

2026 Noninterpretive Skills



Study Guide

ABR | AMERICAN
BOARD OF
RADIOLOGY

This study guide is to be used in preparation for all Diagnostic Radiology Core and Certifying exams administered through calendar year 2026.

Table of Contents

| | |
|---|-----------|
| Introduction | 4 |
| Chapter 1. Core Elements of Professionalism | 5 |
| 1.1 ABIM Physician Charter for Medical Professionalism in the New Millennium..... | 5 |
| 1.2 Ethical Considerations Specific to Radiology..... | 7 |
| Chapter 2. Core Concepts of Quality and Safety | 9 |
| 2.1 Core Concepts of Quality | 9 |
| 2.1.1 Introduction to Quality..... | 9 |
| 2.1.2 Quality as a Discipline..... | 9 |
| 2.1.3 2001 Institute of Medicine Report, <i>Crossing the Quality Chasm</i> | 10 |
| 2.1.4 Core Competencies of the ABMS and ACGME | 11 |
| 2.2 Core Concepts of Safety..... | 12 |
| 2.2.1 2000 Institute of Medicine Report, <i>To Err is Human</i> | 12 |
| 2.2.2 2015 Institute of Medicine Report, <i>Improving Diagnosis in Health Care</i> | 12 |
| 2.2.3 Human Factors..... | 14 |
| 2.2.4 Human Error | 16 |
| 2.2.5 Culture of Safety | 16 |
| Chapter 3. Practical Quality and Safety Applications in Healthcare | 20 |
| 3.1 Practical Quality Applications in Healthcare | 20 |
| 3.1.1 Daily Management Systems | 20 |
| 3.1.2 Project-based Improvement Methods | 21 |
| 3.2 Practical Safety Applications in Healthcare..... | 27 |
| 3.2.1 Periprocedural Care | 27 |
| 3.2.2 Hand Hygiene..... | 30 |
| 3.2.3 Root Cause Analysis | 31 |
| Chapter 4. Practical Safety Applications in Radiology..... | 33 |
| 4.1 MR Safety..... | 33 |
| 4.1.1 Zoning and Screening..... | 33 |
| 4.1.2 Implanted Devices..... | 39 |
| 4.1.3 MR and Pregnancy | 40 |
| 4.1.4 MR-induced Burns | 40 |
| 4.1.5 Quenching (Emergency Magnet Shutoff)..... | 42 |
| 4.2 Management of Intravascular Contrast Media | 43 |
| 4.2.1 Iodinated Contrast Media..... | 43 |
| 4.2.2 Gadolinium-based Contrast Media (GBCM) | 51 |
| 4.2.3 Treatment of Acute Contrast Reactions | 54 |
| Chapter 5. Reimbursement, Regulatory Compliance, and Legal Considerations in Radiology | 59 |
| 5.1 Reimbursement and Regulatory Compliance..... | 59 |
| 5.1.1 Coding, Billing, and Reimbursement | 59 |
| 5.1.2 Patient Privacy and HIPAA | 61 |
| 5.1.3 Human Subjects Research | 62 |
| 5.2 Malpractice and Risk Management | 63 |
| 5.2.1 General Principles of Malpractice | 63 |
| 5.2.2 Malpractice Related to Diagnostic Errors..... | 64 |
| 5.2.3 Malpractice Related to Procedural Complications..... | 65 |

| | |
|--|-----------|
| 5.2.4 Malpractice Related to Communications Deficiencies | 65 |
| 5.2.5 Discoverability of Communications..... | 68 |
| Chapter 6. Core Concepts of Imaging Informatics | 69 |
| 6.1 Standards | 69 |
| 6.2 The Reading Room Environment..... | 69 |
| 6.3 From Order to Report: Workflow Considerations | 71 |
| 6.4 Data Privacy and Security | 71 |
| 6.5 Image Post-processing and Artificial Intelligence..... | 72 |
| 6.6 Image Artificial Intelligence..... | 72 |

Introduction

This study guide has been created to assist examinees in preparing for the noninterpretive skills (NIS) section of the American Board of Radiology (ABR) Core and Certifying exams administered during calendar year 2026.

The guide has undergone a few changes compared to the 2025 version, consisting mainly of updates reflecting recently published guidelines related to MR safety and contrast administration.

Decisions regarding whether specific NIS topics merit inclusion in the study guide — and on the exams — are based primarily on two factors. First, material contained in the NIS section should reflect knowledge that is needed to perform effectively in a modern radiology practice. Second, inclusion of the material should serve the public interest by ensuring that examinees possess this knowledge.

Core Elements of Professionalism are included because they reflect fundamental principles to which all physicians, including radiologists, should adhere. Core Concepts of Quality and Safety address underlying principles that drive quality and safety in complex work environments. Practical Quality and Safety Applications in Healthcare contain quality and safety strategies as they are applied to healthcare. Practical Safety Applications in Radiology focus on radiology-specific topics such as MR safety and management of intravenous contrast material. Reimbursement, Regulatory Compliance, and Legal Considerations in Radiology reflect mechanisms that external parties use to ensure quality and safety in radiology practice. Informatics and artificial intelligence represent a growing area where knowledge is increasingly integral to the modern practice of radiology.

The guide covers the majority of general conceptual and practical NIS information contained in the Core and Certifying exams. However, the exams may also include questions on important subspecialty-specific quality and safety knowledge and skills not addressed in this guide, especially those related to nuclear medicine and other procedure-based specialties. Additionally, examinees should be knowledgeable in basic quality and safety practices relevant to all subspecialties regardless of whether they are included in this study guide. This study guide does not cover medical physics, including radiation safety, as it is considered a separate topic; examinees should consult the ABR Physics Study Guide for relevant physics material covered on the respective exams.

Examinees are expected to understand general NIS concepts rather than esoteric details. For example, examinees should understand regulatory requirements that are relevant to daily radiology practice, as well as their underlying purpose. Less emphasis is placed on superficial details, such as the names of the various regulatory agencies.

This study guide will continue to evolve in future years to reflect continuing changes in the noninterpretive knowledge and skills needed to practice effectively in a modern radiology practice.

We also draw your attention to the references provided at the end of each chapter. Examinees are encouraged to consult these deeper resources, which provide additional perspective and depth beyond the high-level overview presented in this study guide.

Chapter 1: Core Elements of Professionalism

1.1 ABIM Physician Charter for Medical Professionalism in the New Millennium

Merriam-Webster defines a profession as “a calling requiring specialized knowledge and often long and intensive academic preparation.” Professionalism, defined as “the conduct, aims, or qualities that characterize or mark a profession or a professional person,” has been characterized as the basis of medicine’s contract with society. Several fundamental principles and physician responsibilities that apply to all professionals in medicine have been specified in a Physician Charter supported by the American Board of Internal Medicine (ABIM). Ten professional responsibilities support the following three fundamental principles of medical professionalism:

1. **Principle of primacy of patient welfare.** Physicians must be dedicated to serving the interest of the patient. Trust is central to the physician-patient relationship, which must not be compromised by market forces, societal pressures, or administrative exigencies.
2. **Principle of patient autonomy.** Physicians must be honest with their patients and empower them to make informed decisions about their treatment. Patients’ decisions about their care must be paramount, as long as they are in keeping with ethical practice and do not lead to demands for inappropriate care.
3. **Principle of social justice.** The medical profession must promote the fair

distribution of healthcare resources. Physicians should work actively to eliminate discrimination in healthcare.

The 10 professional responsibilities are summarized below:

1. **Commitment to professional competence.** Physicians must be committed to lifelong learning of medical knowledge and team skills necessary for the provision of quality care. More broadly, the profession as a whole must strive to see that all of its members are competent and must ensure that appropriate mechanisms are available for physicians to accomplish this goal.
2. **Commitment to honesty with patients.** Physicians must ensure that patients are completely and honestly informed before the patient has consented to treatment and after treatment has occurred. Medical errors should be communicated promptly to patients whenever injury has occurred. Physicians should be committed to reporting and analyzing medical mistakes to develop appropriate prevention and improvement strategies.
3. **Commitment to patient confidentiality.** Physicians are responsible for safeguarding patient information. Fulfilling this commitment is more pressing now than ever before, given the widespread use of electronic information systems. However, considerations of public interest may occasionally override this commitment,

such as when patients endanger others.

4. **Commitment to maintaining appropriate relations with patients.** Given the inherent vulnerability and dependency of patients, certain relationships between physicians and patients must be avoided. In particular, physicians should never exploit patients for any sexual advantage, personal financial gain, or other private purpose.
5. **Commitment to improving quality of care.** Physicians should not only maintain clinical competence, but should work collaboratively with other professionals to continuously improve the quality of healthcare, including reducing medical errors, increasing patient safety, improving utilization of healthcare resources, and optimizing outcomes of care.
6. **Commitment to improving access to care.** Physicians should work individually and collectively toward providing a uniform and adequate standard of care and reducing barriers to equitable healthcare. These barriers may be based on education, laws, finances, geography, or social discrimination. This commitment entails the promotion of public health and preventive medicine, without promotion of the self-interest of the physician or the profession.
7. **Commitment to a just distribution of finite resources.** To provide cost-effective health care, physicians should work with other physicians, hospitals, and payers to develop evidence-based guidelines for effective use of healthcare resources. This includes the scrupulous avoidance of superfluous tests and procedures to reduce patient exposure

to harm, decrease health expenses, and improve access to resources for patients who need them.

8. **Commitment to scientific knowledge.** Physicians should uphold scientific standards, promote research, and create new medical knowledge and ensure its appropriate use. The integrity of this knowledge is based on scientific evidence and physician experience.
9. **Commitment to maintaining trust by managing conflicts of interest.** Medical professionals and organizations can compromise their professional responsibilities by pursuing private gain or personal advantage, especially through interactions with for-profit companies. Physicians have an obligation to recognize, disclose to the general public, and deal with conflicts of interest that arise in the course of their professional duties and activities. Relationships between industry and opinion leaders should be disclosed, especially when physicians are determining criteria for conducting and reporting clinical trials, writing editorials or therapeutic guidelines, or serving as editors of scientific journals.
10. **Commitment to professional responsibilities.** Physicians have both individual and collective obligations to work collaboratively to maximize patient care, be respectful of one another, and participate in the processes of self-regulation, including remediation and discipline of members who have failed to meet professional standards. The profession should also define and organize the educational and standard-setting process for current and future members. These obligations include

engaging in internal assessment and accepting external scrutiny of all aspects of their professional performance.

1.2 Ethical Considerations Specific to Radiology

The ABIM professional responsibilities largely overlap with the Code of Ethics as described in the American College of Radiology (ACR) Bylaws. However, several principles and rules of ethics apply specifically to the field of radiology, as stated by the ACR.

- 1. Professional limitations.** The Bylaws state that radiologists should be aware of their limitations and to seek consultations in clinical situations where appropriate. Any limitations should be appropriately disclosed to patients and referring physicians.
- 2. Reporting of illegal or unethical conduct.** To safeguard the public and the profession against physicians deficient in moral character or professional competence, radiologists are expected to report any perceived illegal or unethical conduct of medical professionals to the appropriate governing body.
- 3. Report signature.** Radiologists should not sign a report or claim attribution of an imaging study interpretation that was rendered by another physician, making the reader of a report believe that the signing radiologist was the interpreter.
- 4. Participation in quality and safety activities.** Radiologists who actively interpret images should participate in quality assurance, technology assessment, utilization review, and other matters of policy that affect the quality and safety of care.
- 5. Self-referral.** Referring patients to healthcare facilities in which radiologists have a financial interest is not in the best interest of patients and may violate the Rules of Ethics.
- 6. Harassment.** Radiologists are expected to relate to other members of the healthcare team with mutual respect and refrain from harassment or unfair discriminatory behavior.
- 7. Undue influence.** Radiologists should seek to ensure that the system of healthcare delivery in which they practice does not unduly influence the selection and performance of appropriate available imaging studies or therapeutic procedures.
- 8. Agreements for provision of high-quality care.** Radiologists should not enter into an agreement that prohibits the provision of medically necessary care or that requires care at below acceptable standards.
- 9. Misleading billing arrangements.** Radiologists should not participate in billing arrangements that mislead patients or payers concerning the fees charged.
- 10. Expert medical testimony.** Radiologists should exercise extreme caution to ensure that the testimony provided is nonpartisan, scientifically correct, and clinically accurate. Compensation that is contingent upon the outcome of litigation is unacceptable.
- 11. Research integrity.** Radiologic research must be performed with integrity and be honestly reported.

