of MR safety screening for equipment.
7. Recognize emergencies that can occur in MR imaging, and explain appropriate reactions.

Content

I. Introduction

A. Magnetic fields in MR
   1. Main static field
   2. Radiofrequency field
   3. Gradient field

B. 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. Intersocietal Accreditation Commission (IAC)
   9. American Board of Magnetic Resonance Safety (ABMRS)

II. Static Magnetic Field

A. Potential biological effects
   1. Magnetophosphenes
   2. Magnetohydrodynamic effect
   3. Elevated/inverted T-wave
   4. Vertigo/dizziness

B. Potential dangers
   1. Field strength
   2. Translational force
   3. Rotational force
   4. Lenz's forces
   5. Device interactions
   6. Magnetic shielding
      a. Active
      b. Passive
   7. Static magnetic field gradient (T/m, G/cm)

C. Guidelines for static field safety
   1. Safety policies and procedures
   2. Safety zones
   3. Warning signage
   4. Personnel
      a. Level 1
      b. Level 2
      c. Non-MR
   5. Patient screening

III. Time-varying Radio Frequency (RF) Magnetic Field

A. Potential dangers
   1. Thermal heating
      a. Core (whole body) and localized heating
      b. Implanted devices
   2. Burns
      a. Proximity
      b. Looping
      c. Resonant
      d. Reflective

B. Specific Absorption Rate (SAR)
   1. IEC/FDA limits for whole-body heating
      a. Normal limit mode
      b. First level controlled mode
      c. Second level controlled mode
   2. SAR reduction methods
   3. Specific energy dose (SED)
   4. B_1+rms

C. Guidelines for RF safety
   1. Patient positioning
   2. Monitoring equipment
   3. Patient screening
   4. Patient monitoring
      a. Physiological conditions
      b. Sedation
      c. Pregnancy

IV. Time-varying Gradient Magnetic Fields

A. Potential dangers
   1. Nerve stimulation – peripheral neurostimulation & magnetophosphenes
      a. Orientation of field gradient
      b. Location in the body
      c. Duration of the gradient pulse
      d. Stimulation threshold
      e. FDA limits
   2. Hearing damage
      a. OSHA regulations
      b. Acoustic noise
   3. Device interactions/malfunctions

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

C. Guidelines for gradient safety
    1. Hearing protection
    2. Acoustic noise reduction
    3. Pulse sequence selection
    4. Patient screening
    5. Patient monitoring

V. Patient and Personnel Safety Screening in MR

A. Safety screening questionnaire
    1. Trained personnel
    2. Documentation review
        a. Written
        b. Verbal
    3. Contraindications for entering the MR suite
        a. Implanted electronic devices
        b. Implanted metallic objects at risk of deflection
        c. Foreign bodies

B. Informed or special consent

C. Monitoring patients
    1. Verbal/auditory
    2. Visual
    3. Claustrophobia/anxiety disorder

D. Laser and alignment light (eye safety)

E. Reporting of MR safety incidents

VI. Equipment Safety Screening in MR Environment

A. MR safety labeling

B. MR-conditional and MR-unsafe equipment

C. Conductive equipment (e.g. ECG leads, coils, cables)

D. Monitoring
    1. Cryogen levels
    2. Climate control factors (e.g., temperature, humidity)

E. Identify gauss lines

F. Pulse receptor, ECG cables, and disposable electrodes check

G. Spills (e.g., phantom fluid)
    1. SDS forms

2. First aid
3. Mandatory reporting
4. Disposal

VII. Emergencies in the MR Environment

A. Emergency code (e.g., code blue)
   1. Evacuate patient
   2. Emergency plan
   3. Follow-up documentation

B. Fire emergency
   1. Patient and staff evacuation
   2. Institutional fire emergency procedure
      a. Suspending electricity to the MR scanner
      b. Quench protocol
   3. MR-safe fire equipment
   4. Training for local fire departments

C. Pinned metallic items
   1. Patient danger
   2. Pinned equipment

D. Emergency protocols
   1. Table-stop
   2. Emergency shutdown
   3. Quench
      a. Causes
      b. Evacuation procedure
      c. Entry procedure for positive pressure seal
      d. Notifying support personnel
      e. Cryogen boil-off

VIII. Safety in MR Contrast Administration

A. Patient history

B. Preparation

C. Contrast administration
   1. IV
      a. Manual
      b. Power injector
   2. Oral
   3. Rectal
   4. Intrathecal
   5. Intra-articular

