Magnetic Resonance Curriculum

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Introduction

The goal of this document is to provide a common body of knowledge that is essential for entry-level magnetic resonance (MR) technologists. The 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 American Registry of Radiologic Technologists (ARRT®), and the Joint Review Committee on Education in Radiologic Technology (JRCERT).

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

- Core content: content in this section reflects essential 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 reflects specialized or emerging content that might not be practiced in every MR facility. It will assist program planners wishing to enhance the curriculum by selecting 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 MR procedures.

General Education Recommendations

General education is an integral part of the development of an MR technologist. This content is designed to assist in developing skills in communication, human diversity, scientific inquiry, critical thinking and judgment. All of these skills are required to perform the responsibilities of an entry-level MR technologist. Knowledge gained from general education serves to enhance the content and application of the MR imaging curriculum.

The ARRT® requires an associate degree (or higher) to apply for the certification exam. The content listed below is designed to serve only as guidance for program development as individual states, accreditation agencies and educational systems have unique general education requirements. Postsecondary general education should be gained through courses that provide college credit and meet the general content objectives listed below:

Mathematics and reasoning

- Demonstrate skills in analysis, quantification and synthesis.
- Apply problem-solving or modeling strategies.

Communication

- Write and read critically.
- Speak and listen critically.
- Perceive, gather, organize and present information.
- Locate, evaluate and synthesize material from diverse sources and points of view.

Humanities

- Demonstrate respect for diverse populations.
- Define ethics and its role in personal and professional interactions.
- Critically examine personal attitudes and values.

Information systems

- Use computerized systems to acquire, transfer and store digital information.
- Use technology to retrieve, evaluate, apply and disseminate information.

Social sciences

- Adapt interactions to meet the cultural and psychological needs of individuals.
- Describe individual and collective behavior.
- Exhibit and develop leadership skills.
- Exercise responsible and productive citizenship.
- Function as a public-minded individual.

Natural sciences

- Arrive at conclusions using the scientific method.
- Make informed judgments about science-related topics.
- Develop a scientific vocabulary.

Core Content

Fundamentals of Imaging Science and Health Care

Objectives

1. Identify other health science professions that participate in the patient's total health care.
2. Explain the relationships and interdependencies of departments within a health care organization.
3. Discuss the responsibilities and relationships of personnel and support systems in the medical imaging organization.
4. Differentiate between accreditation types.
5. Describe continuing education requirements and evaluation mechanisms at the national, state and regional levels.
6. List the regulatory agencies relevant to the imaging sciences and health care.
7. Define credentialing, certification, registration, licensure and regulations.
8. Discuss the purpose, function and activities of professional organizations at the local, state, national and international level and identify professional development and advancement opportunities.

Content

I. The Health Science Professions

A. Medical imaging professions
   1. Diagnostic radiography
   2. Fluoroscopy
   3. Mammography
   4. Bone densitometry
   5. Computed tomography
   6. Positron emission tomography
   7. Magnetic resonance imaging
   8. Diagnostic medical sonography
   9. Nuclear medicine technology
   10. Cardiac interventional
   11. Vascular interventional
   12. Radiologist assistant
   13. Radiation therapy (i.e., photon and proton therapy)
   14. Medical dosimetry
   15. MIMPS (formerly PACS) administration
   16. Education
   17. 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. Respiratory therapy
10. Social services
11. Others

II. The Health Care Continuum

A. Health care systems
   1. Hospitals
      a. Veterans Administration/military
      b. Not-for-profit
      c. For-profit
      d. System/network
   2. Outpatient ambulatory care facilities
   3. Mental health facilities
   4. Long-term residential facilities
   5. Home health care
   6. Hospice
   7. Preventive care
   8. Telemedicine

B. Payment and reimbursement systems
   1. Medicare
   2. Medicaid
   3. Private insurance
   4. Self-pay

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. Board of Trustees
   2. Hospital administration
   3. Admissions
   4. Information systems
   5. Materials management
   6. Support services
   7. Human resources

8. Legal counsel

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. Magnetic resonance
    4. Radiologists
    5. Radiology oncologists
    6. Radiology assistants
    7. Physician assistant
    8. Radiology nursing
    9. Medical physicist
    10. 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 preceptor
    5. Clinical staff

V. Accreditation

A. Definition

B. Programmatic

C. Institutional

D. Regional

VI. Continuing Education

A. Biennial requirements

B. Continuing qualifications requirements (CQR)

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. 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)

E. International organizations
   1. International Society of Radiographers and Radiological Technologists (ISRRT)
   2. International Society for Magnetic Resonance in Medicine (ISMRM)
   3. International Society for MR Radiographers & Technologists (ISMRT)

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)
6. American Board of Magnetic Resonance Safety (ABMRS)

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
   4. Webinars

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
   11. MR safety officer (MRSO)

Clinical Practice and Patient Management

Objectives

1. Describe the code of ethics and professional behaviors.
2. Communicate professionally with patients, staff members and the public, and demonstrate cultural competence.
3. Explain the role of health care team members.
4. Perform the steps of the MR examination, from proper scheduling and sequencing of imaging procedures to image evaluation and charting.
5. Apply infection control precautions and describe communicable disease terminology.
6. Evaluate and respond to medical emergencies.
7. Differentiate the functions of tubes, catheters, lines and infusion devices.
8. Apply national, organizational and departmental standards, protocols, policies and procedures regarding MR imaging and patient care.
9. Explain environmental considerations (e.g., gauss lines, radiofrequency (RF) shielding and magnetic shielding, etc.) and apply safety practices to protect patients, employees and staff entering the MR environment.

Content

I. Clinical Practice

A. Rules of ethics

B. Code of ethics and professional behavior
   1. Standards for supervision
      a. Direct
      b. Indirect
   2. The patient care partnership: (i.e., expectations, rights and responsibilities)

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
      a. Contraindications for MR imaging
      b. Laboratory results – normal ranges and values
         1) Blood creatinine level
         2) Estimated glomerular filtration rate calculation (eGFR)
         3) Hemoglobin test
         4) Arterial blood gas
         5) Prothrombin time (PT)

6) Part thromboplastin time (PTT)

2. Adult vs. pediatric considerations
3. Patient monitoring – emergent and nonemergent
   a. Visually and verbally
   b. Vital signs – normal ranges and values
      1) Temperature
         a) Fahrenheit
         b) Celsius
      2) Pulse
      3) Oxygen (O2 saturation)
      4) Respiration
      5) Noninvasive blood pressure (NIBP)
   c. Physiologic monitoring
      1) Electrocardiogram (ECG)
      2) Pulse oximetry
      3) End-tidal carbon dioxide (ETCO2)
      4) Temperature changes
      5) Invasive blood pressure
      6) Mental status

E. Protocol selection

F. Performance of imaging procedures
   1. Parameter adjustment
   2. Image evaluation/quality control

G. Charting
   1. Medical reconciliation
   2. Documentation

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
        c. Safe cleaning of equipment and disposal of contaminated materials
            1) Handling linens
            2) Needles
            3) Patient supplies
            4) Blood and body fluids
            5) Scanner, bore, coils, ancillary equipment
            6) Wound dressing care
            7) Handling and disposal of toxic or hazardous material
    2. Transmission-based precautions
        a. Airborne
        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
        b. Procedures
            1) Opening sterile packaging
            2) Donning sterile attire
            3) Skin preparation
            4) Draping
            5) Dressing changes
        c. Packing of supplies

d. Storage of supplies

B. Safe cleaning of equipment
   1. Scanner bore
   2. Coils
   3. Ancillary equipment

C. Communicable disease terminology
   1. Patient transportation
   2. Disease-specific
   3. Communicable
   4. Infectious pathogens