12. Plagiarism. Claiming others' intellectual property as one's own is unethical. This includes plagiarism or the use of others' work without attribution.

13. Misleading publicizing. Radiologists should not publicize themselves through any medium or forum of public communication in an untruthful, misleading, or deceptive manner.

References

1. American Board of Internal Medicine Foundation. Medical Professionalism in the New Millennium: The Physician Charter. American Board of Internal Medicine Foundation Website. <http://abimfoundation.org/what-we-do/medical-professionalism-and-the-physician-charter/physician-charter>. Accessed October 1, 2016.
2. American College of Radiology. Code of Ethics. American College of Radiology Website. <https://www.acr.org/Member-Resources/Commissions-Committees/Ethics>. Accessed June 13, 2018.

Chapter 2: Core Concepts of Quality and Safety

2.1 Core Concepts of Quality

2.1.1 Introduction to Quality

Merriam-Webster defines quality as “a level of value or excellence.” The Institute of Medicine has defined quality of care as “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge.” As it relates to diagnostic imaging and image-guided treatment, quality can be considered to be “the extent to which the right procedure is done in the right way, at the right time, and the correct interpretation is accurately and quickly communicated to the patient and referring physician. The goals are to maximize the likelihood of desired health outcomes and to satisfy the patient.”

Several important concepts are connected to these statements.

First, quality has two important dimensions: excellence and consistency. It is not enough to provide excellent care; it must be done on a consistent basis. Lack of consistency is a marker of poor quality.

Second, performance must be monitored to ensure consistent quality. It is unlikely for an organization to achieve consistent excellent performance in the absence of performance standards or measurements.

Third, the goals are twofold: 1) maximize the likelihood of health outcomes desired by the patient and 2) satisfy the patient. In other words, optimizing health outcomes and patient experience are both important goals of healthcare. Furthermore, while excellence may be a subjective term, the ultimate arbiter of

“quality” is the patient. Those who wish to provide quality care must understand and seek to achieve consistent excellence from the perspective of the patient—which may differ from that of the provider.

Fourth, the goal is to consistently achieve desired health outcomes using methods that are consistent with current professional knowledge. Achieving excellent outcomes on a consistent basis depends on consistency in the methods, or processes, that are used to achieve those outcomes. Therefore, a major goal of quality is that of decreasing unnecessary variation, both in processes and outcomes. In a practice with multiple professionals, this generally requires those professionals to collaborate in developing and adhering to practice standards based on the evidence.

2.1.2 Quality as a Discipline

Achieving consistent excellence in processes and outcomes is challenging in healthcare, including in radiology. However, healthcare is by no means the only field in which consistent excellence is desired. Over the past century, “quality” has emerged as its own discipline of study and practice, with a set of broadly applicable definitions, principles, and tools.

Quality control (QC) refers to measuring and testing elements of performance to ensure that standards are met and correcting instances of poor quality. An example of a QC activity is when a radiologist reviews and corrects errors in a radiology report before finalizing it.

Quality assurance (QA) refers to a process for monitoring and ensuring performance quality in an organization. This includes QC activities, but also refers to strategies designed to prevent instances of poor quality. An example of a QA

activity is the use of standardized report templates to minimize errors in reporting accompanied by verification of appropriate use with audit-based performance metrics.

Quality improvement (QI) refers to activities designed to improve performance quality in an organization in a systematic and sustainable way. This requires a deliberate effort within an organization to agree on a measurable performance objective, measure the relevant performance, understand the causes of poor performance, develop and implement strategies to improve performance, and ensure that those strategies are embedded in the organization such that performance will not relapse. An example of QI is a project whereby radiologists agree to improve consistency in reporting using standardized radiology report templates, implement those templates, monitor radiology reports and make necessary adjustments, and ensure that consistency is maintained through feedback and accountability.

QC is generally considered to be the most basic level of quality-related activities in an organization. QA is more comprehensive than QC and is required to maintain consistently high performance levels in an organization. However, QA typically is designed to maintain rather than improve performance, implying that quality was presumed to be adequate in the first place. QI, on the other hand, assumes that quality is not as good as it could be and employs strategies to successfully improve quality through a variety of means, including changes in processes, systems, and even organizational structure. As organizations' focus has transitioned in recent decades from seeking to maintain the status quo to seeking to constantly improve performance, the field of quality has transitioned from relying solely on a QA approach to one of *continuous quality improvement (CQI)*.

Quality methods and philosophies have evolved in several other important ways in the past several decades:

- Rather than being solely the purview of a “quality department,” quality has come to be recognized as the responsibility of everyone in the organization—especially organizational leaders.
- The focus has shifted from detecting and correcting errors that have already occurred to improving processes and systems to prevent errors from happening or from causing harm.
- Frontline staff are increasingly engaged to help improve processes.
- The value of making errors visible rather than quietly fixing them without sharing them with the staff is increasingly recognized. Exposing errors allows them to be more easily detected so they can be corrected and their causes addressed.

2.1.3 2001 Institute of Medicine Report, *Crossing the Quality Chasm*

In 2001, the Institute of Medicine (IOM) published a report entitled, “Crossing the Quality Chasm: A New Health System for the 21st Century.” In this report, the IOM committee members maintained that all healthcare constituencies, including policymakers, purchasers, regulators, health professionals, health-care trustees and management, and consumers, should commit to a shared explicit purpose to continually reduce the burden of illness, injury, and disability, and improve the health and functioning of the people of the United States.

The committee asserted that healthcare should be:

- *Safe*—avoiding injuries to patients from the care that is intended to help them.
- *Effective*—providing services based on scientific knowledge to all who can benefit and refraining from providing services to those not likely to benefit (avoiding underuse and overuse).
- *Patient-centered*—providing care that is respectful of and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions.
- *Timely*—reducing waits and potentially harmful delays for both those who receive and those who give care.
- *Efficient*—avoiding waste, in particular waste of equipment, supplies, ideas, and energy.
- *Equitable*—providing care that does not vary in quality because of personal characteristics.

Since its publication, the IOM “Chasm” report, which was itself a follow-up to a 2000 IOM report on medical error, has provided a road map for individuals and organizations in healthcare to focus their improvement efforts.

2.1.4 Core Competencies of the ABMS and ACGME

To encourage active physician participation in advancing the goals of continuous improvement, in 1999 the Accreditation Council for Graduate Medical Education (ACGME) and the American Board of Medical Specialties (ABMS), which is composed of subspecialty boards including the American Board of Radiology, described six core competencies that all physicians should attain.

- *Practice-based Learning and Improvement:* Show an ability to investigate and evaluate patient care practices, appraise

and assimilate scientific evidence, and improve the practice of medicine.

- *Patient Care and Procedural Skills:* Provide care that is compassionate, appropriate, and effective treatment for health problems and promote health.
- *Systems-based Practice:* Demonstrate awareness of and responsibility to the larger context and systems of healthcare. Be able to call on system resources to provide optimal care (e.g., coordinating care across sites or serving as the primary case manager when care involves multiple specialties, professions, or sites).
- *Medical Knowledge:* Demonstrate knowledge about established and evolving biomedical, clinical, and cognitive sciences and their application in patient care.
- *Interpersonal and Communication Skills:* Demonstrate skills that result in effective information exchange and teaming with patients, their families, and professional associates (e.g., fostering a therapeutic relationship that is ethically sound; using effective listening skills with nonverbal and verbal communication; and working both as a team member and, at times, as a leader).
- *Professionalism:* Demonstrate a commitment to carrying out professional responsibilities, adhering to ethical principles, and being sensitive to diverse patient populations.

By establishing this set of competencies, the ACGME and ABMS assert that the skills necessary to effectively practice medicine in a modern complex healthcare environment extend beyond the traditional domains of

medical knowledge and individual practice. It is not enough for professionals to gain adequate knowledge; they must also continuously improve their knowledge and practice for the duration of their careers. They must be not only technically competent, but also compassionate and ethical. They must practice effectively not only as individuals, but also as members of teams, organizations, and systems of care. Organizations and leaders who are responsible for certifying competence of practitioners must demonstrate adequacy of the professional's competence in all domains.

2.2 Core Concepts of Safety

2.2.1 2000 Institute of Medicine Report, *To Err is Human*

In 1998, the National Academy of Sciences' Institute of Medicine (IOM) initiated the Quality of Health Care in America project to develop a strategy that would result in improved quality of care in the United States. *To Err is Human: Building a Safer Health System*, published in 2000, was the first in a series of reports arising from this project. The report's findings that between 44,000 and 98,000 in-hospital deaths per year were attributable to medical errors made national headlines, including a suggestion that an epidemic of death from medical errors exceeded that from motor vehicle accidents, breast cancer, or AIDS. The report projected total societal costs of medical errors to be between \$17 billion and \$29 billion.

The report defined medical error as the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim, with the highest risk for errors occurring in high-acuity environments such as the intensive care unit, operating room, and emergency department. The report identified several

fundamental factors contributing to the errors, including the following: 1) the decentralized nature of the healthcare delivery system (or "nonsystem," as the report calls it); 2) the failure of licensing systems to focus on errors; 3) the impediment of the liability system to identify errors; and 4) the failure of third-party providers to provide financial incentive to improve safety.

The report authors emphasized that most errors are multifactorial; most errors can be attributed to unsafe systems and processes of care as well as to human error. Therefore, the only strategy to decrease medical errors that is likely to be both successful and sustainable in the long run is to design safety into systems and processes of care. Blaming and "rooting out the bad apples," the authors contended, is not a viable strategy to decrease error.

2.2.2 2015 Institute of Medicine Report, *Improving Diagnosis in Health Care*

In 2015, the IOM issued what it considered to be a follow-up report to its 2000 report on medical error, this time focusing on diagnostic error. In this report, *Improving Diagnosis in Health Care*, the IOM committee defined diagnostic error as "the failure to establish an accurate and timely explanation of the patient's health problem(s) or (b) communicate that explanation to the patient." The definition is purposely patient-focused because, according to the report, patients are considered to be key team members in the collaborative efforts required to prevent diagnostic error.

Quickly establishing a correct diagnosis is critical to the provision of safe and effective patient care. The problem of diagnostic error tends to be underappreciated, for several reasons. Data on diagnostic error are sparse, few reliable measures exist, and often the error is identified only in retrospect. The best estimates indicate that nearly all Americans will

likely experience a meaningful diagnostic error in their lifetimes. A poll commissioned by the National Patient Safety Foundation in 1997 found that approximately one in six of those surveyed had experience with diagnostic error, either personally or through a close friend or relative.

On average, 10% of postmortem exams were associated with diagnostic errors that might have affected patient outcomes. The report authors maintained that reducing diagnostic error should be a key component of quality improvement efforts by healthcare organizations.

Similar to the 2000 IOM report, this report called for objective, nonpunitive efforts to understand error and to improve systems and processes accordingly. This includes learning from both errors and near misses on one end of the spectrum and from exemplary accurate and timely diagnoses on the other end. The report authors viewed the diagnostic process as a collaborative activity, often between numerous professionals and professional groups. Therefore, improving diagnosis often requires collaborative efforts between professionals to understand error and improve performance.