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

E. ACR Manual on Contrast Media

MR Instrumentation and Imaging

Description
Content provides a comprehensive overview of the instrumentation associated with MR imaging. 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. Explain magnetism and magnetic properties.
2. Define gauss (g), Tesla (T) and the electromagnetic spectrum.
3. Recognize the basic types of commercially available clinical magnets, citing the advantages and disadvantages of each.
4. Describe the effect of field strength on 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: nonmagnetic
      1) Electron configurations
      2) Effects of externally applied magnetic fields
   b. Materials
      1) Examples of materials (e.g., wood, glass, gold, etc.)
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. Spatial magnetic field (dB/dx)
    3. Safety considerations

C. 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

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

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

F. 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. B_1
    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 (B_0)
   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 field shielding
   1. Regulations and recommendations
   2. Mechanisms for RF field shielding
      a. Faraday cage
         1) Copper
         2) Steel

H. 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

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. ROI
    2. Annotations
    3. Postprocessing
    4. Archiving and data storage media
    5. Other functions

VII. Operational Flow

A. Magnet selection

B. Site selection

C. Facility design

D. Government regulations and certificate of need

E. Ancillary equipment

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

VIII. Scanning System Maintenance

A. Preventive maintenance

B. Repairs

C. Quality assurance (testing)

MR Physical Principles

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. Explain the discoveries of various scientists associated with 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)
7. Denis Le Bihan (DWI/DTI/fMRI)

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. 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 (ω_0)
      a. Hertz (Hz)
      b. Megahertz (MHz)
   3. Larmor equation
      a. Field strength (B_0)
      b. Gyromagnetic ratio

C. Resonance
   1. Excitation
      a. RF pulse (B_1)
      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
            b) Other T1 agents
         2) Enhanced T2* relaxation with contrast agents
            a) Gadolinium
            b) Iron oxide

c) Other T2 agents

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

MR Parameters and Imaging Options

Description
Content lists and explains the sequences, parameters and imaging options used to create MR images. In addition, the content introduces measures used to maintain image quality and minimize artifacts.

Objectives
1. Describe imaging parameters that relate to image contrast, spatial resolution, and high signal-to-noise ratio (SNR) on MR images.
2. Apply MR imaging parameters in the clinical setting.
3. Define imaging options used to optimize image quality.
4. Explain how to apply parameters and imaging options in order to minimize image artifacts.

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) Echo planar imaging (EPI)
      6) 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) Coherent
         a) PC MRA
         b) Steady-state dynamic cine
      3) Incoherent
      4) Echo planar imaging (EPI)
   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)
      7) Perfusion-weighted imaging (PWI)
3. 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)

4. Spectroscopy
5. Flow studies

B. Image contrast parameters
1. Extrinsic contrast parameters (user selectable parameters)
a. TR – repetition time
b. TE – echo time (effective TE)
c. TI – Inversion time (tau)
1) STIR
2) FLAIR
3) T1 FLAIR
4) Double inversion recovery (DIR)
5) Triple inversion recovery (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
c. Oral agents
1) Bulk gastrointestinal (GI) expansion agents
2) negative contrast agent (e.g., blueberry juice, barium sulfate)
d. Off-label applications

C. Resolution parameters
1. Matrix
a. Pixel
b. Voxel
c. Pixel/Voxel size parameters

1) FOV
    a) Rectangular FOV
2) Slice thickness

d. Effect on Quality
1) SNR
2) resolution
3) scan time
4) Pediatric vs adult considerations

D. Scan time parameters
1. Number of signals averaged (NSA)
2. Concatenations/acquisitions
3. Number phase & frequency encodings (matrix)
4. Slice thickness and spacing
5. Number of slices
6. Echo train length (ETL)/turbo factor
7. Slices in a 3-D (volume) acquisition
8. Acceleration techniques
    a. Parallel imaging
    b. Compressed sensing
    c. Multi-band/multi-slice

E. Dimensionality (mode)
1. 2-D
2. 3-D
3. 4-D/time resolved
4. Slice thickness/gap
5. Slice order
6. Phase encoding considerations

II. Imaging Options

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

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. Phase/frequency orientation

F. In/out of phase

III. Artifacts

A. Physics artifacts
    1. Dielectric effect
    2. B_1 inhomogeneity
    3. Chemical shift
    4. Susceptibility
        a. Metal
        b. Tissues with dissimilar chemical composition

B. Sampling artifacts
    1. Aliasing
    2. Cross-talk/cross-excitation
    3. Parallel imaging
    4. Gibbs truncation
    5. Partial volume averaging