D. Transmission-based precautions
   1. Human immunodeficiency virus (HIV)
   2. Hepatitis
   3. Tuberculosis (TB)
   4. Respiratory syncytial virus (RSV)
   5. Hospital-acquired infection (HAI)
   6. Methicillin-resistant staphylococcus aureus (MRSA)
   7. Vancomycin-resistant enterococci (VRE)
   8. Clostridium difficile (C-diff)
   9. Influenza
   10. Candida Albicans
   11. Candida Auris
   12. Severe acute respiratory syndrome (SARS)
   13. Other (e.g., bird flu, Ebola)

E. Precautions for compromised patient (e.g., reverse isolation)
   1. Purpose
   2. Procedure

F. Psychological considerations

II. Medical Emergencies

A. Terminology

B. Emergency equipment

C. 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. Vasovagal response

7. Vertigo
8. Seizures
9. Epistaxis
10. Latex reactions
11. Mental illness
12. Neurological
    a. Head injuries
    b. Spinal injuries
13. Extremity fractures
14. Wounds
15. Burns
16. Reactions
    a. Contrast agents
    b. Latex
    c. Medications

III. Tubes, Catheters, Lines and Infusion Devices

A. Terminology

B. Function of devices

C. Nasogastric and nasointestinal tubes (i.e., weighted)

D. IVs, butterflies, and angiocatheters

E. Power injectors

F. Infusion pumps

G. Suction

H. Chest (thoracostomy) tube

I. Central venous lines
   1. Central lines
   2. PICC lines
   3. Mid lines

J. Postoperative drains

K. Oxygen administration using MR-conditional equipment

L. Ostomies

M. Urinary catheters (e.g., PureWick)

N. MR safety status of tubes, catheters, lines and infusion devices

IV. 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. Weighting (i.e., fat saturation)
   3. Spatial resolution
   4. Artifacts
   5. Anatomy

E. Image storage
   1. Digital imaging and communications in medicine (DICOM)
   2. Medical image management and processing system (MIMPS, formerly PACS)
      a. Legal requirements for image documentation
      b. Retention of storage media

F. Patient and personnel protection
   1. Screening (patient, personnel and 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. Previous contrast reactions
      j. Chronic hypertension
      k. Diabetes
      l. Unsafe clothing/underclothes (e.g., copper fit garments)
   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
    a. Gauss lines
    b. RF shielding and magnetic field shielding
    c. Warning alarms and signs
    d. Safety zones I - IV
    e. Climate control (i.e., temperature and humidity)
    f. Ferromagnetic metal detector
    g. Quench button
    h. Handheld magnets
4. Safety considerations
    a. Time-varying radiofrequency magnetic field ($B_{1)}$
    b. Static magnetic field (B_0)
    c. Spatial field gradient (dB/dx)
    d. Time-varying gradient magnetic field (dB/dt)
    e. Remote scanning

V. 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

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 drug administration 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.

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 MR Imaging (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. 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

VII. Intravenous Administration

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. Extravasation
   2. Phlebitis
   3. Air embolism
   4. Drug incompatibility
   5. Low IV fluid level

F. Initiation of intravenous administration
   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
      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 access
      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

G. Monitoring and care during invasive procedures
   1. Preparation for MR conditional cardiac monitoring
   2. Electrocardiogram (ECG) rhythms

VIII. Current Practice Status

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

B. State statutes

C. Employer prerogative

MR Contrast Administration

Objectives

1. Discuss specific considerations of MR contrast administration.
2. Identify the types of contrast agents used in MR imaging and the purpose for each.
3. Recall current practice standards regarding contrast administration.
4. Review policies and procedures for managing adverse effects of MR contrast.

Content

I. MR Contrast Media

- A. Definition
  1. Chelating agents
  2. Relaxivity
  3. Composition
     - a. Linear vs. macrocyclic
     - b. Ionic vs. nonionic
  4. Route of Administration
     - a. IV
     - b. Oral
     - c. Rectal
     - d. Intraarticular

- B. Types
  1. T1 contrast agents
     - a. Mechanism of action
     - b. Gadolinium
       1) Agents
          a) Extracellular
          b) Intracellular
          c) Blood pool
          d) Organ specific
       2) Dose
     - c. Manganese
       1) Agents
          a) Extracellular
          b) Intracellular
          c) Organ specific
       2) Dose
     - d. Helium
       1) Hyperpolarized
       2) Dose
  2. T2 contrast agents
     - a. Mechanism of action
     - b. Gadolinium
       1) Perfusion

2) Dose
c. Iron oxide
1) Agents
a) Extracellular
b) Oral GI agents
2) Dose
3. Oral agents
a. Negative contrast agents
b. Positive contrast agents
4. Off-label applications

II. Effect on images
A. T1-weighted images

B. T2-weighted images

C. T2*-weighted images

III. Safety in MR contrast administration
A. Patient history
1. Asthma
2. Drug allergy
3. Adverse reaction to contrast media
4. Kidney function
5. Cardiac function
6. Pregnancy
7. Breastfeeding

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

C. Preparation
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. Intravenous
        a. Manual
            1) Integrity of venous access
            2) Extravasation monitoring
            3) Follow-up care
        b. Power injector
            1) Integrity of venous access
            2) Monitor angiocatheter gauge for rate of contrast media flow (angiocatheter manufacturer guidelines)
            3) Alternative access sites (e.g., venous access ports, central lines)
            4) Extravasation monitoring
            5) Follow-up care
    2. Oral
    3. Rectal
    4. Intrathecal
    5. Intra-articular

F. Adverse reactions
    1. Local events
        a. Stop contrast administration
        b. Treatment/follow-up guidelines
            1) Compress (outlined by ACR)
            2) Monitoring the site
            3) Written patient discharge instructions
            4) Physician notification
            5) Documentation and reporting
    2. Systemic events
        a. Stop contrast administration
        b. Remove patient from MR suite
        c. Assess for breathing difficulty
        d. Treatment/follow-up guidelines
            1) Health care provider to administer medications
            2) Written patient discharge instructions
            3) Physician notification
            4) Documentation and reporting
        e. Availability of emergency medications
        f. Emergency contact phone numbers
        g. Emergency code buttons or switches
    3. Additional effects of gadolinium-based MR contrast
        a. Nephrogenic systemic fibrosis
        b. Gadolinium retention/deposition
        c. ACR/FDA guidelines regarding renal function and dialysis
        d. Gadolinium associated plaques (GAP)
        e. Anthropogenic gadolinium

Ethics and Law in the Imaging Sciences

Objectives

1. Review medical professional ethics and moral reasoning, highlighting key ethical considerations in healthcare delivery and patient care decision-making.
2. Identify specific ethical dilemmas in healthcare.
3. Describe legal issues related to patients' rights, informed consent, and other patient-related concerns.
4. Analyze the legal implications of professional liability, malpractice, professional negligence, and other relevant legal doctrines in professional practice.
5. Examine standards for securing and managing 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

II. Ethical Considerations in Health Care

A. Individual and societal rights

B. Cultural competence
   1. Organizational
   2. Interpersonal

C. Health equity
   1. Structural discrimination
   2. Implicit bias
   3. Health disparities

4. Social determinants of health
5. Intersectionality of identities
6. Equity versus equality
7. Health literacy

D. Access to quality health care

E. Medical and health care research

F. End-of-life decisions

III. Legal Issues

A. 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 Bill of Rights and Responsibilities
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 and sections
2. Legal doctrines
3. Legal and professional standards

4. Medical liability
5. Sources of law
6. Civil and criminal liability

G. Cyber security

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

Objectives

1. Discuss computer fundamentals.
2. Describe health care informatics and its applications in medical imaging.
3. Explain how regulations, laws, and standards related to informatics affect health care delivery.