The report authors made eight specific recommendations for improvement in the diagnostic processes:

1. Facilitate more effective teamwork among healthcare professionals, patients, and their families. Radiologists and pathologists are an integral part of the diagnostic team.
2. Enhance healthcare professional education and training in the diagnostic process.
3. Ensure that health information technologies support patients and healthcare professionals.

4. Develop and deploy organizational approaches to identify, learn from, and reduce diagnostic errors and near misses in clinical practice.
5. Establish a work system and culture that supports the diagnostic process and improvements in performance. This may include redesigning payment structures since fee for service (FFS) payments lack incentives to coordinate care among team members, such as communication among treating clinicians, pathologists, and radiologists about diagnostic test ordering, interpretation, and subsequent decision making.
6. Develop a reporting environment and medical liability system that facilitates improvement.
7. Design a payment and care delivery environment that supports the diagnostic process. Specifically, oversight bodies should require that healthcare organizations have programs in place to monitor the diagnostic process and identify, learn from, and reduce diagnostic errors and near misses in a timely fashion.
8. Provide dedicated funding for research on the diagnostic process and diagnostic errors.

With respect to radiology, the 2015 IOM report identified failures in communication as being a significant contributor to diagnostic error. The report authors made several recommendations for IT professionals and organizational leaders to improve communication, including the following:

- Standardize communication policies and definitions across networked organizations

- Ensure clear identification of the patient’s care team to facilitate contact by the radiology team
- Implement effective results management and tracking processes
- Develop shared quality and reporting metrics

2.2.3 Human Factors

Background

An obstetric nurse connects a bag of pain medication intended for an epidural catheter to the mother’s intravenous (IV) line, resulting in a fatal cardiac arrest. Newborns in a neonatal intensive care unit are given full-dose heparin instead of low-dose flushes, leading to three deaths from intracranial bleeding. An elderly man experiences cardiac arrest while hospitalized, but when the code blue team arrives, the team is unable to administer a potentially life-saving shock because the defibrillator pads cannot be connected to the defibrillator itself.

Busy healthcare workers rely on equipment to carry out life-saving interventions with the underlying assumption that technology will improve outcomes.

But as these examples illustrate, the interaction between workers, equipment, and the environment can actually increase the risk of consequential errors. Each of these safety hazards ultimately was attributed to a relatively simple, yet overlooked, problem with system design.

The bag of epidural anesthetic was similar in size and shape to IV medication bags, and, crucially, the same catheter could access both types of bags. Full-dose and prophylactic-dose heparin vials appeared virtually identical, and both concentrations were routinely stocked in automated dispensers at the point of care.

Multiple brands of defibrillators exist that differ in physical appearance as well as functionality; a typical hospital may have many different models scattered around the building, sometimes even on the same unit.

Human Factors Engineering

Human factors engineering as a discipline attempts to identify and address such problems in a systematic way. It takes into account human strengths and limitations in the design of interactive systems that involve people, equipment, technology, and work environments to ensure safety, effectiveness, and ease of use. A human factors engineer examines a particular activity in terms of its component tasks and then assesses the human physical, mental and skill demands in the context of team dynamics, work environment (e.g., adequate lighting, limited noise, or other distractions), and device design required to optimally perform a task.

In essence, human factors engineering focuses on how systems work in actual practice, with real—and fallible—human beings at the controls. It attempts to design systems that optimize safety and minimize the risk of error in complex environments.

Human factors engineering has long been used to improve safety in many industries, including aviation and nuclear power. Its application to healthcare is relatively recent; pioneering studies of human factors in anesthesia were integral to the redesign of anesthesia equipment, significantly reducing the risk of injury or death in the operating room.

Standardization

Human factors engineering asserts that equipment and processes should be standardized whenever possible to increase reliability, improve information flow, and minimize cross-training needs. Standardizing

equipment across clinical settings is one basic example, but standardized processes are increasingly recognized as a requirement for safety. The use of checklists as a means of ensuring that safety steps are performed, and performed in the correct order, has its roots in human factors engineering principles. Establishing an agreed-upon, standardized approach for the basic elements of a procedure allows team members to identify when unintended variances from that approach occur (which may represent errors) and frees the team members to better focus on the unique aspects of the case.

Communication

Effective communication is a critical aspect of quality and safety in any complex environment. Communication can be defined as the meaningful exchange of information between individuals or groups of individuals; it is often bidirectional or multidirectional and is successful when it results in shared understanding of meaning. Communication consists of two major parts: 1) *conveyance*—transmission of information from a sender to a receiver, and 2) *convergence*—verification, discussion, and clarification until both parties recognize that they mutually agree (or fail to agree) on the meaning of the information. Convergence activities are especially critical when information is ambiguous or when the negative impact of a miscommunication would be severe.

High Reliability Organization (HRO)

In modern medicine, care delivery is frequently performed in a high complexity setting. A so-called “high reliability organization (HRO)” is an organization that, despite operating in a high-stress, high-risk, complex environment, continually manages its environment mindfully, adopting a constant state of vigilance that results in the fewest number of

errors.

Many healthcare organizations are attempting to adopt high-reliability behaviors and organizational strategies to reduce medical errors for their patients.

According to the authors of the concept, HROs maintain resilience through stressful situations by both *anticipating* unexpected events and containing their impact when they occur.

Anticipation has three elements: *preoccupation with failure*, *reluctance to simplify*, and *sensitivity to operations*. Containment has two elements: *commitment to resilience* and *deference to expertise*. These can be described as follows:

Anticipation

1. **Preoccupation with failure.** Members of the organization recognize that even minor lapses can have severe consequences and tend to be deliberately watchful for clues that indicate trouble. The organizations have processes in place to enable individuals, teams, and systems to quickly detect and respond to potential threats before they result in harm.
2. **Reluctance to simplify.** When problems arise, rather than accept simple explanations, individuals are expected to dig deeper to understand the source of the problem.
3. **Sensitivity to operations.** Members of the organization—especially the leaders—continuously understand the messy reality of the details of what is *actually happening* in the place of work rather than what is *supposed to be happening* and respond accordingly.

Containment

1. **Commitment to resilience.** It is assumed that unexpected trouble is both

ubiquitous and unpredictable. HROs recognize that they can never fully anticipate each unexpected event, so they empower individuals to adjust and innovate as necessary and then seek to learn from those situations.

2. **Deference to expertise.** No one individual ever knows everything about any situation. People with greater authority often have less useful knowledge about a situation than those with lesser authority. HROs overcome the dangers of hierarchy by enabling leaders to defer to the relevant expertise, regardless of its source, while preserving the organizational structure.

2.2.4 Human Error

People are prone to error, but not all errors are identical.

A commonly used human error classification scheme is the “skill-rule-knowledge” (SRK) model. This model refers to the cognitive mode in which the individual is operating when he or she commits an error. Actions that are largely performed automatically, requiring little conscious attention, are considered *skill-based actions*, such as tying one’s shoes or driving on the open freeway. Actions that require an intermediate level of attention are considered *rules-based actions*, such as deciding which clothes to wear or when to proceed at a four-way stop. Actions that require a high level of concentration, usually in the setting of situations that are new to the individual, are knowledge-based actions, such as playing a sport for the first time or driving in poor visibility conditions in an unfamiliar city.

Appropriate strategies for ensuring safety in the face of human error depend on the type of error committed. Skill-based errors tend to be amenable to behavior- shaping constraints that

make it hard to perform the wrong action (i.e., forcing functions, such as a microwave that cannot be operated with the door open) and enablers that make it easy to perform the right action (i.e., affordances, such as installing a door handle for pulling and a plate for pushing). Rules- and knowledge-based errors tend to be amenable to increased supervision, additional training and coaching, deliberate practice, and intelligent decision support.

Note that additional training is generally less effective for skill-based errors, and behavior shaping constraints are less effective for rules- or knowledge-based mistakes. For example, a radiologist who accidentally dictates “100 mg” instead of “100 µg” is unlikely to benefit from an educational course on units of measure in the metric system. Conversely, a simple clinical decision-support rule that forces a physician to order ultrasonography when he or she thinks that magnetic resonance imaging is warranted is more likely to be ignored and thus less likely to be successful than education and consensus-building efforts. Thus, in learning from an error, it is important to determine the cognitive mode in which the individual was operating at the time.

2.2.5 Culture of Safety

Background

The concept of *safety culture* originated in studies of high reliability organizations. High reliability organizations maintain a commitment to safety at all levels, from frontline providers to managers and executives. According to the Agency for Healthcare Research and Quality (AHRQ), this commitment establishes a “culture of safety” that encompasses the following key features:

- Acknowledgment of the high-risk nature of an organization’s activities and the determination to achieve

consistently safe operations

- A blame-free environment where individuals are able to report errors or near misses without fear of reprimand or punishment
- Encouragement of collaboration across ranks and disciplines to seek solutions to patient safety problems
- Organizational commitment of resources to address safety concerns

Studies have documented considerable variation in perceptions of safety culture across organizations and job descriptions. Historically, nurses have often complained of the lack of a blame-free environment and providers at all levels have noted problems with organizational commitment to establishing a culture of safety. The underlying reasons for the underdeveloped healthcare safety culture include poor teamwork and communication, a “culture of low expectations,” and the presence of steep authority gradients.

Authority Gradient

In an organization with steep authority gradients, especially where there is fear of punishment for errors, quality and safety problems are rarely reported to senior leadership. In this way, such authority gradients not only undermine the safety culture, but increase the difficulty of accurately measuring error rates.

Measuring and Achieving a Culture of Safety

Perceptions by the staff of poor safety culture have been linked to increased error rates. Safety culture can be measured by surveys of providers at all levels. Available validated surveys include the AHRQ’s Patient Safety Culture Surveys and the Safety Attitudes Questionnaire.

Just Culture

The traditional culture of individual blame, which still dominates some healthcare organizations, impairs the advancement of a safety culture. However, while blame is generally an undesirable approach to safety, individuals need to be held accountable for their actions to a certain degree. In an effort to reconcile the need for reducing a focus on blame and maintaining individual accountability, the concept of “just culture” was proposed by David Marx. The just culture model distinguishes between human error (e.g., slips), at-risk behavior (e.g., taking shortcuts), and reckless behavior (e.g., flaunting firmly established safety rules). In this model, the response to an error or near miss is predicated on the type of behavior associated with the error, not the outcome or severity of the event.

For example, reckless behavior, in which firmly established safety norms are willfully ignored, such as a physician who refuses to perform a time out before surgery, may merit firm—possibly punitive—action, even if no patients were harmed. In contrast, a person who makes an innocent human error, even if this error resulted in significant patient harm, would be consoled since human errors are considered to be inevitable and not necessarily the result of negligence. In the middle ground, those persons who engage in at-risk behavior—e.g., workarounds of convenience, such as failing to communicate critical results, that could subvert established safety precautions—probably underestimate the risks of their actions. These persons are counseled or coached in the Just Culture Model (**Table 2.1**).

A safety coach or champion is a person in the organization who takes ownership of the processes and fosters the creation and maintenance of the safety culture, including oversight of safety-reporting systems whereby

safety incidents and near-miss events are reported and archived. In a safety-reporting system, the primary focus is on the patient, the event, and the processes and systems to identify opportunities for sustainable improvement. The individual who made the error should not be the focus of the investigation, as long as the individual was not acting recklessly. In other words, the reporting system should not be used as a means of instigating punitive action.

The term “second victim” has been coined for a healthcare worker who is traumatized by an error or adverse patient event in which they were involved.