C. Motion artifacts
    1. Voluntary
    2. Involuntary
    3. Ghosting
    4. Blurring

D. Technical errors
    1. Improper centering
    2. Coil selection/placement

E. Hardware artifacts
    1. Moiré
    2. Corduroy
    3. Shading
    4. RF leak

F. Cause and appearance

G. Compensation

H. Operator-adjustable parameters

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 and extrinsic contrast characteristics and describe their impact on image quality.
2. Construct pulse sequence diagrams based on the specific timing of RF pulses and gradient applications.
3. Determine the appropriate pulse sequence for specific clinical applications based on the desired image contrast.
4. Explain the process of MR image formation.
5. Identify the various postprocessing techniques used in MR.
6. Explain the use of contrast media and its effects on image quality.

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. Spin echo (SE)
      b. Fast spin echo (FSE)
      c. Gradient echo (GRE), echo planar imaging (EPI)
      d. Inversion recovery (IR)
   2. Effects on image quality
      a. T1
      b. Scan time
      c. SNR
      d. Number of slice locations

B. Echo Time (TE)
   1. Time constant (time to echo)
      a. Spin echo (SE)
      b. Fast spin echo (FSE)
      c. Gradient echo (GRE)
   2. Effects on image quality
      a. T2
      b. SNR
      c. Number of slice locations

d. Susceptibility artifact

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

D. Flip angle
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
b. Flow direction
2. Diffusion imaging
a. Single/multi 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) Slice selection
2) Phase encoding
3) Frequency encoding

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) PSIR
        5) SPIR
4. Rapid acquisition recalled echo (RARE)
5. Fast spin echo (FSE)
6. 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
        4) Blood oxygenation-level dependent (BOLD)
7. 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. Physical 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 Imaging Procedures

Description

This content identifies 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 planes that best demonstrate anatomy are discussed, as well as signal characteristics of normal and abnormal structures.

Objectives

1. Describe elements of patient screening.
2. Demonstrate effective communication skills with patients, family members, and the health care team.
3. Apply MR safety principles and protective practices associated with MR imaging procedures.
4. Recognize and use MR-safe monitoring devices.
5. Describe the coils available for MR and their specific applications.
6. Explain the use of contrast media in evaluating pathology.
7. List positioning criteria for different areas of the body.
8. Recognize the advantages and disadvantages of axial, sagittal, coronal and oblique images (i.e., which structures are best demonstrated from each projection).
9. Describe common pulse sequences used to evaluate the different areas of the body.
10. Explain the considerations involved in designing an imaging protocol and state the application of protocols in specific situations.
11. Identify when and how to modify a protocol.
12. Recognize common artifacts that occur during imaging.
13. List image quality problems and appropriate solutions.
14. Differentiate adult and pediatric pulse sequences in MR.
15. Describe the differences in tissue signal characteristics between adult and pediatric examinations.
16. Evaluate images for positioning, anatomy, pulse sequences, coil placement and overall quality.
17. Identify common indications and pathologies for body systems in adult and pediatric patients.
18. Describe normal MR tissue characteristics of anatomical structures of interest.
19. Describe the MR tissue characteristics of pathological processes.
20. Discuss considerations for contrast studies.
21. List technical and practical considerations for special procedures, including functional techniques and procedures requiring 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 a patient
      3) Screening for physical contraindications
      4) Determine any contrast contraindications
4. Patient education
   a. Communication
      1) Types
      2) Cultural competency
      3) Identifying and 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

II. Procedural Considerations for Contrast Studies

A. Equipment and materials needed

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

III. Considerations for MR Procedures

A. Patient instructions

B. Patient positioning

C. Protocol considerations

D. Equipment and accessories

E. Coil type, selection, and positioning

F. Use of contrast agents
   1. Linear vs macrocyclic
   2. NSF
   3. Gadolinium deposition

G. Patient comfort

H. Image quality analysis

I. Image storage

J. Age-related

K. General anesthesia

L. Moderate sedation

M. Monitoring of conditional devices

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

IV. Imaging Considerations

A. Pulse sequences considerations
   1. Imaging planes
      a. Positioning criteria
      b. Axial, sagittal and coronal
      c. Anatomy best demonstrated
   2. Image contrast
      a. Proton density-weighted
      b. T1-weighted
      c. T2-weighted
      d. T2*-weighted
      e. Inversion recovery
      f. Diffusion-weighted
      g. Susceptibility-weighted
      h. Perfusion-weighted