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

II. Health Care Informatics

A. Definition

B. Theories

C. Databases

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. Medical image management and processing system (MIMPS, formerly PACS)

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

C. Health information exchanges (HIE)

D. Coding and standardization for obtaining patient health information

MR Safety

Objectives

1. Define the different magnetic fields associated with MR imaging and list the safety concerns associated with each one.
2. Apply safety measures to reduce the risk of safety incidents.
3. Identify and discuss the various components of MR safety screening for patients and personnel.
4. Describe the process of reporting MR safety incidents.
5. Discuss the various components of MR safety screening for equipment.
6. Recognize emergencies that can occur in MR imaging and explain appropriate reactions.
7. List MR safety organizations and identify the role of each organization in MR safety.

Content

I. Magnetic Fields in MR

A. Main static field

B. Radiofrequency field

C. Gradient field

II. Static Magnetic Field

A. Definitions
   1. Field strength (i.e., tesla [T])
   2. Fringe field (i.e., gauss [g])

B. Magnetic shielding
   1. Active
   2. Passive

C. Mechanical effects
   1. Translational force
   2. Rotational force
   3. Lenz's forces
   4. Device interactions
   5. Static magnetic field gradient

D. Biological effects
   1. Magnetophosphenes
   2. Magnetohydrodynamic effect (i.e., elevated/inverted T-wave)
   3. Vertigo/dizziness

E. Guidelines for static field safety
    1. Safety policies and procedures
    2. Safety zones
    3. Warning signage
    4. Patient screening
    5. Remote scanning

III. Time-Varying Radiofrequency (RF) Magnetic Field

A. Definition

B. Non-thermal effects

C. Thermal effects
    1. Core (whole body)
    2. Focal heating (e.g., burns)
        a. Transmitted RF coil proximity burns
        b. Conductive tissue loop burns
        c. Electrically conductive wires/leads
        d. Resonant wavelength-related heating of conductors
        e. Electrically conductive material–related burns
        f. Internal
        g. External

D. Device interactions

E. Specific absorption rate (SAR)
    1. IEC/FDA limits for whole-body heating
    2. Normal Operating Mode
    3. First Level Controlled Operating Mode
    4. Second Level Controlled Operating Mode

F. SAR reduction methods

G. Specific energy dose (SED)

H. B1+rms

I. Guidelines for RF safety
    1. Patient positioning and padding
    2. Monitoring equipment
    3. Patient screening
    4. Patient monitoring
    5. Physiological conditions
    6. Sedation
    7. Pregnancy

IV. Time-varying Gradient Magnetic Fields

A. Definition

B. Thermal effects (e.g., heating)

C. Non-thermal effects
   1. Nerve stimulation – peripheral neurostimulation
      a. Orientation of field gradient
      b. Location in the body
      c. Duration of the gradient pulse
      d. Stimulation threshold
      e. FDA limits
   2. Magnetophosphenes

D. Acoustic effects
   1. Hearing damage
   2. OSHA regulations

E. Induced voltages

F. Device interactions
   1. Gradient coils and current waveforms
   2. Linear magnetic fields for spatial encoding

G. 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 Environment

A. Personnel
   1. Non-MR
   2. MRMD, MRSE, MRSO
   3. Level 1
   4. Level 2

B. Safety screening questionnaire
   1. Approved by Level 2 personnel
   2. Documentation review
      a. Written
      b. Verbal
      c. Surgical and medical history

C. Contraindications for entering the MR suite
    1. Implanted devices/objects
        a. Electronic
        b. Metallic
        c. Magnetic
    2. External devices/objects (e.g., patches, pain pump)
    3. Foreign bodies

D. Informed or special consent

E. Monitoring patients
    1. Verbal/auditory
    2. Visual
    3. Claustrophobia/anxiety disorder
    4. Mechanical
        a. ECG
        b. Pulse oximeter

F. Reporting of MR safety incidents

VI. Equipment Safety Screening in MR Environment

A. MR safety labeling
    1. MR Safe
    2. MR Conditional
    3. MR Unsafe

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 (i.e., 9 gauss line)

F. Monitoring equipment 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
   3. Suspending electricity to the MR scanner
   4. Quench protocol
   5. MR Safe fire equipment
   6. Training for local fire departments

C. Pinned metallic items
   1. Patient danger
   2. Pinned equipment
   3. Quench protocol

D. Other 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. MR Safety Organizations

A. International Electrotechnical Commission (IEC)

B. U.S. Food and Drug Administration (FDA)

C. National Electrical Manufacturers Association (NEMA)

D. American Society for Testing and Materials (ASTM)

E. American College of Radiology (ACR)

F. International Society for Magnetic Resonance in Medicine (ISMRM) Safety Group

G. Institute for Magnetic Resonance Safety Education and Research (IMRSER)

H. Intersocietal Accreditation Commission (IAC)

I. American Board of Magnetic Resonance Safety (ABMRS)

MR Instrumentation and Imaging

Objectives

1. Explain magnetism and magnetic properties.
2. Define gauss (g), Tesla (T) and the electromagnetic spectrum.
3. Identify the main types of clinical magnets and their advantages and disadvantages.
4. Describe the effect of field strength on image quality.
5. Explain the importance and function of the shim, radiofrequency, and gradient systems in MR imaging.
6. Demonstrate the use of ancillary equipment in MR imaging.

Content

I. Categories of Magnetism

A. Diamagnetism (i.e., nonmagnetic)
   1. Electron configurations
   2. Effects of externally applied magnetic fields
   3. Materials (e.g., wood, glass, gold)

B. Paramagnetic (i.e., slightly magnetic)
   1. Electron configurations
   2. Effects of externally applied magnetic fields
   3. Materials (e.g., gadolinium)

C. Superparamagnetic (i.e., slightly higher than paramagnetic [hemosiderin])

D. Ferromagnetism (i.e., highly magnetic)
   1. Electron configuration
   2. Materials (e.g., iron)
   3. Permanently magnetized after exposure to static field

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

II. Types of Magnets

A. Permanent
   1. Characteristics
      a. Field strength
      b. Configuration
      c. Magnetic field direction
      d. Maintenance considerations
      e. Ohm's Law
   2. Alnico

B. Resistive

1. Characteristics
    a. Field strength
    b. Configuration
    c. Magnetic field direction
    d. Maintenance considerations
2. Ohm's Law
3. Materials

C. Superconductive
1. Characteristics
    a. Field strength
    b. Configuration
    c. Magnetic field direction
    d. Maintenance considerations
2. Materials
3. Maintenance considerations
    a. Cryogens
    b. Quench/emergency rundown

D. Hybrid
1. Characteristics
    a. Field strength
    b. Configuration
    c. Magnetic field direction
    d. Maintenance considerations
2. Materials

E. Field configuration
1. Static magnetic field (B_0)
2. Spatial magnetic field (dB/dx)
3. Safety considerations

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

G. Magnetic field shielding
1. Regulations

a. 5-gauss
b. 9-gauss (new guidelines)
c. Shielding methods
1) Passive
2) Active
2. Methods
3. Nuclei in a magnetic field
a. Magnetic moments
b. Vectors (NMV)
c. Alignment

III. Shim Systems

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

B. Shim function
1. Maintain homogeneity
a. Units of measurement
2. Personnel who perform shimming
a. Technologists
b. Service engineers
c. Physicists