These individuals often feel an intense sense of guilt, sorrow, and anxiety, and may even exhibit signs similar to post-traumatic stress disorder. Many hospitals have begun to develop internal programs to identify, console, and advocate on behalf of such individuals.

| Three Manageable Behaviors of the Just Culture Model | | | |
|---|---|---|---|
| Behavior or event | <i>Human Error</i> | <i>At-risk Behavior</i> | <i>Reckless Behavior</i> |
| Definition | A product of our current system design and our behavioral choices | A choice where the risk is believed to be insignificant or justified | A conscious disregard for a substantial and unjustifiable risk |
| Management Strategies | <ul style="list-style-type: none"> • Modify available choices • Change processes/ workflows • Improve training programs • Redesign system or facility | <ul style="list-style-type: none"> • Counsel individual • Better incentivize correct behavior • Modify processes, training, etc. as needed | <ul style="list-style-type: none"> • Remediate or remove from the environment • Take punitive action as warranted |
| Recommended approach to the individual | Console | Coach | Punish/Sanction |
| Table 2.1 Outline of the Just Culture Model. Adapted from Marx 2009. | | | |

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Chapter 3: Practical Quality and Safety Applications in Healthcare

3.1 Practical Quality Applications in Healthcare

Quality improvement activities can be divided into two aspects: 1) frequent small improvement efforts conducted in close association with the management of the day-to-day clinical operations and 2) dedicated improvement projects to address areas of performance that generally require more focused improvement efforts.

3.1.1 Daily Management Systems

A daily management system (DMS) provides a day-to-day operating framework for leaders to engage with staff to solve problems on a continuous basis. The objective of the DMS is to facilitate communication and coordination within and across organizational units and roles in the organization. For example, in a radiology department, a DMS allows for coordination and communication between 1) radiologists, technologists, nurses, medical assistants, IT professionals, administrators, etc.; 2) front line staff, managers, and leaders; and 3) the radiology department and other units such as the emergency department, inpatient units, medical and surgical specialties, etc.

A DMS can be implemented in a variety of ways to meet local organizational needs. However, DMS programs tend to have a few core elements that help them achieve the programs' objectives.

Tiered Huddles

A huddle is a brief structured meeting occurring in an organizational unit in which participants review what has recently occurred, the current status of the unit, and what is

anticipated in the near future. First-tier huddles are held within local units and involve all frontline staff on service for the day. Unit leaders then attend huddles at a higher tier, whose leaders in turn attend huddles at a higher tier, up to the executive team. Huddles generally take place at a *visibility board* (often simply an organized white board), which tracks important elements of the daily management huddles for all staff members to see.

Goal and Metrics Review

Organizational goals help focus the members on making tangible progress toward better fulfillment of the organization's missions. Performance metrics enable members of the organization to objectively determine how well those goals are being met. Ideally such goals and metrics should be aligned with the stated values of the organization, including excellence in care, patient safety, patient and family experience, efficiency, etc. A brief review of quantitative metrics at the huddle on a regular basis helps the organization make iterative improvements to facilitate continued progress toward the goals.

Daily Readiness Assessment

A daily readiness assessment reviewed at the huddle helps the staff be aware of the number and types of patients to be seen that day and to determine whether they are prepared to accommodate their needs. Topics that are typically reviewed include 1) methods: ensuring that the proper protocols and plans are in place to accommodate patients, especially those with special needs, 2) equipment: reviewing whether all of the equipment is operational and staff have appropriate training,

3) supplies: ensuring that all needed supplies are available for use, and 4) associates: ensuring that appropriate staff are in place to meet patient needs and that any staff shortages have been accommodated.

Problem Management and Accountability Cycle

Continuous problem solving is a critical element of the DMS. Staff are encouraged to identify problems at the daily huddle. Problems are documented on the visibility board, along with an “owner” of the problem and an expected resolution date. Problems that are more complex often are listed on a separate board along with the owner of the problem, the date the issue was first identified, and a date on which the owner is expected to make a progress report.

Regular Follow-up

The regular cadence of the daily huddles, along with the tracking of assignments on the visibility board, provides a mechanism to routinely follow up on assignments.

This visibility and follow-up greatly increases the likelihood that assignments will be completed or revised as needed.

Frequent Visits to the Workplace

A core tenet of effective management is that one must see what is happening in the workplace to truly understand it. Managers and leaders are encouraged to minimize the time spent in closed-door meetings in favor of spending time where the work is done. When individuals visit the workplace, they are expected to respectfully observe and ask questions to learn about the work; they should not give direction, solve problems, or otherwise interfere with the work during this time.

3.1.2 Project-based Improvement Methods

Problems that are too difficult to solve using routine daily problem-solving methods may be

more amenable to dedicated improvement projects. Several well-known improvement models exist, including Lean, Six Sigma, and the Model for Improvement. Each of these models uses a similar approach to structuring improvement projects, though framed in different ways. The following sections summarize the major steps that the models share.

Identifying a Problem

As it relates to improvement, the term “problem” can be interpreted two ways: 1) something that is difficult to deal with, a source of trouble, worry, etc. and 2) something to be worked out or solved, such as an arithmetic problem.

The fact that the problem is a source of trouble is what drives the organization to decide to focus improvement in a specific area. Before beginning the project, leaders should make sure that it addresses a problem that is of high importance to the organization, so that it will receive needed support when challenges arise.

Framing the problem as a challenge to be solved helps depersonalize the issue and turn it into an opportunity for improvement. Clearly defining the problem is the first step in solving the problem, helping to ensure that the project team remains focused and aligned as team members evaluate causes and consider possible solutions.

Forming a Team

To effectively carry out the project, a dedicated team is organized for a limited period of time and given the guidance, resources, instruction, and authority needed to make process and other organizational changes to improve performance in a sustainable way. Project roles typically include the following:

- *Project Sponsor*: This individual provides

organizational oversight and support, removing barriers as they arise. The sponsor should have the organizational authority to provide resources and resolve interpersonal conflicts. Projects may have more than one sponsor. While sponsors may provide general guidance and suggestions, they should be careful to avoid overstepping their bounds and assuming the project leader's role.

- *Project Leader:* The project leader's role is to direct and coordinate activities of the project to ensure its success. The leader helps assemble the team, manage the project, delegate and follow up on assignments, report on progress, alert the project sponsor when more help is needed, and ensure the timely completion of the project. Project leaders should have strong organizational and leadership skills.
- *Project Participants:* Participants should be selected from the areas targeted for improvement; each organizational unit included in the process targeted for improvement must be represented on the team. It is generally more effective to select "front-line" staff who perform the work on a daily basis rather than supervisors, managers, or other organizational leaders. Participation should be voluntary.
- *Project Coach:* The project coach is an expert in improvement methods who advises and supports the team. The coach helps guide the project leader and team, facilitates communication with the sponsor, and alerts organizational leaders when the project appears to be veering off track. However, the coach

should avoid encroaching on the role of project leader or performing tasks of the project participants.

Assessing Current Performance

Improvement project team members are expected to visit the workplace and spend at least several hours quietly observing and taking notes. Team members should respectfully ask questions to deeply understand the process: what is done and why it is done that way. They should convene and discuss their observations, mapping out the process, and then revisit the workplace to validate their observations. They should, to the extent possible, observe all steps in the process at different times of day and days of the week.

Measuring Performance

To be able to assess performance in an objective and repeatable fashion, team members should develop performance measures. These may include *outcome measures*, including those of *end outcomes* such as morbidity, patient satisfaction, and costs, as well as those of *intermediate outcomes*, such as service times, error rates, and supply utilization. In addition to outcomes measures, *process measures* can be used such as adherence to standard work, equipment utilization rates, and times for each process step.

After one or more quantitative measures are established, performance should be tracked and monitored. Performance can be monitored with a *run chart*, which displays data over time. The run chart should display the mean before the beginning of the project and at the end of the project, as well as the performance goal. An *annotated run chart* is a run chart that also indicates the dates and the nature of interventions implemented during the project (Fig. 3.1).

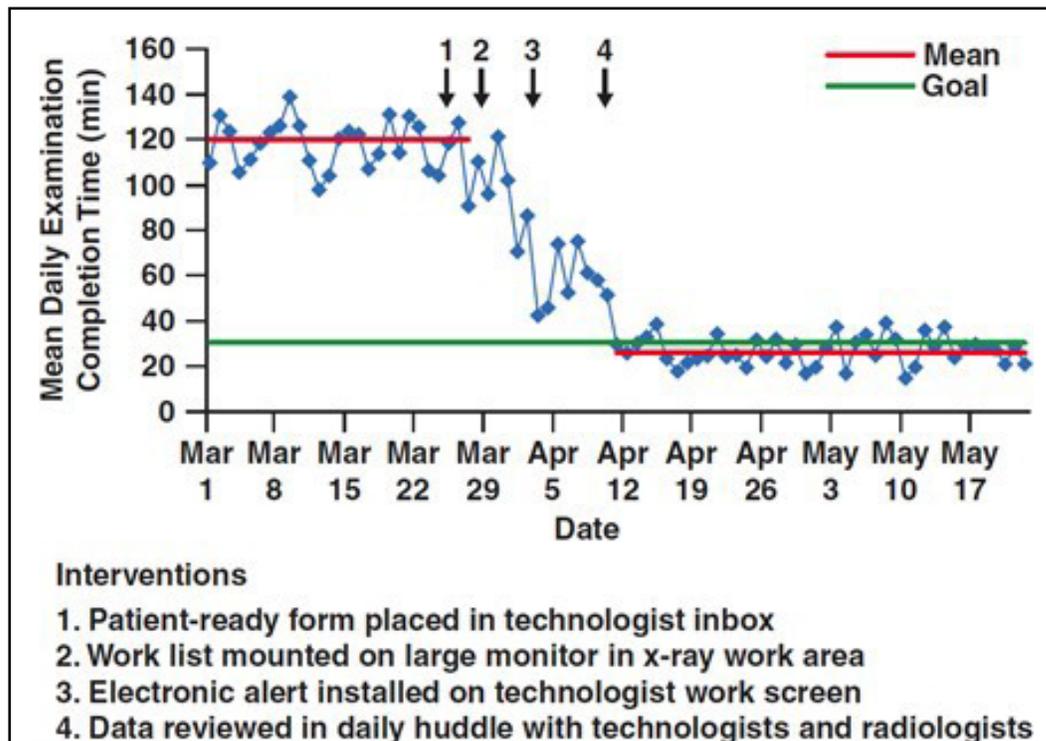


Figure 3.1 Example of an annotated run chart. Each point represents the mean daily examination completion time. Dates that interventions were implemented are plotted on the chart and described in the key. The goal for this hypothetical project was to decrease mean daily examination completion time from 120 minutes to 30 minutes. Source: Larson and Mickelsen. *AJR Am J Roentgenol* 2015.

Establishing a Specific Goal

The project team should establish a performance goal (often referred to as an aim statement). A commonly used acronym to describe the attributes of the goal is “SMART,” meaning that the goal should be specific, measurable, achievable, relevant, and time-bound. The goal should state the beginning performance, the end performance, and the date (i.e., “from what, to what, by when”). For example, the goal might state, “Our goal is to decrease mean daily examination completion

time from 120 minutes to 30 minutes by July 1, 2018.”

Identifying Causes of Problems

After establishing a measure and a goal and observing the process in detail, the project team should seek to discover and document the causes of problems that negatively impact performance. A tool for documenting these causes is a *cause-and-effect diagram*, also known as a *fishbone diagram* (**Fig. 3.2**).