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

C. Image viewing
    1. Windowing
    2. Proper orientation

V. Positioning and Procedural Considerations

A. Clinical indications
    1. Vascular disease
    2. Trauma
    3. Neoplasia
    4. Infection and/or inflammation
    5. Anomalies
    6. Myelination patterns
    7. Degenerative disease
    8. Developmental anomalies and/or congenital malformations
    9. Implants

B. Anatomic regions
    1. MR/Magnetic resonance angiography (MRA) of the central nervous system
        a. Brain
            1) Stroke
            2) Multiple sclerosis
            3) Seizure
            4) Cerebrospinal fluid (CSF) flow
            5) Pituitary
            6) Orbit
            7) Internal auditory canal (IAC)
            8) Sinuses
            9) Infant
            10) Angiography
                a) Vascular head MRA
                b) Vascular head MRV
            11) Spectroscopy
            12) Perfusion
            13) Cranial nerves
        b. Vertebral column

1) Sternoclavicular joints
2) Cervical spine
3) Thoracic spine
4) Lumbar spine
5) Sacrum/coccyx

c. Spinal cord
1) Lumbar plexus
2) Sacroiliac (SI) joints
3) Brachial plexus

d. Neck
1) Soft tissue
2) Vascular neck MRA

2. MR of the musculoskeletal system
a. Temporomandibular joint (TMJ)
b. Sternum
c. Sternoclavicular (SC) joints
d. Shoulder
e. Elbow
f. Wrist
g. Hands and fingers
h. Thumb
i. Bony pelvis
j. Hip
k. Knee
l. Ankle
m. Foot
n. Long bones (i.e. upper & lower extremity)
o. Arthrogram
p. Vascular extremities

3. MR/MRA of the thorax, abdomen and pelvis
a. Thorax
1) Chest
2) Vascular thorax
3) Cardiac
4) Breast

b. Abdomen
1) Liver, spleen
2) Pancreas
a) Magnetic resonance cholangiopancreatography (MRCP)
3) Alimentary canal (enterography)
4) Vascular abdomen

c. Retroperitoneum
1) Kidney
2) Adrenals

d. Pelvis
1) Soft tissue pelvis (bladder, rectum, anus)

2) Female (uterus, cervix, ovaries, vagina)
3) Male (anatomical position variation and slice positioning, prostate, penis, testes)
4) Femoral; iliac

C. Special imaging techniques
1. MRA/MRV
a. Flow dynamics
b. Time-of-flight
c. Phase-contrast
d. Contrast-enhanced
e. Fluoro-triggering
f. Timing bolus
g. Automatic bolus detection
h. Vascular extremities: iliac and runoff
2. Functional techniques
a. Diffusion
b. Perfusion
1) BOLD
c. Surgical planning
3. Dynamic imaging
4. Image postprocessing
a. Maximum intensity projections (MIP)
b. Multiplanar reformats (MPR)

Sectional Anatomy

Description
Content is intended to develop understanding of multiplanar images (axial, sagittal, coronal) of human anatomy created by modalities such as CT and MR. Anatomical knowledge will aid in 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 and sagittal imaging planes.
   a. Head
   b. Neck
   c. Spine
   d. Thorax
   e. Abdomen
   f. Pelvis
   g. Upper extremity
   h. 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. Diploe and subcutaneous soft tissue

B. 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) Clivus
      5) Anterior and posterior clinoid process
      6) Optic canals
   b. Greater wings
      1) Foramen rotundum
      2) Foramen ovale
      3) Foramen spinosum
      4) Foramen lacerum
5. Occipital
   a. Foramen magnum
   b. Internal and external occipital protuberance
   c. Jugular foramen
6. Temporal
   a. Zygomatic process
   b. External auditory canal (EAC)
   c. Internal auditory canal (IAC)
   d. Bones and structures of the inner ear
   e. Mastoid air cells
   f. Mastoid process
   g. Petrous portion or ridge

C. Facial bones
1. Mandible
2. Maxillae
3. Zygomas
4. Nasal bones
5. Inferior nasal concha
6. Lacrima
7. Palatine
8. Vomer

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

E. Facial muscles
    1. Masseter
    2. Frontalis
    3. Temporalis
    4. Obicularis muscles
    5. Platysma

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

G. Lobes of the brain and midline cerebral hemisphere structures
    1. Frontal
    2. Parietal
    3. Occipital
    4. Temporal
    5. Insula (Island of Reil)
    6. Tentorium cerebelli
    7. Cerebellum
    8. Centrum semiovale
    9. Corpus callosum (genu, rostrum, body and splenium)
    10. Septum pellucidum
    11. Falx cerebri
    12. Septum pellucidum