C. Shim field power supply

IV. Radiofrequency Systems

A. Types of RF coils and RF configurations
1. Transmit-only coils
a. Linear
b. Quadrature, circularly polarized
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 coils
a. Linear

b. Quadrature, circularly polarized
c. Multichannel

B. RF field configuration
1. B_1
2. Oscillating field
3. Safety considerations

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

D. Resonance
1. Precession
a. Spin alignment
b. Precessional frequency
2. Larmor equation
3. Larmor frequency
a. Field strength (B_0)
b. Related to elements
c. Gyromagnetic ratio
4. Units of measurement
a. MHz (megahertz)
b. Hz (hertz)
5. Electromagnetic spectrum
a. Nonionizing radiation vs. ionizing radiation
b. Electromagnetic radiation
1) Magnetic component (B1)
2) Electric component
6. RF excitation pulses

E. Faraday's law of induction

F. RF and field strengths

G. RF field shielding
1. Regulations and recommendations
2. Faraday cage
a. Copper
b. Steel

V. Gradient Systems

A. Types of gradients and gradient configurations
1. Characteristics
2. Gradient slope
3. Polarity

B. Gradient characteristics
    1. Strength and amplitude
    2. Rise time
    3. Slew rate (T/m/sec)
    4. Duty cycle

VI. Ancillary Equipment

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

B. Power injectors
    1. Syringes
    2. Tubing

C. Ancillary patient care equipment

D. 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 for purchase

B. Facility design

C. Government regulations and certificate of need

D. Ancillary equipment

E. 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

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 use of contrast media and its effects on image quality.
9. Recognize common MR artifacts, including causes and compensations for each.

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. Atomic structure
   1. Nucleus
      a. Proton
      b. Neutron
   2. Mass number
   3. Atomic number
   4. Electron

B. Charge and motion

C. MR active nuclei

1. Characteristics
    a. Angular momentum
    b. Magnetic moment
2. Elements
    a. Hydrogen
    b. Others

III. Relaxation and Contrast Media in MR

A. Enhanced T1 relaxation with contrast agents
    1. Gadolinium
    2. Other T1 agents

B. Enhanced T2* relaxation with contrast agents
    1. Gadolinium
    2. Iron oxide
    3. Other T2 agents

IV. MR Image Contrast Characteristics

A. Weighting in MR imaging
    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

B. Pulse sequences and weightings

V. Signal Production

A. Vectors
    1. Magnitude
    2. Direction
    3. Net magnetization vector

B. Cartesian coordinates
    1. X, Y, Z
    2. Mx, My, Mz
    3. Transverse plane
    4. Longitudinal plane

C. Effect of the static magnetic field
    1. Thermal equilibrium
    2. Low energy protons, spin-up, parallel
    3. High energy protons, spin-down, anti-parallel
    4. Precessional frequency

a. Larmor equation
b. Field strength
c. Gyromagnetic ratio
d. Elements

D. Resonance/excitation
1. Definition
2. Larmor frequency
3. RF energy/pulse (B1)
a. 90-degree flip angle
b. Partial flip angle
4. Phase
a. Coherent
b. Incoherent

E. Relaxation
1. T1 relaxation
a. Longitudinal recovery
b. Spin-lattice
c. T1 recovery
2. T2 relaxation
a. Transverse decay
b. Spin-spin
c. T2 decay

F. MR signal induction
1. Free induction decay (FID)
a. T2*
b. T2 prime
2. MR echo
a. Spin echo (i.e., Hahn)
b. Gradient echo (i.e., stimulated)

G. MR signal conversion
1. Fourier transformation
2. *k*-space
a. Definition
b. Characteristics
1) Conjugate symmetry
2) Phase domain (i.e., pseudo frequency)
3) Frequency domain
4) k-space rows
a) Outer rows
(1) Spatial resolution
b) Center rows
(1) Contrast resolution

(2) Signal

3. Filling options
   a. Echo dephasing/rephasing
   b. Partial (fractional) echo
   c. Half Fourier
   d. Rectangular FOV
   e. Parallel imaging
   f. Fast imaging sequences
   g. Sequential
   h. Volumetric
      1) 2D
      2) 3D
   i. Linear
   j. Elliptic centric
   k. Single shot
   l. Motion resistant
   m. Temporal filling

VI. Spatial Localization

A. Physical gradients (i.e., X, Y, Z)
   1. Definition
   2. Effect on the magnetic field B_0
   3. Slice select gradient
      a. Effect on *k*-space
      b. Image selection
         1) Axial/transverse
         2) Coronal
         3) Sagittal
      c. Slice thickness
         1) Amplitude
         2) Transmit bandwidth
   4. Phase encoding gradient
      a. Effect on *k*-space
         1) Phase matrix
            a) Amplitude
            b) Signal intensity
   5. Frequency encoding gradient
      a. Effect on *k*-space
         1) Frequency matrix
            a) Amplitude
            b) FOV
   6. Refocusing of gradient echo

B. Signal sampling
   1. Analog/digital
   2. Nyquist theorem

3. Receive bandwidth
4. Sampling time/acquisition window
5. Sampling rate/frequency
6. Sampling interval
7. Frequency matrix

VII. Artifacts

A. Definition

B. Causes and appearances

C. Coil selection and placement

D. Solutions
   1. Operator-adjustable parameters
   2. Patient care and communication
   3. Engineer service call

E. Types
   1. Physics artifacts
      a. Dielectric effect
      b. B_1 inhomogeneity
      c. Chemical shift
      d. Susceptibility
         1) Metal
         2) Tissues with dissimilar chemical composition

   2. Sampling artifacts
      a. Aliasing
      b. Cross-talk
      c. Cross-excitation
      d. Parallel imaging
      e. Truncation (i.e., Gibbs)
      f. Partial volume averaging

   3. Motion artifacts
      a. Voluntary
      b. Involuntary
      c. Ghosting
      d. Blurring

   4. Technical errors
      a. Improper centering
      b. Incorrect coil selection/placement

   5. Hardware artifacts

a. Moiré
b. Corduroy
c. Shading
d. RF leak (i.e., zipper)

MR Imaging Parameters

Objectives

1. Describe imaging parameters that relate to image contrast, spatial resolution and signal-to-noise ratio (SNR) on MR images.
2. Explain the role of parameter selection in MR weighting.
3. Apply MR imaging parameters in the clinical setting.

Content

I. Resolution Parameters

A. Signal-to-noise

B. Spatial resolution
   1. Field-of-view (FOV)
   2. Slice thickness
   3. Matrix (phase and frequency)
      a. Pixel
      b. Voxel

C. Contrast resolution

D. Temporal resolution

E. Patient considerations (e.g., adult, pediatric)

II. Scan Time Parameters

A. Scan time formula
   1. Repetition time (TR)
   2. Number of phase encodings (matrix)
   3. Number of signals averaged (NSA)
   4. Echo train length (ETL)/turbo factor
   5. Other considerations
      a. Concatenations/acquisitions
      b. Slice thickness and spacing
      c. Number of slices
      d. Slices in a 3D (volume) acquisition

B. Acceleration techniques
   1. Parallel imaging
   2. Compressed sensing
   3. Multi-band/multi-slice

III. Signal-to-Noise Parameters

A. Number of signals averaged (NSA)

B. Number phase & frequency encodings (matrix)

C. Slice thickness

IV. Dimensionality (mode)

A. 2D

B. 3D

C. 4D/time-resolved

D. Slice thickness/gap

E. Slice order

F. Phase encoding considerations

MR Imaging Options

Objectives

1. Define signal-to-noise, contrast-to-noise, spatial resolution, contrast resolution and temporal resolution, and the relationships between each.
2. Identify how patient considerations affect MR imaging protocols.
3. Review MR imaging parameters used to optimize signal-to-noise and spatial resolution.
4. Explain how acceleration and suppression techniques are used in the clinical setting.
5. Define and use intensity correction, tailored RF, zero-filling techniques, no phase-wrap, and extended dynamic range in MR imaging.