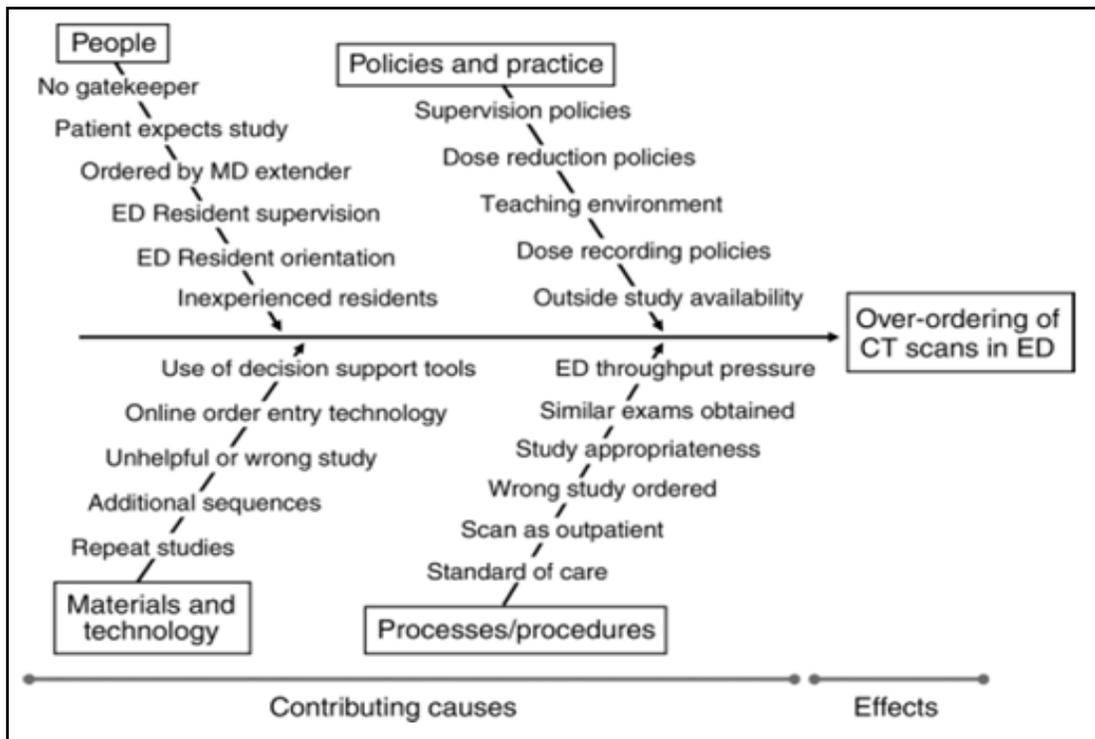


Figure 3.2. Cause-and-effect diagram or fishbone diagram. This diagram lists and categorizes possible contributing causes to the problem of over-ordering of CT scans in the emergency department (ED). Source: Kruskal et al. *Radiographics* 2011.

Prioritizing Problem-solving Efforts

After possible causes of problems are documented, the frequency of those causes should be measured in some way. Often this is accomplished with a simple tally sheet, in which staff members document every time the problem occurs over a period of time along with the cause for the occurrence. These can then be plotted in a Pareto chart (**Fig. 3.3**), which illustrates which causes occur most frequently. The Pareto principle, also known as the “80/20 rule,” states that a few causes are usually responsible for the majority of the problems. Problem-solving efforts can then be

prioritized accordingly.

Developing Solutions through Iterative Testing

After the problem has been thoroughly investigated, including likely causes, it is the project team’s task to develop strategies to solve the problem by making process changes. However, such changes are rarely successful in the form in which they are originally conceived and typically require multiple revisions before they can be fully implemented. The process of iteratively testing, refining, and validating process changes is known as the Plan-Do-Study-Act (PDSA) cycle.

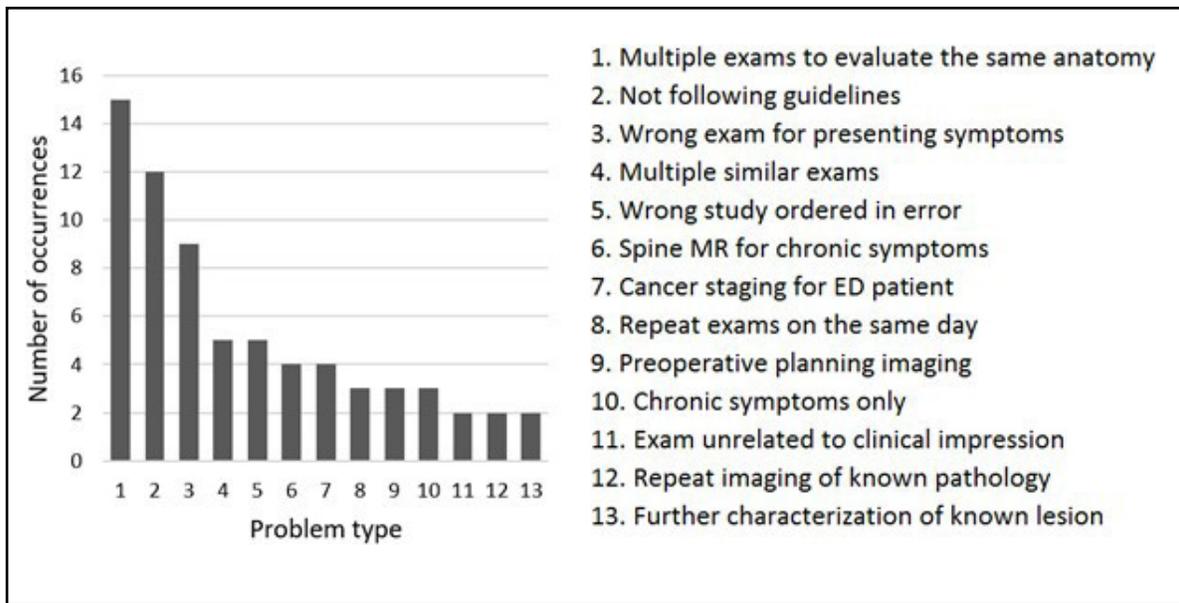


Figure 3.3. Pareto chart. This chart illustrates which causes are most commonly responsible for the problem. In this case, the team was seeking to identify the most common types of unhelpful emergency department (ED) exams. Source: Kruskal et al. *Radiographics* 2011.

The PDSA cycle is essentially a restatement of the scientific method. A synonym for a PDSA cycle is a planned test of change. A cycle starts with a hypothesis of how a process change will lead to a desired outcome. The steps include developing a plan to test that hypothesis (planning the test), testing the hypothesis (doing the test), analyzing the data (studying the results), and drawing actionable conclusions and determining next steps (acting accordingly).

Because the effects of process changes are not known in advance, initial changes are typically tested on as small a scale as possible and in a relatively protected environment. It is expected that many of these proposed changes will be unsuccessful. For this reason, the team is wise to generate a number of potential changes through brainstorming. When a test of change does not result in the desired outcome, the project team may wish to modify the approach and test it again or abandon it altogether and

try a different approach.

Changes are tested on a larger scale only after they have been proven successful on a smaller scale. The final determination of whether the changes are effective in practice is if they result in improved performance. Hence, it is critical to continuously monitor performance throughout the life of an improvement project.

Improvement is generally most effective when multiple PDSA cycles are run in parallel or in rapid succession. With each test, the improvement team gains greater insight and knowledge of how specific changes impact outcomes—for better and for worse. Only after the problems have been worked out and the team is confident that the changes will result in the desired improved outcomes are the changes fully implemented. Despite the fact that multiple PDSA cycles are needed for most successful improvement projects, if they are executed well and kept as small and brief as

possible, the process of testing, refining, and validating changes need not be protracted.

Sustaining the Improvement

Without deliberate mechanisms to sustain improvements, performance usually reverts to the initial state. Strategies to increase the likelihood that results will be sustained include 1) establishing regular measurement and feedback, 2) using handoffs to enforce standards by ensuring that all staff expect the same standard, 3) establishing the practice of stopping the process and summoning immediate supervisors whenever a problem is encountered, 4) embedding checks into the process, and 5) using high-reliability solutions.

High-reliability Solutions: Process changes may take many forms, including education and feedback, standardization of procedures, and infrastructure and system changes. In general, processes that rely on education and feedback tend to result in lower consistency in outcome, or reliability, than those that rely on standardization of procedures, which in turn tend to result in lower consistency of outcome than those that rely on changes to infrastructure and organizational culture. As a general rule, high-reliability process changes are more effective and require less effort by the process owner to sustain than low-reliability solutions.

QI Project Management

A project is defined as “a temporary group activity, designed to produce a unique product, service, or result.” Project management is the “application of knowledge, skills, and techniques to execute projects effectively and efficiently.” Effective project management techniques bring order to what can otherwise be a chaotic process, to help ensure that projects meet their objectives.

Examples include 1) task management: defining each task, clearly setting expectations of what is

to be done by whom and by when, and following up on each task; 2) progress tracking: keeping people apprised of project progress, reminding individuals as deadlines approach, and alerting appropriate individuals when milestones are missed; 3) conducting effective meetings; and 4) avoiding mistakes common to quality improvement.

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3.2 Practical Safety Applications in Healthcare

3.2.1 Periprocedural Care

Patient Identifiers

Patient identification is critical to ensure that the right patient receives the right treatment, medication, invasive or noninvasive procedure, and blood products, as well as to reduce the chance of unnecessary radiation exposure. At least two patient identifiers should be used before every procedure. Identifiers can include patient name, assigned identification number, telephone number, or other person-specific identifier (e.g., date of birth, government-issued photo identification, and last four digits of the social security number). Transient factors such as patient's location or room number cannot be used. Sources of identifiers may include the patient, a relative, a guardian, a domestic partner, or a healthcare provider who has previously identified the patient. In the case of a discrepancy between identifiers, the practitioner should stop and seek additional information to confirm the identity before proceeding.

Patient Assessment

Before sedation is initiated, a patient must be assessed and approved for sedation. Recent oral intake, recent illness, pulmonary status (including upper airway), cardiac status, baseline vital signs, level of consciousness, pulse oximetry, capnography (if available), and electrocardiography (when applicable) should be obtained and documented.

Sedation

The Joint Commission and the American Society of Anesthesiologists have defined four levels of sedation, analgesia, and anesthesia:

1. **Minimal Sedation or Anxiolysis.** A drug-induced state, created by the

administration of medications to reduce anxiety, during which the patient responds to verbal commands. In this state, cognitive function and coordination may be impaired, but ventilatory and cardiovascular functions are unaffected.

2. **Moderate Sedation/Analgesia.** A mildly depressed level of consciousness, induced by the administration of pharmacologic agents, in which the patient retains a continuous and independent ability to maintain protective reflexes and a patent airway and to be aroused by physical or verbal stimulation.
3. **Deep Sedation/Analgesia.** A drug-induced depression of consciousness during which the patient cannot be easily aroused but responds purposefully after repeated or painful stimulation. Independent ventilatory function may be impaired. The patient may require assistance in maintaining a patent airway. Cardiovascular function is usually maintained.
4. **General Anesthesia.** A controlled state of unconsciousness in which there is a complete loss of protective reflexes, including the ability to maintain a patent airway independently and to respond appropriately to painful stimulation.

It is important to recognize that these "levels" are actually a continuum. Patients may rapidly move between the levels and may reach a deeper level of sedation than desired. Sedation may result in the loss of protective reflexes. Thus, all sedated patients require monitoring regardless of the intended level of sedation.

Patients who are candidates for sedation by a

non- anesthesia provider such as a radiologist must be screened to determine if they have risk factors that may increase the likelihood of an adverse outcome. Such risk factors include, but are not limited to, congenital or acquired abnormalities of the airway, liver failure, lung disease, congestive heart failure, symptomatic brain stem dysfunction, apnea or hypotonia, a history of adverse reaction to sedating medications, morbid obesity, and severe gastroesophageal reflux.