H. Cranial nerves
    1. Olfactory
    2. Optic
    3. Oculomotor
    4. Trochlear
    5. Trigeminal nerve
    6. Abducens
    7. Facial
    8. Vestibulocochlear
    9. Glossopharyngeal

10. Vagus
11. Accessory
12. Hypoglossal

I. Brainstem and adjoining structures
    1. Diencephalon
        a. Thalamus
        b. Hypothalamus
        c. Hippocampus
        d. Fornix
        e. Optic chiasm
        f. Optic tracts
        g. Infundibulum (pituitary stalk)
        h. Pituitary gland
        i. Mammillary bodies
        j. Pineal gland
    2. Midbrain
        a. Cerebral peduncles
        b. Tectum
    3. Pons
    4. Medulla oblongata
        a. Spinal cord

J. 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
    7. Middle cerebral

K. Venous structures
    1. Venous sinuses
        a. Superior and inferior sagittal sinus
        b. Superior and inferior anastomotic
        c. Great cerebral (Vein of Galen)
        d. Straight sinus
        e. Occipital sinus
        f. Confluence of sinuses (torcular herophili)
        g. Transverse sinus
        h. Sigmoid sinus
    2. Internal jugular

L. 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

M. Cisterns
1. Cisterna magna
2. Interpeduncular
3. Pontine cistern
4. Cerebellopontine angle (CPA)
5. Ambient
6. Quadrigeminal
7. Suprasellar (Chiasmatic)

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

O. Basal ganglia
1. Caudate nucleus
2. Lentiform
3. Claustrum
4. Internal capsule
5. External capsule
6. Extreme capsule

P. 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

Q. Lines of angulation (imaging baselines)
1. Supraorbitomeatal line
2. Orbitomeatal line
3. Infraorbitomeatal line
4. Anterior commissure - posterior commissure line (AC-PC line)

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

II. Neck

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

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

C. Musculature
1. Anterior triangle
2. Posterior triangle
3. Sternocleidomastoid
4. Sternohyoid/sternothyroid
5. Scalene
6. Trapezius

III. Spine

A. Cervical
    1. Vertebrae
    2. Arteries
    3. Musculature

B. Thoracic
    1. Vertebrae
    2. Arteries
    3. Musculature

C. Lumbar
    1. Vertebrae
    2. Arteries
    3. Musculature

IV. Chest and Mediastinum

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

B. Bony thorax
    1. Sternum
    2. Ribs
    3. Costal cartilages
    4. Scapulae
    5. 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. Serratus posterior
4. Levator scapulae
5. Latissimus dorsi
6. Rhomboid major/minor
7. Intercostal muscles external/internal

V. Abdomen

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

B. Quadrants

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
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. Large intestine
12. Musculature
    a. Linea alba
    b. Rectus abdominis
    c. Internal/external obliques
    d. Transversus abdominis
    e. Psoas
    f. Quadratus lumborum
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. Left gastric
5. Superior pancreaticoduodenal
6. Cystic

VI. 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. Gonadal
2. Venous
   a. External iliacs
   b. Internal iliacs
   c. Common iliacs
   d. Gonadal

C. Pelvic organs
    1. Urinary bladder
    2. Small intestine
    3. Large intestine
    4. Female reproductive organs
    5. Male reproductive organs

D. Musculature
    1. Iliacus
    2. Iliopsoas
    3. Piriformis
    4. Obturator internus/externus
    5. Pectineus
    6. Levator Ani
    7. Gluteus

VII. Musculoskeletal

A. Upper extremities
    1. Shoulder
        a. Bony anatomy
            1) Clavicle
            2) Scapula
            3) Humerus
            4) Acromioclavicular joint
        b. Musculature and tendons
            1) Deltoid
            2) Supraspinatus
            3) Infraspinatus
            4) Teres minor/major
            5) Subscapularis
            6) Coracobrachialis
            7) Supraspinatus tendon
            8) Biceps tendon
        c. Labrum and ligaments
            1) Glenoid labrum
            2) Glenohumeral ligaments
            3) Coracoacromial ligament
            4) Coracoclavicular ligaments
            5) Bursa
        d. Vasculature
    2. Elbow
        a. Bony anatomy
            1) Humerus
            2) Radius
            3) Ulna
        b. Musculature and tendons