Content

I. Definitions

A. Signal-to-noise

B. Contrast-to-noise

C. Spatial resolution

D. Contrast resolution

E. Temporal resolution

F. Relationships
   1. Direct relationship
   2. Inverse (indirect) relationship

II. Pediatric vs Adult Considerations

III. Phase Encoding Considerations

IV. Factors Affecting Signal-to-Noise Ratio (SNR)

A. Magnetic field strength (B_0)

B. Proton density

C. Matrix
   1. Spatial resolution
   2. Pixel
   3. Voxel
   4. Pixel/voxel calculations
   5. Effect on scan time

D. Field-of-view

E. Slice thickness

F. Number of excitations

G. Flip angle

H. Relaxation time (TR)

I. Echo time

J. Receive bandwidth

V. Factors Affecting Spatial Resolution

A. Voxel size
   1. Slice thickness
   2. FOV
      a. Square
      b. Rectangular
   3. Matrix
   4. Pixel size

B. Partial volume averaging

VI. Additional Imaging Selections

A. Concatenations/acquisitions

B. Dimensionality (mode)
   1. Multi-echo
   2. Multi-slice
   3. Sequential (2D)
   4. Volume imaging
      a. Isotropic/anisotropic
      b. 2D acquisition
      c. 3D acquisition
   5. 4D/time resolved

VII. Acceleration Techniques

A. Echo train length (ETL)/turbo factor

B. Parallel imaging

C. Compressed sensing

VIII. Signal Suppression and/or Separation Techniques

A. Spatial saturation band

B. Spectral/frequency specific saturation
    1. Fat saturation
    2. Water saturation
    3. Silicone saturation

C. Spectral/frequency specific suppression (i.e., SPIR)

D. Magnetization transfer

E. Dixon techniques
    1. Fat only
    2. Water only
    3. In-phase
    4. Out-of-phase

F. Motion modification
    1. Gradient moment nulling (flow compensation)
    2. Physiologic gating and triggering
        a. Respiratory gating
        b. Peripheral gating
        c. Cardiac gating
            1) Prospective
            2) Retrospective
    3. Navigator pulse

IX. Intensity Correction

X. Tailored RF

XI. Zero-Interpolation Filling (ZIP)

A. 1024

B. 512

C. x 2

D. x4

XII. No Phase-Wrap

XIII. Extended Dynamic Range

MR Pulse Sequences

Objectives

1. Describe the characteristics and uses of spin-echo-based pulse sequences.
2. Identify the characteristics and uses of gradient-echo-based pulse sequences.
3. Review the characteristics and uses of susceptibility-weighted pulse sequences.
4. Explain the principles, characteristics, and clinical applications of MR spectroscopy.

Content

I. Saturation/Partial Saturation Sequence

II. Spin-Echo Group

A. Characteristics (e.g., refocusing pulse)

B. Conventional spin-echo
   1. Pulse sequence diagram
   2. Characteristics (e.g., *k*-space)
   3. Advantages and disadvantages
   4. Image characteristics

C. Fast (turbo) spin-echo
   1. Pulse sequence diagram
   2. Characteristics
      a. *k*-space
      b. Echo train length (turbo factor)
      c. Echo spacing
      d. J coupling
      e. Effective TE
      f. Magnetization transfer
   3. Advantages and disadvantages
   4. Image characteristics

D. Single-shot fast (turbo) spin-echo
   1. Pulse sequence diagram
   2. Characteristics
   3. Advantages and disadvantages
   4. Image characteristics

E. Inversion recovery
   1. Spin-echo inversion recovery
      a. Pulse sequence diagram
      b. Characteristics (e.g., inversion time)
      c. Advantages and disadvantages
      d. Image characteristics
   2. Fast (turbo) spin-echo inversion recovery

a. Pulse sequence diagram
b. Characteristics (e.g., inversion time)
c. Advantages and disadvantages
d. Image characteristics

3. Double inversion recovery (driven equilibrium)
   a. Pulse sequence diagram
   b. Characteristics (e.g., inversion time)
   c. Advantages and disadvantages
   d. Image characteristics
4. Short tau inversion recovery (STIR)
   a. Pulse sequence diagram
   b. Characteristics
      1) Inversion time
      2) TE/TR
   c. Advantages and disadvantages
   d. Image characteristics
5. Fluid attenuating inversion recovery (FLAIR)
   a. Pulse sequence diagram
   b. Characteristics
      1) Inversion time
      2) TE/TR
   c. Advantage and disadvantages
   d. Image characteristics

F. Spectral attenuated inversion recovery (SPAIR/SPIR)
   1. Pulse sequence diagram
   2. Characteristics (e.g., inversion time)
   3. Advantages and disadvantages
   4. Image characteristics

G. Phase sensitive inversion recovery (PSIR)
   1. Pulse sequence diagram
   2. Characteristics (e.g., inversion time)
   3. Advantages and disadvantages
   4. Image characteristics

III. Gradient Echo Group

A. Gradient echo
   1. Coherent gradient echo
      a. Pulse sequence diagram
      b. Characteristics (e.g., rewinder pulse)
      c. Advantages and disadvantages
      d. Image characteristics
   2. Incoherent gradient echo
      a. Pulse sequence diagram
      b. Characteristics (e.g., spoiler pulse)

c. Advantages and disadvantages
d. Image characteristics

3. Fast gradient echo
   a. Steady state free precession
      1) Pulse sequence diagram
      2) Characteristics
      3) Advantages and disadvantages
      4) Image characteristics
   b. Balance gradient echo
      1) Pulse sequence diagram
      2) Characteristics
      3) Advantages and disadvantages
      4) Image characteristics

B. Echo planar imaging
   1. Diffusion
      a. Pulse sequence diagram
      b. Characteristics
      c. Advantages and disadvantages
      d. Image characteristics
   2. Perfusion
      a. Pulse sequence diagram
      b. Characteristics
      c. Advantages and disadvantages
      d. Image characteristics
   3. Blood oxygen level dependent (BOLD)
      a. Pulse sequence diagram
      b. Characteristics
      c. Advantages and disadvantages
      d. Image characteristics

IV. Susceptibility Weighted Imaging (T2*)

A. Pulse sequence diagram

B. Characteristics

C. Advantages and disadvantages

D. Image characteristics

V. Spectroscopy

A. Characteristics

B. Spectra

C. Single voxel

D. Multivoxel

MR Image Contrast

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.