The patient's American Society of Anesthesiologists (ASA) Physical Status Classification should also be assessed. This is a six-level classification as follows:

- Class I - A normal healthy patient
- Class II - A patient with mild systemic disease
- Class III - A patient with severe systemic disease
- Class IV - A patient with severe systemic disease that is a constant threat to life
- Class V - A moribund patient who is not expected to survive without the operation
- Class VI - A declared brain-dead patient whose organs are being removed for donor purposes

Patients in Classes III and IV or with other significant risk factors may require a consultation with anesthesiology or the performance of sedation by an anesthesiologist or anesthesiologist. Patients in Class V should not be sedated by non-anesthesiologists.

When sedation is performed under the supervision of a radiologist, there must be a separate qualified healthcare professional whose primary focus is the monitoring, medicating, and care of the patient. The patient

must have intravenous access. Continuous monitoring should include, at a minimum, level of consciousness, respiratory rate, pulse oximetry, blood pressure (as indicated), heart rate, and cardiac rhythm. Similar monitoring is needed in the recovery period from sedation. The supervising physician should have sufficient knowledge of the pharmacology, indications, and contraindications for the use of sedative agents, including the use of reversal agents. A key point related to reversal agents is that their duration of effect may be shorter than that of the sedating agent, leading to a risk of relapse into a deeper level of sedation. It is recommended that consciousness and vital signs return to acceptable levels and remain at those levels for a period of two hours from the time the reversal agent was administered before monitoring ends and the patient is discharged.

Informed Consent

Informed consent is required for invasive image- guided procedures. Apart from legal or regulatory requirements, patients have the right to be informed about the procedures they undergo and may request to speak with a radiologist even when local policy does not require the radiologist to initiate an informed consent process.

Despite the fact that a consent form is often used to document the discussion, the *ACR-SIR Practice Parameter on Informed Consent for Image-Guided Procedures* states that "informed consent is a process and not the simple act of signing a formal document." Consent can also be documented by a note in the patient's medical record, by a recording on videotape, or by another similar permanent modality. Consent should be obtained from the patient or the patient's legal representative by a physician or other healthcare provider performing the procedure. The final responsibility for answering the patient's questions and

addressing any patient concerns rests with the physician performing or supervising the procedure.

Elements of informed consent include 1) the purpose and nature of the intended procedure, 2) the method by which the procedure will be performed, 3) likely risks, complications, and expected benefits, 4) risks of not proceeding, 5) any reasonable alternatives to the proposed procedure, and 6) the right to decline the proposed procedure. An exception to these steps exists when a delay in treatment would jeopardize the health of a patient who is unable to provide informed consent (e.g., an unconscious trauma patient for whom family has not yet been identified). Since the patient must be able to understand the consent process for it to be valid, consent must be obtained before procedure-related sedation is administered.

When the patient is not able to give valid consent because of short-term or long-term mental incapacity, whether from pain medications or otherwise, or when the patient has not achieved the locally recognized age of majority, consent should be obtained from the patient's appointed healthcare representative, legal guardian, or appropriate family member. In emergency situations when the patient needs immediate care, the patient's predetermined wishes are not known or appropriately documented, and consent cannot be obtained from the patient's representative, the physician may provide treatment or perform a procedure "to prevent serious disability or death or to alleviate great pain or suffering."

Minors' Rights in Medical Decision Making Courts in the United States have recognized that children younger than 18 years deserve a voice in determining their course of medical treatment if they show maturity and competence. However, rules that govern the

issue of parental rights versus minors' rights vary from state to state. States and courts have never allowed children younger than 12 years to make medical decisions and exercise self-determination, whereas adolescents between ages 12 and 18 (or 19 in some states) experience a gradual transition to self-determination. Factors that impact the determination of adolescents' rights include the following:

1. **Legal determination of maturity**, such as married status, parenthood, self-sufficiency, or active duty in the armed services.
2. **Evidence that the child is sufficiently mature to make his or her own decisions**, such as age greater than 14 years; evidence that the minor has the ability to understand the implications of treatment, including risks, benefits, likely short- and long-term consequences, and alternatives; and evidence that the minor can make an informed decision without coercion.
3. **Conditions exempting parental consent**, such as seeking testing or treatment for sexually transmitted diseases, including HIV; seeking contraception, prenatal care, or abortion; or seeking mental health treatment, emergency care, or treatment of alcohol or drug abuse after the age of 12 years.

Universal Protocol

Universal protocol refers to the three-part process of *conducting a preprocedure verification, marking the procedure site, and performing a preprocedure time out*. Note that site marking may be performed before completing the preprocedure verification.

1. **Preprocedure verification**. This is an ongoing process of information gathering and confirmation before the

procedure. The purpose is to ensure that all relevant information and equipment are 1) available before the start of the procedure, 2) correctly labeled, identified, and matched to the patient's identifiers, and 3) reviewed and are consistent with the expectations of the procedure to be performed.

Preprocedural verification may occur at more than one time and place before the procedure.

- 2. Marking of the procedure site.** At a minimum, a procedure site should be marked when there is more than one possible location for the procedure and when performing the procedure in a different location could harm the patient. If possible, the patient should be involved in the site marking. The site must be marked by a licensed independent practitioner who will be present when the procedure is performed. In limited circumstances, site marking may be delegated to medical residents, physician assistants (PAs), or advanced practice registered nurses (APRNs), but ultimately the licensed independent practitioner is accountable for the procedure, even when delegating site marking.

The mark should be made at or near the procedure site, and should be sufficiently permanent to be visible after skin preparation and draping. It should also be unambiguous and used consistently throughout the organization. An organization should have written alternative processes for situations such as procedures on mucosal surfaces or perineum, minimal access procedures treating a lateralized internal organ, interventional procedure

cases for which the catheter or instrument insertion site is not predetermined (such as cardiac catheterization), procedures on teeth, and procedures on premature infants, for whom the mark may cause a permanent tattoo.

- 3. Preprocedure time out.** A standardized time out should be conducted immediately before an invasive procedure is started or an incision is made. The designated member of the team starts the time out. The time out should involve the immediate members of the team, including the individual performing the procedure, anesthesia providers, the circulating nurse, the operating room technician, and other active participants who will be present throughout the case. During the time out, all relevant members of the team actively communicate and at a minimum agree on the following: correct patient identity, correct site, and procedure to be done. Documentation of the time out should be performed according to the organization's policy.

3.2.2 Hand Hygiene

Hand hygiene refers to cleaning one's hands by using either handwashing (washing hands with soap and water), antiseptic hand wash, antiseptic hand rub (i.e., alcohol-based hand sanitizer including foam or gel), or surgical hand antisepsis.

Alcohol-based hand sanitizers are the most effective products for reducing the number of bacteria on the hands. When hands are not visibly dirty, alcohol-based hand sanitizers are the preferred method for cleaning one's hands in the healthcare setting. Soap and water are recommended when hands are visibly dirty, before eating, after using a restroom, or after

known or suspected exposure to *Clostridium difficile*, norovirus, or *Bacillus anthracis*.

Hand hygiene should be performed 1) before eating, 2) before and after having direct contact with a patient's skin, 3) after contact with blood, body fluids or excretions, mucous membranes, nonintact skin, or wound dressings, 4) after contact with inanimate objects in the immediate vicinity of the patient, 5) if hands will be moving from a contaminated-body site to a clean- body site during patient care, 6) after glove removal, and 7) after using a restroom. When hands are cleaned with soap and water, the soap and water should cover all surfaces of the hands and fingers. When alcohol-based hand sanitizer is used, the product should cover all surfaces as hands are rubbed together. Adequate cleansing can be achieved in about 20 seconds via either route.

3.2.3 Root Cause Analysis

Root cause analysis (RCA) is a structured method used to analyze serious adverse events to decrease the likelihood of recurrence. The goal of RCA is to identify both active errors (errors occurring at the point of interface between humans and a complex system) and latent conditions (the hidden problems within healthcare systems that increase the likelihood of an adverse event). For example, an active error occurs when a nurse accidentally administers a full dose of heparin rather than a heparin flush; an associated latent condition might be the fact that the two vials appear virtually identical and both are routinely stocked near each other in the same cabinet at the point of care.

RCAs should generally begin with data collection to create an objective narrative of the event based on a review of the medical record and interviews with people involved. A multidisciplinary team should then analyze the

sequence of events leading to the error, with the goals of identifying how the event occurred (active errors) and underlying conditions that contributed to the event (latent conditions). It should be recognized that serious adverse events are almost never the result of a single cause, and often are associated with numerous contributing factors. The RCA should culminate in an analysis of issues that should be addressed to decrease the likelihood of recurrence and a plan for addressing those issues, including a timeline and individual responsibility.

In the setting of a serious adverse event, immediate interventions may be implemented to quickly reduce the risk of recurrence of a similar error. However, such quickly generated solutions typically do not address the root cause and should only serve as a placeholder until more reliable and sustainable solutions can be developed, tested, and implemented.

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Chapter 4: Practical Safety Applications in Radiology

4.1 MR Safety

An MRI scanner has been described as a coil within a coil within a coil, with each coil producing different magnetic fields for different purposes (**Figs. 4.1 and 4.2**). The three unique magnetic fields in MRI are the static magnetic field (B_0), time-varying gradient magnetic field (dB/dt), and time-varying radiofrequency magnetic field (B_1). These fields are generated by the main coil, the gradient coils (in the x, y, and z directions), and the radiofrequency (RF) coils, respectively. The superconducting main coil is contained in a helium-cooled cryogenic assembly, whereas the gradient and RF transmit coils are contained in a non-cryogenic assembly cooled by chilled water.

The construct and function of the MR scanner pose unique safety risks. For example, because the strong static magnetic field is always on, a ferromagnetic object may become a projectile anytime it enters the MRI scan room. Patients undergoing MRI may be subjected to burns or displacement of devices such as aneurysm clips. Additionally, the quenching of the supercooled magnetic can cause helium to displace room air, leading to asphyxiation.

Due to these and other risks, strict safety precautions must be enforced in the MR environment. The American College of Radiology (ACR) Manual on MR Safety provides a comprehensive set of recommendations for the design, operation, and oversight of MRI suites to ensure patient and personnel safety. This manual is available in the form of a free online document which is periodically updated.

MRI-related risks apply to all who may enter the MRI scanner environment, including

patients, research subjects, MRI personnel, and visitors. Greater risk exists for non-MR personnel who do not regularly work in the MR environment, including physicians and nurses who rarely enter the MR environment but may do so in urgent situations. Improperly trained and inadequately screened staff such as security and cleaning personnel may also unknowingly bring ferromagnetic materials into the MR environment. Without dedicated attention, patients' family members who could also carry such materials can be overlooked.

To address these risks, operators of MRI scanners are expected to establish specific MR safety management roles, including the following: (1) a designated physician MR Medical Director (MRMD) for MR safety; (2) an MR safety officer (MRSO); and (3) an MR safety expert (MRSE). The MRMD assumes ultimate responsibility for a site's operational MR safety and the safe execution of all MR examinations. The MRMD appoints MRSOs and MRSEs, maintains MR safety policies and procedures, and appropriately investigates any MR safety adverse events. The MRSO, a role typically filled by a technologist, ensures that policies and procedures are followed, emergency procedures are in place and trained for, and sufficient education is completed by relevant personnel, among other responsibilities. The MRSE, typically an MR physicist, is a resource for the MRMD and MRSOs, rendering expertise related to the safe use of MR equipment, and providing recommendations for appropriate scanning conditions for patients with implanted devices, for example.