1) Biceps brachii
2) Brachialis
3) Brachioradialis
4) Anconeus
5) Triceps brachii
6) Supinators
7) Pronator teres
8) Flexors
9) Extensors
10) Anterior group
11) Posterior group
12) Lateral group
13) Medial group

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

d. Bursa and Fat pads

e. 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) Ulna

d. Musculature
1) Pronator quadratus
2) Flexors
3) Extensors
4) Thenar
5) Palmar

e. Tendons
1) Palmar tendon group
2) Dorsal tendon group
3) Triangular fibrocartilage complex (TFCC)

f. 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. Musculature
1) Iliopsoas
2) Hamstring muscles
3) Gemellus superior/inferior
4) Piriformis
5) Quadratus femorius
6) Quadriceps
7) Abductor/adductor
8) Sartorius
9) Gracilis
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. Musculature
1) Hamstring muscles
2) Quadriceps
3) Gracilis
4) Popliteal
5) Gastrocnemius
6) Soleus
7) Sartorius
8) 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. Musculature
    1) Plantaris
    2) Peroneus brevis/longus
    3) Popliteal
    4) Gastrocnemius
    5) Soleus
    6) Sartorius
    7) Abductor hallucis/digiti
e. Vasculature
    1) Dorsalis pedis artery
    2) Lateral plantar artery
    3) Plantar arch

Pathology

Description
Content familiarizes students 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. Recognize common pathologies identified in MR.
2. Describe signal characteristics displayed by abnormal tissues during various pulse sequences and imaging modes in illustrating pathological processes.
3. Explain changes in sizes and shapes of anatomical structures that can indicate pathology.
4. Describe the effect of contrast agents on visualization of common pathologies.

Content

I. Neurological

A. Head and neck

1. Brain

a. Neoplastic disorders

1) Intra-axial

a) Astrocytoma
b) Glioblastoma
c) Ganglioma
d) Neuroblastoma
e) Metastases
f) Medulloblastoma
g) Hemangioblastoma

2) Extra-axial

a) Meningioma
b) Epidermoid
c) Dermoid
d) Lipoma
e) Pituitary adenoma
f) Pineal gland tumors and cysts

b. Infections and inflammatory disorders

1) Meningitis
2) Cerebral abscess
3) Encephalitis
4) HIV and associated infections
5) Sarcoidosis
6) Multiple sclerosis
7) Fungal, bacterial and viral infections

c. Vascular disorders

1) Stroke

a) Types

(1) Ischemic
(2) Hemorrhagic

b) Acute
c) Subacute
d) Brain hypoxia

2) Venous sinus occlusion
3) Arterial origin

a) Aneurysm
b) Vascular malformation
c) Nontraumatic hemorrhage
d) Arteritis

d. Congenital and hereditary disorders

1) Aqueductal stenosis
2) Chiari malformations
3) Dandy-Walker syndrome

e. Trauma
    1) Skull fracture
    2) Hematomas
    3) Shearing injury
    4) Contusion
    5) Hemorrhage
    6) Non-accidental trauma (NAT)
    7) Arterial dissection
f. Other (e.g., aging, metabolic, idiopathic, iatrogenic, phakomatoses)
g. 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
h. Paranasal sinuses, pharynx (nasal and oral) and larynx
    1) Ostiomeatal unit obstruction
    2) Cysts and polyps
    3) Sinusitis
    4) Malignancy
    5) Mucocele
    6) Papilloma
i. 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

2. Neck
    a. Masses
        1) Angiofibroma
        2) Hemangioma
        3) Paraganglioma
            a) Glomus jugulare
            b) Glomus tympanicum
            c) Glomus vagale
        4) Pleomorphic adenoma

5) Thyroid masses
b. Metastases
c. Cysts
d. Sialolithiasis
e. Trauma

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

II. Body

A. Thorax
   1. Mediastinum
   2. Thymoma
   3. Thymic hyperplasia
   4. Lymph node enlargement

5. Lymphoma
6. Teratoma
7. Neurogenic
8. Pancoast tumors
9. Aneurysms
10. Esophageal tumors
11. Chest wall
    a. Malignant processes
    b. Inflammatory lesions
12. Respiratory system
13. Cardiac and aorta
    a. Aneurysm
    b. Dissection
    c. Coarctation
    d. Thrombus
    e. Ischemic disease
        1) Infarction
        2) Viability
    f. Hypertrophic cardiomyopathy
    g. Pericardial disease
    h. Sarcoidosis
    i. Amyloidosis
    j. Intracardiac masses
        1) Myxoid tumor
        2) Myosarcoma
    k. Valvular heart disease
    l. Congenital heart conditions
    m. Arrhythmogenic right ventricular cardiomyopathy (ARVC)
14. Breast
    a. Dysplasia
    b. Cysts
    c. Benign tumors
    d. Inflammatory conditions
    e. Carcinomas
    f. Post-surgery or radiation
    g. Implant rupture