Content

I. Image Contrast Weighting

A. Definition

B. Intrinsic contrast characteristics
   1. Definition
   2. Longitudinal regrowth (T1 recovery)
   3. Transverse decay (T2 decay)
   4. Spin density
      a. Actual proton density (total number of mobile water protons)
      b. Relative proton density (spin excess during thermal equilibrium)
   5. Flow and motion
      a. Orders of motion
      b. Flow characteristics
         1) Laminar flow
         2) Vortex flow
         3) Turbulent flow
         4) Stagnant flow
   6. Intrinsic characteristics affecting contrast
      a. Inherent energy
      b. Proximity of molecules
      c. Tumbling rate of molecules

C. Extrinsic contrast characteristics
   1. Definition
   2. Repetition time (TR)
   3. Echo time (TE)
   4. Flip angle
   5. Inversion time
   6. b-value

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. Other options for MR image contrast
    7. PC-MRA
        a. Velocity encoding (VENC) value
        b. Flow direction
    8. Diffusion imaging
        a. Single/multi shots
        b. b-value
    9. Flow imaging
        a. Saturation pulses
            1) Spatial presaturation
            2) Spectral saturation
        b. Gradient moment nulling

II. Image Contrast Characteristics

A. T1-weighted image
    1. Spin echo
    2. Gradient echo

B. T2-weighted image
    1. Conventional spin echo
    2. Gradient echo
    3. 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

III. MR Image Formation

A. Physical gradients
    1. X
    2. Y
    3. Z

B. Spatial localization
    1. Slice selection

2. Phase encoding
3. Frequency encoding

C. Refocusing
1. Gradient
2. RF

IV. Postprocessing

A. Measurements

B. Reconstruction and reformatting
1. Multiplanar reconstruction (MPR)
2. 3D reformats
3. Volume reconstruction (VR)
4. Maximum-intensity pixel (MIP)
5. Shaded surface display (SSD)

MR Imaging Procedures

Objectives

1. Describe elements of patient screening and demonstrate effective communication skills with patients, family members and the health care team.
2. Apply MR safety principles and protective practices associated with MR imaging procedures.
3. Describe the coils available for MR and describe common pulse sequences used to evaluate the different areas of the body.
4. Recognize common artifacts that occur during imaging.
5. List image quality problems and appropriate solutions.
6. Evaluate images for positioning, anatomy, pulse sequences, coil placement and overall quality.
7. Identify common indications and pathologies for body systems in adult and pediatric patients.
8. Describe normal MR tissue characteristics of anatomical structures of interest and describe the MR tissue characteristics of pathological processes.
9. 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
- B. Establish patient rapport
  1. Explain procedure
  2. Proper patient screening
     a. Metal on patient
     b. Metal inside of a patient
     c. Physical contraindications
     d. Contrast contraindications
  3. Patient assistance
- C. Patient education, communication and monitoring
  1. Preprocedural
  2. Intraprocedural
  3. Postprocedural
  4. Cultural competency
  5. Identifying and overcoming barriers
  6. Clinical situations
  7. Common MR safety issues and concerns
- D. Patient preparation
  1. Appropriate disrobing and gowning
  2. Removal of artifact-causing items

E. Room preparation
    1. Maintain a clean and organized environment
    2. Ensure necessary supplies and accessory equipment are available
F. Exam time out

II. Intraprocedural Considerations

A. Equipment and materials needed

B. Contrast media

C. Use of contrast agents
    1. Linear vs macrocyclic
    2. Ionic vs nonionic
    3. NSF Category I-III GBCAs
    4. Extracellular vs hepatobiliary agents
    5. Gadolinium deposition

III. Considerations for MR Procedures

A. Patient/staff related
    1. Patient instructions
    2. Patient positioning
        a. Patient comfort
        b. Age-related
        c. Pathology-related
    3. Procedural sedation
        a. Minimal sedation
        b. Moderate sedation
        c. Conscious sedation
        d. General anesthesia
    4. Monitoring of conditional devices
    5. Special needs patients
        a. Atypical conditions
        b. Trauma
    6. Ancillary staff considerations

B. Imaging examination related
    1. Coil type, selection and positioning
    2. Protocol considerations
    3. Pulse sequences considerations
    4. Imaging planes
        a. Positioning criteria
        b. Axial, sagittal and coronal
        c. Anatomy best demonstrated
    5. 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

6. Parameter considerations
   a. Timing
   b. Flow and motion effect
   c. Signal-to-noise
   d. Artifacts
   e. Spatial resolution
   f. Contrast resolution
7. Image viewing and quality analysis
   a. Window level
   b. Proper orientation
   c. Image quality analysis
8. Image transmission/storage/archive

IV. 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. MR/MRA anatomic procedure regions
1. Neurological system
   a. Head and neck
      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/MRV)
         b) Vascular head neck (MRA/MRV)

11) Spectroscopy
12) Perfusion
13) Cranial nerves
14) Soft tissue neck

b. Spine
1) Cervical
2) Thoracic
3) Lumbar
4) Sacrum/coccyx
5) Total spine
6) Lumbar plexus
7) Sacroiliac (SI) joints

2. 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 of the body
a. Thorax
1) Chest
2) Vascular thorax
3) Cardiac
4) Breast
5) Brachial plexus

b. Abdomen
1) Liver
2) Pancreas
a) Adrenals
b) Kidneys
3) Enterography
4) Vascular abdomen (MRA/MRV)
5) Magnetic resonance cholangiopancreatography (MRCP)

c. Pelvis
1) Soft tissue pelvis (e.g., bladder, rectum)

2) Female soft tissue pelvis (e.g., uterus)
3) Male soft tissue pelvis (e.g., prostate)
4) Vascular pelvis (MRA/MRV)

B. Special imaging techniques
   3. 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
   4. Functional techniques
      a. Diffusion
      b. Perfusion (e.g., BOLD)
      c. Surgical planning
      d. CINE
      e. Subtraction
      f. Spectroscopy
      g. fMRI
      h. Fiber tracking
   5. Dynamic imaging
   6. Image postprocessing
      a. Maximum intensity projections (MIP)
      b. Minimum intensity projections (MinIP)
      c. Multiplanar reformats (MPR)
   7. Fusion imaging

V. Technical Errors in Postprocessing

B. Noise

C. Segmentation misrepresentation

D. False stenosis

E. Wrap artifacts

F. Motion

G. Parallel imaging

H. Mismapping

I. Threshold levels

J. Aliasing of signal

K. Source image errors

L. Measurement errors

Sectional Anatomy

Objectives

1. Identify anatomical structures in MR images across various planes of the body (transverse, coronal, sagittal, oblique).
2. Translate anatomical structures from their 2D planar image appearance into their appearance within multiplanar, curved planar and 3D volumetric reformations.
3. Review 3D volumetric data used to enhance 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

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

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
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. Retroorbital fat
12. Ophthalmic artery
13. Retinal vein

Q. Lines of angulation (imaging baselines)
1. Supraorbitomeatal line (SM)
2. Orbitomeatal line (OM)
3. Infraorbitomeatal line
4. Anterior commissure – posterior commissure line (AC-PC line)
5. Subcallosal line (SC)
6. Reid's baseline
7. Brainstem

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

D. Sacrum/coccyx
1. Sacroiliac joints
2. Vertebrae
3. Lumbar plexus

IV. Chest and Mediastinum

A. Bony thorax
1. Sternum
2. Ribs
3. Costal cartilages

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

C. Mediastinum
1. Thymus gland
2. Heart
    a. Coronary vessels

a. Arteries
b. Veins (e.g., coronary sinus)
c. 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. Pulmonary vessels
a. Pulmonary arteries
b. Pulmonary veins

4. Aorta and branches
a. Ascending aorta
b. Aortic arch
c. Branches of the aortic arch
d. Subclavian arteries
1) Mammary arteries
2) Vertebral arteries

e. Descending (thoracic) aorta
1) Bronchial arteries
2) Intercostal arteries
a) Anterior arteries
b) Posterior arteries
c) 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