4.1.1 Zoning and Screening

To ensure that the strictness of safety measures matches the level of risk inherent in the proximity to the scanner, the MRI site is divided into four zones, with progressively increasing monitoring requirements and

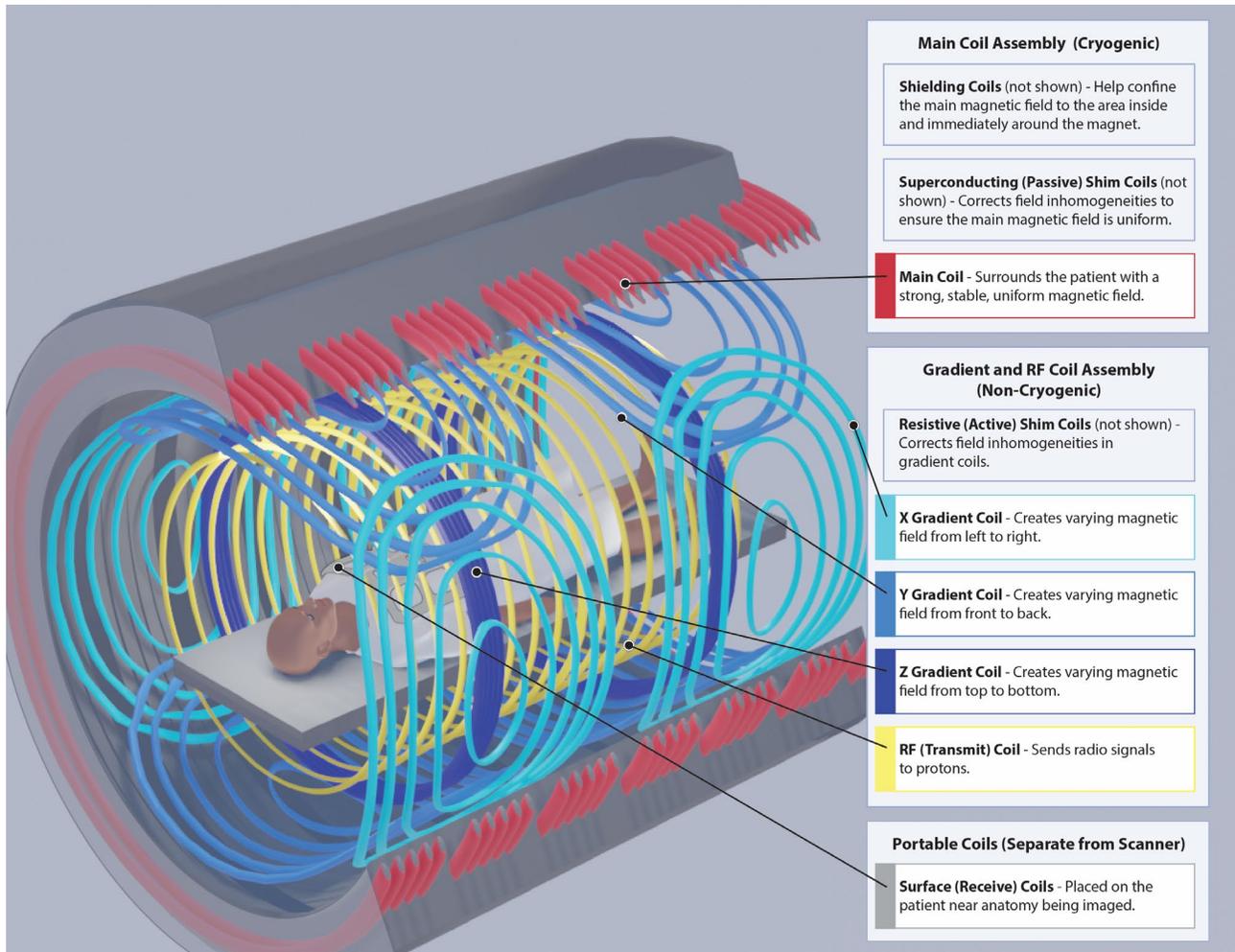


Figure 4.1. Diagram illustrating the magnetic coils of an MRI scanner. The three primary sets of coils embedded in the scanner are the main coil (red), gradient coils (blue) and radiofrequency (RF) transmit coil (yellow). The portable surface (receive) coil is placed on the patient. Note that the main coil assembly is supercooled with cryogenic liquid helium.

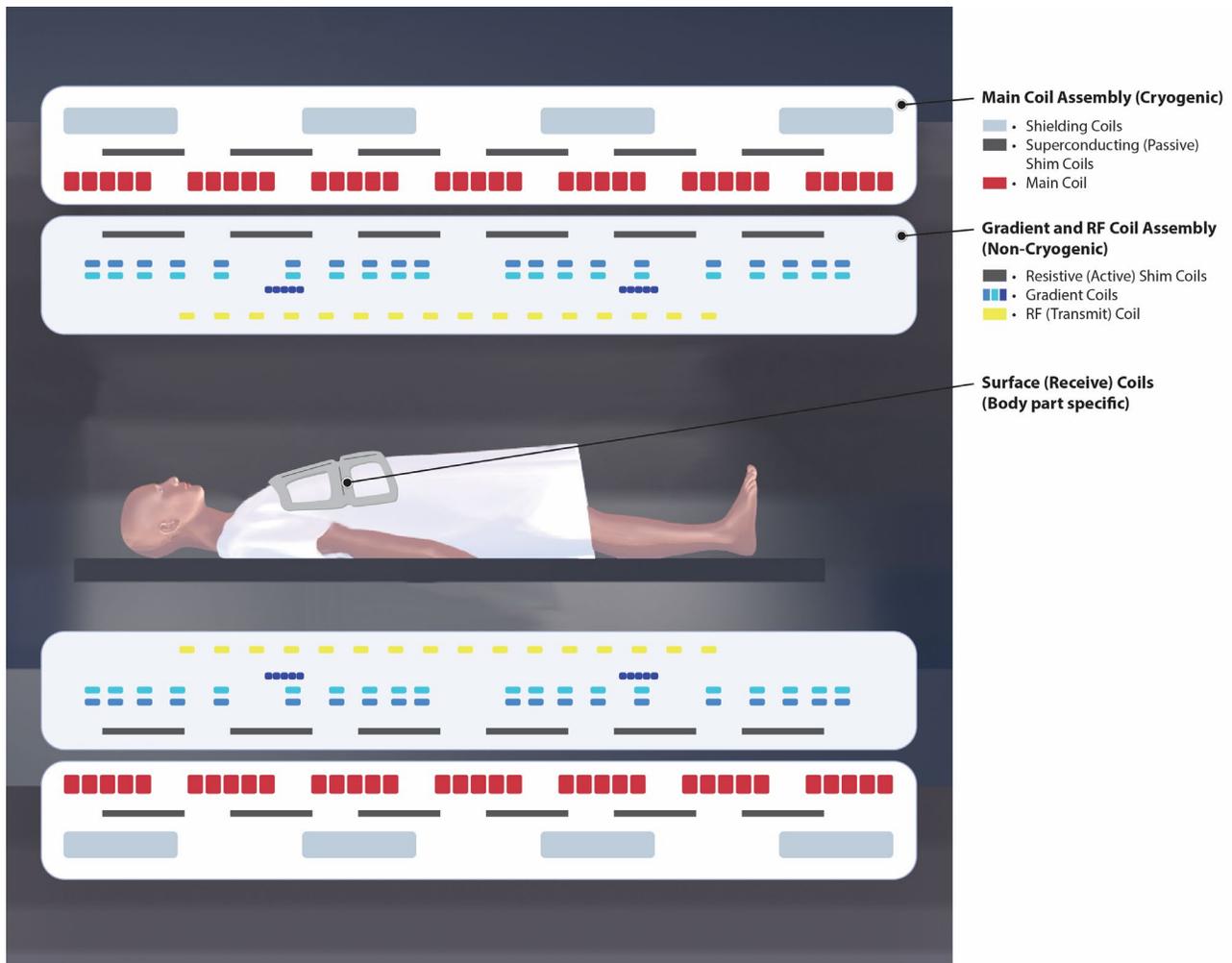


Figure 4.2. Cross-section view (longitudinal to the scanner) of the magnetic coils depicted in Figure 4.1.

restriction of entry into higher numbered, more controlled zones. A depiction of MRI zones in an MRI suite is provided in **Figure 4.3**. These zones are defined as follows:

Zone I: Access is unrestricted. This zone includes all areas that are freely accessible to the public. This is the area through which patients and others pass before they access the controlled MR environment.

Zone II: This is the interface between the uncontrolled Zone I and the strictly controlled Zones III and IV. Zone II may be used to greet patients, obtain patient histories, and screen patients for MR safety issues. Patients in Zone II should be under the supervision of MR personnel.

Zone III: This is a strictly controlled area near the scanner, with a risk from interaction between unscreened people or ferromagnetic objects and the magnetic field of the scanner. The scanner control room is typically in Zone III. Access to Zone III must be strictly restricted and under the supervision of MR personnel, with physical restriction such as locks or passkey systems.

Zone IV: This is the MR scanner magnet room and therefore is the highest risk area. This zone contains the “Projectile Zone” where an uncontrolled ferromagnetic object could fly dangerously into the magnet. Therefore, it should be clearly demarcated and marked as potentially hazardous.

Access to Zone IV should be under the direct observation of MR personnel. The ACR Committee on MR Safety

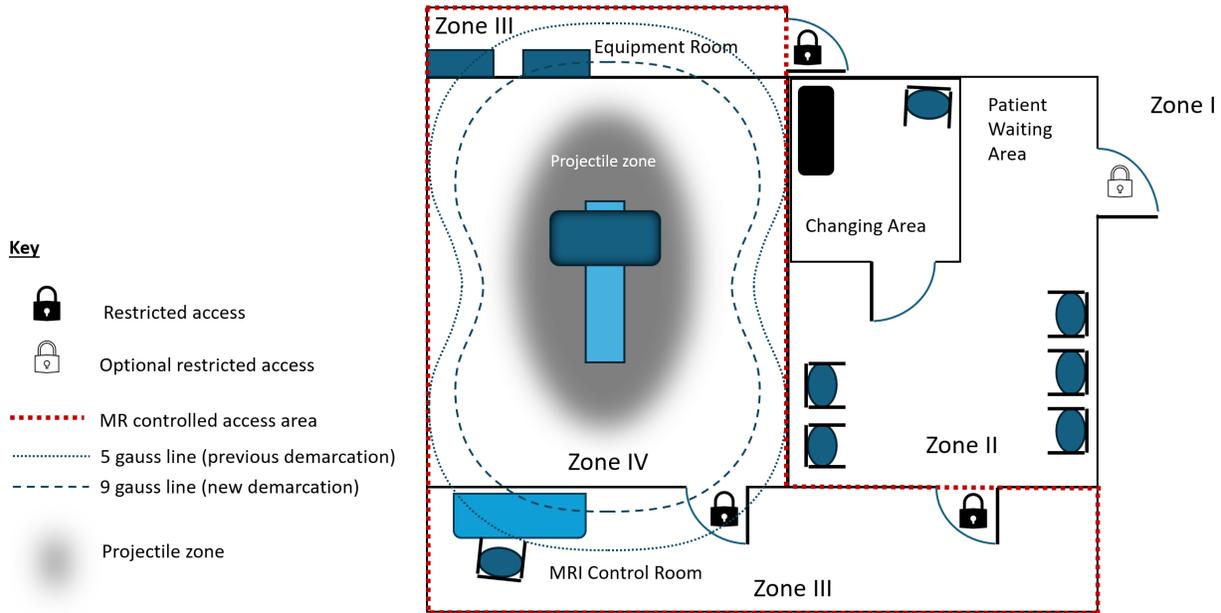
recommends that the door remain closed or protected by a physical barrier such as a retractable safety strap, plastic chain, or specific doorway gate device at all times except when personnel and patients travel across the threshold. When a medical emergency occurs, MR trained and certified personnel should begin basic life support or CPR in Zone IV if required, while urgently moving the patient from Zone IV to a magnetically safe location to allow for others to assist in a safe environment outside the scan room, and securing the door to Zone IV to prevent inadvertent entry.