B. Abdomen
1. Liver
    a. Hemangioma
    b. Cysts
    c. Abscesses
    d. Carcinoma
    e. Hepatic metastases
    f. Venous thrombosis
    g. Hemochromatosis
    h. Cirrhosis

i. Fatty liver (steatosis)
j. Transplant
k. Gall bladder anomalies

2. Pancreas
    a. Pseudocyst
    b. Cystic fibrosis
    c. Pancreatitis
    d. Transplants
    e. Adenocarcinoma
    f. Islet cell tumors
    g. Metastases
3. Biliary system
    a. Ductal anomalies
    b. Biliary carcinoma
    c. Biliary stone
4. Kidneys
    a. Polycystic kidney disease
    b. Renal cell carcinoma
    c. Transitional cell carcinoma
    d. Metastatic disease
    e. Wilms' tumor
    f. Nephroblastoma
    g. Infarction
    h. Infection
    i. Transplant
    j. Hydronephrosis
5. Adrenal glands
    a. Adenoma
    b. Metastasis
    c. Pheochromocytoma
    d. Neuroblastoma
    e. Hemorrhage
6. Spleen and lymphatics
    a. Infections
    b. Benign focal lesions
    c. Hodgkin's and non-Hodgkin's lymphoma
7. Gastrointestinal (GI) tract
    a. Colon polyps
    b. Tumors
    c. Congenital anomalies
    d. Crohn's disease
    e. Fistula
    f. Inflammatory bowel disease (IBD)
8. Vascular disorders
    a. Renal artery stenosis
    b. Vasculitis

c. Abdominal aortic aneurysm (AAA)
d. Dissection
e. Thrombus
f. Atherosclerosis
g. Post radiation injury
h. Graft patency
i. Venous mapping
j. Vena cava tumor invasion

C. Pelvis
1. Female reproductive organs
a. Neoplastic disorders
1) Leiomyoma
2) Endometrial polyps
3) Carcinoma
4) Dermoid/teratoma
5) Fibroma
b. Inflammatory disorders
1) Pelvic inflammatory disease
2) Salpingitis and oophoritis
c. Endometriosis
d. Ovarian cysts
e. Trauma
f. Other (e.g., congenital, hereditary)
2. Male reproductive organs
a. Neoplastic disorders
1) Benign prostatic hyperplasia
2) Prostatic carcinoma
b. Inflammatory disorders
1) Prostatitis
2) Orchitis and epididymitis
c. Trauma
d. Other (e.g., congenital, hereditary)
3. Urogenital
a. Neoplastic disorders
b. Obstructions
c. Inflammatory disorders
d. Trauma
e. Other (e.g., congenital, hereditary)

III. Musculoskeletal

A. Skeletal system
1. Trauma
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. Arthritis
4. Meniscal Disorders
   a. Meniscal tears
   b. Meniscal cysts
   c. Discoid lateral meniscus
5. Temporal bone and temporal mandibular joint (TMJ)
   a. Cholesteatoma
   b. Fractures and dislocations
6. Trauma

   Other (e.g., congenital, hereditary)

Quality Assurance and Quality Control

Description
Content is designed to focus on the components of a quality assurance program for all aspects of MR, from initial MR scanning protocols through final reporting of findings. In addition, the content introduces quality assurance measures used in maintaining image quality.

Objectives
1. Discuss the purpose and importance of quality assurance.
2. List the components of a quality assurance program.
3. Identify errors in acquisition of MR source images.
4. Explain common errors in imaging acquisition that influence quality.
5. Apply methods for improving quality.
6. Apply a routine quality assurance program to maintain image quality.

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 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. Quality Improvement

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 department standard operating procedures

IV. Quality Control (QC)

A. Documentation

B. Cryogen level and pressure

C. Room temperature

D. Slice thickness

E. Spatial resolution

F. Contrast resolution

G. Signal-to-noise ratio

H. Center frequency

I. Transmit gain

J. Geometric accuracy

K. Equipment inspection

Optional Content

Content in this section will assist educators wishing to enhance the curriculum with select topics of instruction intended to satisfy the mission of their program or local employment market.