D. Breasts
1. Lobules
2. Ducts
3. Lymph nodes

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

F. 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
        d. Liver lobes
        e. Living donor variants
    4. Gallbladder and biliary system
    5. Pancreas
    6. Spleen
    7. Adrenal glands
    8. Urinary system and tract

a. Kidneys
    1) Cortex
    2) Medulla
    3) Renal pelvis
b. Ureters

9. Stomach
10. Small intestine
    a. Duodenum
    b. Jejunum
    c. Ilium
11. Large intestine
    a. Cecum
    b. Iliocecal valve
    c. Ascending colon
    d. Transverse colon
    e. Descending colon
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) Proper hepatic arteries
    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
    a. Suprarenal

b. Renal
c. Gonadal

3. Parietal branches
   a. Inferior phrenic
   b. Lumbar
   c. Middle sacral
4. Terminal branches
   a. Right common iliac
   b. Left common iliac

F. Tributaries of the inferior vena cava
1. Anterior visceral (e.g., hepatic veins)
2. Lateral visceral
   a. Right suprarenal
   b. Renal veins
      1) Left gonadal vein
      2) Left suprarenal vein
   c. Right gonadal vein
3. Tributaries of origin
   a. Common iliacs
   b. Median sacral

G. Tributaries of the portal vein
1. Splenic
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. Female reproductive organs
    3. Male reproductive organs
    4. Rectum

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) Proximal 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. Glenoid labrum
        d. Ligaments
            1) Glenohumeral ligaments
            2) Coracoacromial ligament
            3) Coracoclavicular ligaments
            4) Bursa
        e. Vasculature
    2. Elbow

a. Bony anatomy
    1) Distal humerus
    2) Proximal radius
    3) Proximal 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
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
    8) Radial nerve
    9) Median nerve

3. Hand and wrist
    a. Bony anatomy
        1) Phalanges
        2) Metacarpals
        3) Carpal bones
        4) Distal radius
        5) Distal ulna
    b. Musculature
        1) Pronator quadratus
        2) Flexors
        3) Extensors
        4) Thenar
        5) Palmar
    c. Other soft tissue structures
        1) Palmar tendon group
        2) Dorsal tendon group
        3) Triangular fibrocartilage complex (TFCC)

d. Neurovascular
    1) Ulnar artery
    2) Ulnar nerve
    3) Radial artery
    4) Median nerve
    5) Deep palmar arch
    6) Superficial palmar arch
    7) Carpal tunnel

B. Lower extremities
1. Hip/thigh
    a. Bony anatomy
        1) Os cosis
        2) Acetabulum
        3) Proximal femur
    b. Labrum
    c. Ligaments
        1) Iliofemoral
        2) Pubofemoral
        3) Ischiofemoral
        4) Transverse ligament
    d. Musculature
        1) Iliopsoas
        2) Hamstring muscles
        3) Gemellus superior/inferior
        4) Piriformis
        5) Quadratus femorius
        6) Quadriceps
        7) Abductor/adductor
        8) Sartorius
        9) Gracilis
    e. 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
        1) Distal femur
        2) Proximal tibia
        3) Proximal fibula
    b. Menisci
    c. Ligaments
        1) Anterior cruciate

2) Posterior cruciate
3) Medial collateral
4) Lateral collateral

d. Musculature
1) Hamstring muscles
2) Quadriceps
3) Gracilis
4) Popliteal
5) Gastrocnemius
6) Soleus
7) Sartorius
8) Tibialis anterior

e. Vasculature
1) Popliteal artery
2) Anterior tibial artery
3) Posterior tibial artery
4) Fibular artery

3. Foot and ankle

a. Bony anatomy
1) Phalanges
2) Metatarsals
3) Tarsal bones
4) Distal tibia
5) Distal fibula

b. Tendons
1) Achilles
2) Peroneal
3) Flexor group
4) Tibialis group

c. Musculature
1) Plantaris
2) Peroneus brevis/longus
3) Popliteal
4) Gastrocnemius
5) Soleus
6) Sartorius
7) Abductor hallucis/digiti

d. Neurovasculature
1) Dorsalis pedis artery
2) Lateral plantar artery
3) Plantar arch
4) Variations in pedal arterial supply
5) Common peroneal nerve
6) Dorsal nerve group
7) Plantar nerve group

Pathology

Objectives

1. Recognize common pathologies identified in MR imaging.
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) Primary tumors
        - a) Malignant
        - b) Benign
      - 2) Metastases
    - b. Infections and inflammatory disorders
      - 1) Meningitis
      - 2) Cerebral abscess
      - 3) Encephalitis
      - 4) HIV and associated infections
      - 5) Sarcoidosis
      - 6) Multiple sclerosis
    - 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
        - e) Stenosis
    - b. Congenital and hereditary disorders
      - 1) Aqueductal stenosis
      - 2) Chiari malformations
      - 3) Dandy-Walker syndrome
    - c. Trauma
      - 1) Skull fracture

2) Hematomas
3) Shearing injury
4) Contusion
5) Hemorrhage
6) Non-accidental trauma (NAT)
7) Arterial dissection

d. Pituitary gland
1) Adenomas
2) Cysts

e. Pineal gland
1) Tumors
2) Cysts

f. Eye and orbital contents
1) Primary tumors
a) Malignant
b) Benign
2) Infections and inflammatory disorders
c) Optic neuritis
d) Sarcoidosis
e) Abscess
3) Orbital trauma

g. Paranasal sinuses, pharynx and larynx
1) Cysts and polyps
2) Sinusitis
3) Primary tumors
a) Malignant
b) Benign
4) Metastases

h. Ear, cranial nerves and posterior fossa
1) Acoustic neuroma (e.g., Schwannoma)
2) Bell's palsy
3) Trigeminal neuralgia
4) Meniere's disease
5) Tinnitus

i. Other (e.g., aging, metabolic, idiopathic, iatrogenic, phakomatoses)

2. Neck
a. Primary tumors
1) Malignant
2) Benign
b. Metastases
c. Cysts
d. Sialolithiasis
e. Trauma

B. Spine and spinal cord
1. Primary tumors
a. Malignant

b. Benign
2. Metastases
3. Cysts
4. Paget disease
5. Syringomyelia (syrinx)
6. Intramedullary
7. Intradural extramedullary
8. Inflammatory disorders
   a. Spondylitis
   b. Discitis
   c. Abscesses
9. Vascular disorders
   a. Arteriovenous malformation
   b. Cavernous angioma
   c. Infarctions
10. Trauma
    a. Degenerative spine
       1) Herniated disc
       2) Free herniated disc fragment
       3) Postsurgical fibrosis and arachnoiditis
       4) Spondylolysis and spondylolisthesis
       5) Ossified ligaments
       6) Stenosis
    b. Other (e.g., congenital anomalies, demyelinating disorders)
11. Brachial plexus
    a. Primary tumors
       1) Malignant
       2) Benign
    b. Metastases
    c. Neuritis
    d. Trauma

II. Body

A. Thorax
1. Mediastinum and lungs
   a. Lymph node enlargement
   b. Primary tumors
      1) Malignant
      2) Benign
   c. Infection and inflammatory lesions
2. Cardiac and aorta
   a. Aneurysm
   b. Dissection
   c. Coarctation
   d. Thrombus
   e. Ischemic disease

f. Hypertrophic cardiomyopathy
g. Pericardial disease
h. Intracardiac masses
i. Valvular heart disease
j. Congenital heart conditions
k. Arrhythmogenic right ventricular cardiomyopathy (ARVC)

3. Situs
   a. Solitus
   b. Inversus
   c. Ambiguous
      1) Asplenia (right sidedness)
      2) Polysplenia (left sidedness)
4. Breast
   a. Dysplasia
   b. Cysts
   c. Benign tumors
   d. Inflammatory conditions
   e. Carcinomas
   f. Post-surgery or radiation
   g. Implant rupture
   h. Fat necrosis