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
- Postprocedural patient instructions

Objectives

1. Identify the equipment and supplies required for cardiac imaging.
2. Describe techniques for patient monitoring and communication during cardiac imaging.
3. Recognize additional skills needed by MR Technologists for proper cardiac imaging.
4. List the advantages and disadvantages of MR imaging vs. other invasive and noninvasive imaging modalities.
5. Identify normal anatomy of the heart and great vessels as seen on routine MR images.
6. Apply imaging techniques that demonstrate common pathologies.
7. Evaluate images for diagnostic quality.
8. Provide postprocedural patient instructions
9. Describe the benefits of postprocessing 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

F. In and out flow

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. Stress imaging

I. T2*

J. T1 mapping

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

L. 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 post-contrast

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, which will support skill development in the use of clinical-based image workstations.

Objectives
1. Describe the benefits of postprocessing digital images.
2. List the requirements of the source data for each type of postprocessing technique.
3. Explain the fundamentals of image data retrieval stored on Digital Imaging and Communications in Medicine (DICOM) enabled archive systems.
4. Apply techniques and procedures for saving postprocessed images and image sets.
5. Describe various methods for 3-D image viewing.
6. Demonstrate the principles of correct ergonomics for workstation use.
7. Describe the principles, techniques, and applications of:
   a. MPR.
   b. MIP/MinIP.
   c. Subtraction.
   d. Diffusion.
   e. Perfusion.
   f. Spectroscopy
   g. fMRI.
   h. Fiber tracking.
   i. Fusion imaging.
   j. 3-D printing and modeling
   k. 4-D.
8. Acquire 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 them.

Content

I. Image Postprocessing

A. Definition and key aspects

B. Common MR postprocessing
1. MPR
2. MIP/MinIP
3. Subtraction
4. Diffusion
5. Perfusion
6. Spectroscopy
7. fMRI
8. Fiber tracking
9. Fusion imaging
10. 3-D printing and modeling
11. 4-D

C. Benefits to the observer

D. Source data requirements

E. How post processed images are generated

II. Retrieval and Exporting Image Data

A. Communication with configured DICOM devices

B. Image preview

C. Exporting/saving DICOM images

III. Viewing 3-D Images

A. Volume rendering

B. Rotations

C. Temporal images

D. Proper window/level (W/L) display

E. Transmission display

F. 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

D. Diffusion

E. Perfusion

F. Spectroscopy

G. fMRI

H. Fiber tracking

I. Fusion imaging

J. 3-D printing and modeling

K. 4-D

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. Technical Errors in Postprocessing

A. Noise

B. Segmentation misrepresentation

C. False stenosis

D. Wrap artifacts

E. Motion

F. Parallel imaging

G. Mismapping

H. Threshold levels

I. Aliasing of signal

J. Source image errors

K. Measurement errors

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. Apply 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 patient preparation necessary for a successful postprocessed procedure.
4. Determine if contrast media is indicated for each procedure.
5. Recognize the key views to best demonstrate the patient's clinical concern.
6. Identify image artifacts and ways to avoid or alleviate them on the post processed 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

Advanced Imaging Techniques and Emerging Trends

Description

Content presents a systematic approach to the techniques, procedures, and emerging trends in the field of advanced MRI procedures. These topics are becoming more prevalent and may inform future practice and career opportunities.

Objectives

1. Discuss the principles and techniques of advanced pulse sequences.
2. Describe the purpose and importance of emerging trends and techniques.
3. Identify potential risks and concerns of emerging trends and techniques.

Content

I. **Artificial Intelligence (AI)/Machine Learning (ML)**

II. **Fusion Imaging**

III. **Quantitative MR (e.g. fingerprinting, elastography)**

IV. **Neurography**

V. **3-D Printing and Modeling**

VI. **MR Lymphangiogram**

VII. **Remote Scanning**

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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Radiologic Science & Education. Association of Educators in Imaging and Radiologic Sciences, Albuquerque, NM.

Radiologic Technology. American Society of Radiologic Technologists, Albuquerque, NM.

Radiology. Radiological Society of North America, Oak Brook, IL.

Radiology Management. American Healthcare Radiology Administrators, Boston, MA.

Appendix

Curriculum Revision Workgroup

We would like to extend special recognition to the outstanding professionals who volunteered their time as members of the curriculum revision project:

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