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
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. Gallbladder anomalies
   c. Biliary carcinoma

d. Biliary stone
4. Kidneys
   a. Polycystic kidney disease (PKD)
   b. Carcinoma
      1) Renal cell
      2) Transitional cell
   c. Metastasis
   d. Wilms' tumor
   e. Nephroblastoma
   f. Infarction
   g. Infection
   h. Transplant
   i. Hydronephrosis
5. Adrenal glands
   a. Primary tumors
      1) Malignant (adenoma)
      2) Benign (neuroblastoma)
   b. Metastasis
   c. Hemorrhage
6. Spleen and lymphatics
   a. Infections
   b. Benign focal lesions
   c. Hodgkin's and non-Hodgkin's lymphoma
   d. Infarction
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. Primary tumors

1) Malignant
2) Benign

b. Endometrial polyps
c. Inflammatory disorders
1) Pelvic inflammatory disease
2) Endometriosis

d. Ovarian cysts
e. Trauma
f. Other (e.g., congenital, hereditary)

2. Male reproductive organs
a. Primary tumors
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. Primary tumors
1) Malignant
2) Benign

b. Obstructions
c. Inflammatory disorders
d. Trauma
e. Other (e.g., congenital, hereditary)

4. Cancer staging

I. Musculoskeletal

A. Skeletal system

1. Trauma
a. Bone fracture union
b. Contusion/hematoma

2. Primary tumors
a. Malignant
b. Benign

3. Lesions
a. Cartilage lesions
b. Fibrous lesions
c. Metastases

4. Inflammatory disorders
a. Osteomyelitis
b. Periprosthetic infections

5. Other
a. Congenital abnormalities
b. Osteonecrosis and bone infarcts

c. Avascular necrosis

B. Soft tissues
   1. Primary tumors
      a. Malignant
      b. Benign
   2. Lesions
      a. Vascular lesions
      b. Synovial lesions and sarcoma
   3. Inflammatory disorders
      a. Infections and abscesses
         1) Bursitis
         2) Tenosynovitis
         3) Osteomyelitis
         4) Cellulitis
      b. Compartment syndrome
      c. 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
      b. Anterior/posterior cruciate
      c. Patellar tendon
      d. Collateral ligament
      e. Achilles tendon
   3. Ganglion and bursal cysts
   4. Arthritis
   5. Meniscal and labral disorders
      a. Tears
      b. Cysts
      c. Discoid lateral meniscus
   6. Temporal bone and temporal mandibular joint (TMJ)
      a. Cholesteatoma
      b. Fractures and dislocations
   7. Trauma
   8. Other (e.g., congenital, hereditary)

Quality Assurance and Quality Control

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. Documentation

F. Checks for intraoperator consistency

G. Checks for intramanufacturer consistency

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) Procedures

A. Monitor cryogen level and pressure

B. Room temperature

C. Slice thickness

D. Spatial resolution

E. Contrast resolution

F. Signal-to-noise ratio

G. Center frequency

H. Transmit gain

I. Geometric accuracy

J. Equipment inspection

Optional Content

Content in this section is designed to provide educators with additional, optional topics that can be incorporated into the curriculum to address specific needs or interests. These topics offer flexibility for customizing the program to align with the mission of the educational institution, industry standards, or local employment market demands. By including this content, educators can ensure their students are equipped with relevant, up-to-date knowledge and skills that enhance employability meeting the evolving requirements and adaptations in health care and medical imaging practices.

Cardiac MRI

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 and demonstrate how to provide postprocedural patient instructions.
8. 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 equipment

E. Power injector

II. MR Presentation of Normal Cardiac Anatomy

A. 2-chamber (left and right vertical long axis)

B. Short axis

C. 4-chamber (horizontal long axis)

D. 3-chamber (sagittal left ventricular outflow tract)

E. Right and left inflow and outflow tracts

F. Main, right and left pulmonary arteries

G. Aortic and pulmonary valve (for flow analysis)

III. Imaging Techniques

A. Steady-state free precession

B. Inversion recovery techniques

1. Pre-contrast
2. Post-contrast

C. Gating
   1. ECG
   2. Peripheral
   3. Prospective
   4. Retrospective

D. CINE acquisitions

E. Myocardial tagging

F. Perfusion

G. Stress imaging

H. T2*

I. T1 mapping

J. Phase contrast (i.e., velocity encoded gradient echo [VENC] imaging)

K. MRA
   1. 3D time-of-flight
      a. Post-contrast
      b. Breath-hold
      c. Free breathing technique
   2. 3D steady-state free precession
      a. Breath-hold
      b. Navigator imaging
      c. Pre- and post-contrast

L. 4D flow

IV. Techniques for Demonstrating Common Cardiomyopathies

V. Procedural Considerations

A. Preprocedural patient instructions

B. Intraprocedural patient instructions

C. Postprocedural patient instructions

D. Image artifacts

VI. Emergency Care

A. Stress studies

B. ECG accuracy interferences

VII. Post Processing

A. Flow measurement

B. Functional measurements
   1. End-diastolic volume (EDV)
   2. Ejection fraction (EF)
   3. Cardiac output (CO)
   4. Myocardial mass

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

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. Fusion Imaging

A. Hybrid PET MRI

B. Multiscan images

C. MR-linac

II. Quantitative MR (e.g., fingerprinting, elastography)

III. Neurography

IV. 3D Printing and Modeling

V. MR Lymphangiography

VI. Web-Based Enterprise Systems

VII. Remote Scanning

VIII. Cloud-Based Archive Systems

IX. Helium-Free Systems

X. High-V (High Volume, Low Field Strength)

XI. Portable MRI

XII. In-System Entertainment

XIII. Coil Technology

Artificial Intelligence

Objectives:

1. Define terminology associated with artificial intelligence.
2. Discuss data and data sets as they apply to artificial intelligence.
3. Describe the relationship between machine learning and deep learning.
4. Explain natural language processing.
5. Explain how artificial neural networks work.
6. Outline artificial intelligence application to health care and medical imaging.
7. Explain applicable standards and ethics to artificial intelligence in medical imaging.
8. Outline artificial intelligence regulation and workflow integration.
9. Discuss the role of artificial intelligence in precision medicine.

Content

I. Terminology and Concepts

A. Algorithm

B. Automation

C. Artificial intelligence (AI)
   1. Artificial narrow intelligence
   2. Artificial general intelligence
   3. Artificial super intelligence

D. AI-enabled

E. AI-bias

F. Machine learning (ML)
   1. Supervised
   2. Unsupervised
   3. Deep learning (DL)
      a. Signal-to-noise
      b. Reconstruction

G. Neural network
   1. Artificial neural networks (ANN)
   2. Convolutional neural network (CNN)
   3. Recurrent neural network (RNN)

H. Software as a medical device (SaMD)

I. Recursion

J. Natural language processing (NLP)
    1. Pattern recognition
    2. Visual perception
    3. Decision making

II. Data and Data Sets

III. Applications in Health Care

IV. Applications in Medical Imaging

A. Order scheduling and patient screening

B. Exam protocoling

C. Image acquisition

D. Image analysis
    1. Automated detection of findings
    2. Automated interpretation of findings

E. Automated clinical decision support (CDS)

F. Image post-processing

V. Ethics, Legality and Liability

VI. Regulatory and Workflow Integration

VII. Precision Medicine

VIII. Biological Twins

Resources

This categorized 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 for 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, Scranton, PA.

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:

Insert 2024-2025 workgroup names and credentials here

We also wish to express our sincere appreciation for the many contributions and suggestions from the professional community over the course of this project.