The major transition in levels of safety occurs from the interfacing area of Zone II to the higher risk Zone III. MR personnel working within Zone III and Zone IV should have specific education on MR safety and pass an MR safety screening process.

There are two MR personnel safety level designations: Level 1 and Level 2. Level 1 personnel have passed the facility’s basic MR safety education requirements to ensure that they would not be a danger to themselves or others. Level 1 personnel are not to be independently responsible for the safety of others in Zone IV.

Level 2 personnel are more extensively trained, including on topics such as radiofrequency (RF)-induced heating. Level 2 personnel can be independently responsible for the safety of others in Zone IV. However, according to the ACR Manual on MR Safety, a technologist should not work alone; there should always be at least one Level 2 technologist assisted by an additional MR-trained individual (either Level 1 or Level 2) present in Zone III to help ensure patient and personnel safety.

All other non-MR personnel and patients entering Zone III should be appropriately screened. MR screening begins with a focused history to identify potential metallic foreign objects and medical implants. This may be supplemented as needed by reviewing any existing radiographs, CT, or MR of the questioned area as well as operative reports and implanted devices information in electronic medical



Adapted from the 2024 ACR Manual on MR Safety

Figure 4.3. Example of MRI zones in an MRI suite. Access is unrestricted in Zone I, which is the public area outside the MRI suite. Patients are greeted in Zone II, which should be under supervision of MR personnel. Zone III is strictly controlled, including with physical restrictions such as locks; patients entering this Zone must be under the supervision of MR personnel. Zone IV is the highest risk area; patients in Zone IV must be under direct supervision of MR personnel at all times.

records. When an object or implant is identified, its MR safety potential should be assessed specific to the field strength of the magnet and specific factors such as RF deposition (e.g., specific absorption rate or SAR).

Objects that might be brought into the MRI suite should be labeled according to the conventions shown in **Figure 4.4**. Objects that are nonhazardous in all MR environments, such as a plastic tube, are deemed “MR Safe,” whereas those contraindicated, such as a ferromagnetic aneurysm clip, are labeled “MR Unsafe.” “MR Conditional” devices can be safely scanned providing the specific conditions for safe scanning are appropriately

adhered to, including magnetic field strength (e.g., 1.5T or 3T), specific coils that are permissible (e.g., some device conditions require use of a local transmit/receive coil at a distance from a device, and do not permit use of a receive-only coil using the magnet RF coil), and specific RF deposition parameters (e.g. a defined SAR, such as 1.0 W/kg). Published information is available regarding the MR safety of most medical implants, and it is essential that the manufacturer’s most up to date MR safety information defining the MR conditions for safe scanning are used, as these change frequently.

Ferromagnetic objects should be restricted from entering Zone III whenever practical. Ferromagnetic detection devices, either wall mounted or handheld,

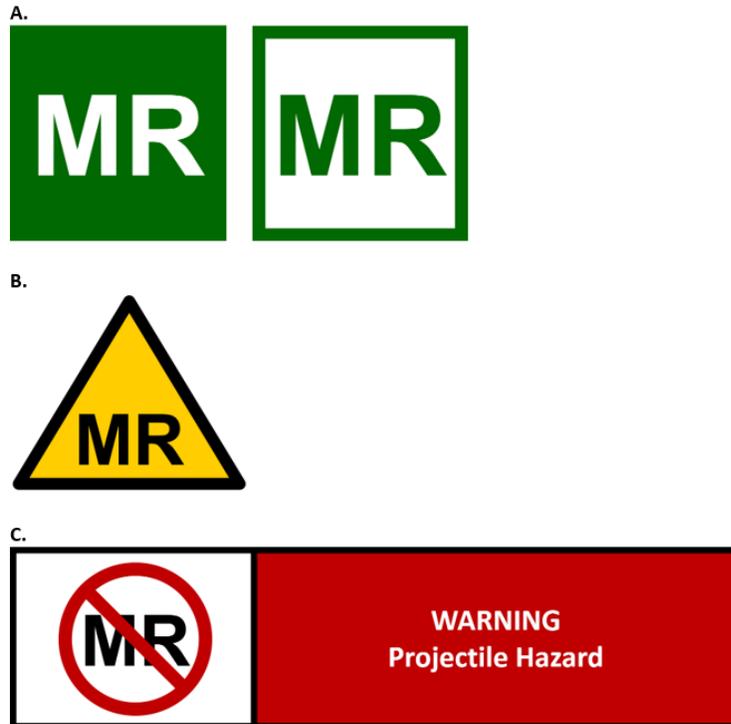


Figure 4.4. MRI labels. **A. MR Safe label.** An MR safe device contains no metal and is composed of materials that are nonconductive, nonmetallic and nonmagnetic **B. MR Conditional label.** An MRI Conditional device may be used only under clearly specified conditions. **C. MR Unsafe label.** MR unsafe devices must be kept outside the MR scanner room.

can augment safety screening processes in helping to identify unknown ferromagnetic objects concealed on a patient, and some superficial internal implants, such as pacemakers. All MR sites should have a handheld magnet (≥ 1000 Gauss) for these purposes. To minimize risk of unsafe items entering Zone IV, and to minimize risk of burns from potential metallic fibers in clothing, the ACR Committee on MR Safety now recommends that all MR patients are changed into MR safe gowns or scrubs.

Occasionally, devices that are determined to be ferromagnetic and MR unsafe may be intentionally permitted into Zone III. In such cases, these must be appropriately secured or tethered at all times and be under the supervision of trained MR personnel.

The strong magnetic field inherent to an MR scanner can pose a risk for projectile injury if a ferromagnetic object (e.g., hospital gurney, scissors, cell phone) is brought too close to the magnet (within the “projectile zone” in **Fig. 4.2**). There have been reports of projectile injuries from ferromagnetic anesthetic gas or oxygen cylinders, and even patient deaths. In addition to injuring patients, projectiles may also cause extensive damage to the MR unit. It is important to understand that magnetic attraction does NOT increase linearly as one approaches the magnet. Rather, the spatial gradient magnetic field increases very steeply in close proximity to the magnet such that one can perceive very little magnetic pull on a ferromagnetic object, and then when moving only a short distance closer, the object is subjected to a tremendously higher

attractive force, typically ripping an object from one's grasp in an uncontrolled manner. For this reason, the ACR Manual on MR Safety now recommends pocketless attire for MR personnel who work in Zone IV on a daily basis.

Screening is more difficult when the patient is unconscious or otherwise unable to provide a reliable history. In such cases, screening information should be obtained as best as possible from other sources, such as family members, the medical record, and available prior imaging. The urgency of the examination should be balanced with the level of uncertainty of the screening process. A physical examination by trained MR personnel should be performed to assess for surgical scars that may warrant additional evaluation.

Radiography may be required to assess for foreign bodies, implants, or devices. If there is a documented history of eye injury from metal and uncertainty as to whether there may be retained intraocular metal, imaging is recommended, which may include either orbital X-rays or thin section head CT.

The 5 Gauss line historically demarcated the threshold of safety for implantable cardiac devices. However, cardiac implantable device manufacturers have been required to demonstrate that their devices are immune to static magnetic fields up to 10 Gauss. Thus, the 5 Gauss line provided a substantial safety margin. The International Electrotechnical Commission (IEC) has recently revised the safety margin demarcation from the more stringent 5 Gauss line to the less stringent 9 Gauss line, which is closer to the magnet. This still allows for 1 gauss tolerance for variability in the device testing methods. This change was recognized by the FDA and endorsed by the ACR MR Safety Committee in 2024. Because the 9 Gauss line is within the 5 Gauss line (closer to the magnet), sites that have been following previous 5 Gauss recommendations are already compliant with the new 9 Gauss recommendations. This line should be marked on

the floors or walls for safety, particularly when it extends beyond the walls of the MR scanner room. It is important to remember that the magnetic field is three-dimensional. Thus, the restricted area may extend through the floor and/or ceiling to adjacent floors.

4.1.2 Implanted Devices

Medical devices contain varying amounts of ferromagnetic material and can be subject to translational and rotational forces when interacting with the magnetic field of an MR unit. In addition, presence of any conducting metal can result in current generation from the radiofrequency B_1 field and interactions with the gradient dB/dt field. All metal-containing implants are considered either MR unsafe (e.g., a ferromagnetic aneurysm clip), or MR conditional (e.g., a titanium aneurysm clip, a nitinol stent, an MR conditional cardiac pacemaker system), but are never considered to be MR safe.

There has been at least one documented case of a fatality due to rotation of an MR unsafe ferromagnetic aneurysm clip while the patient was in the MR scanner. If a patient is identified to have an intracranial aneurysm clip(s), MRI should not be performed until the specific manufacturer, model, and type of (each) aneurysm clip is definitively identified, and its MR safety conditions identified. Although a patient may previously have undergone an MR examination with an aneurysm clip without known complications, that fact alone is not sufficient to conclude that the clip is MR conditional.

Cardiac implantable electronic devices (CIED) similarly can be adversely affected by the B_0 , B_1 , and dB/dt fields, potentially leading to complications, including failure to pace, induction of ventricular fibrillation, and heating of cardiac tissue adjacent to the leads; these complications can potentially be

fatal. The FDA label designation of MR conditional for pacemakers became available in February 2011; such labels specify conditions under which the devices may enter the MR scan room. If MRI is performed on a patient with an MR-conditional CIED, the conditions for scanning must be followed in their entirety, including attention to magnet field strength, scanning parameters, and cardiology programming of the device, and monitoring of the patient throughout the exam in the presence of ACLS trained personnel, with ready availability of a crash cart should resuscitation be necessary.

Of note, CIED systems not specifically labeled as MR conditional are being scanned at some centers in an informed consent manner following guidelines established by the Heart Rhythm Society and the ACR. Some of the specific elements that must be in place for this to occur include: 1) there is to be an institutional protocol in place with a responsible MRMD and CIED MD using a radiology/cardiology team approach; 2) medical necessity must be established for the exam; 3) patient monitoring must be performed, including ECG and pulse oximetry; 4) defibrillator/monitor with external pacing must be available (outside Zone IV); 5) ACLS personnel must be in attendance during exam; and 6) appropriate CIED reprogramming must occur post MRI.

The number of active implanted medical devices (devices that contain an energy source such as a battery or can be inductively coupled) continues to rapidly increase, including many types of neurostimulators (e.g., deep brain, spinal cord, hypoglossal nerve, cochlear implants) and medication pumps. It cannot be emphasized enough that there must be precise identification of the make and model of each component of an implanted device system (e.g., in the case of a spinal cord stimulator system, this is to

include the implanted pulse generator as well as the leads) and if MR conditional, the conditions for scanning must be strictly adhered to.

4.1.3 MR and Pregnancy

MRI exposure alone, without the administration of gadolinium-based contrast media, has not been shown to have a detrimental effect on the developing fetus. For this reason, no special consideration is recommended during pregnancy regarding exposure to noncontrast MRI up to 3T at normal operating mode. However, since it is impossible to completely eliminate all risk, patients and clinicians should consider whether it is safe to delay an MR examination until the end of pregnancy.

Pregnant healthcare workers may work in an MRI environment during all stages of pregnancy, but they should not remain in Zone IV during data acquisition or scanning.

4.1.4 MR-induced Burns

The possibility of thermal injury and burns, some severe, in MRI is predominantly due to the radiofrequency (RF) fields. Examples of MRI burns are shown in **Figure 4.5**.

As shown in **Figures 4.1** and **4.2**, the RF coil is the closest to the patient in the magnet bore and poses specific risks. Physical contact alone with the inner surface of the scanner bore can produce proximity burns, and insulating pads are necessary to keep skin at least 1 to 2 centimeters from the scanner surface. In a large patient, tightly wedging a sheet in place of a pad between the skin and the bore creates a distinct risk of burns as it does not maintain the requisite distance; this practice is specifically recommended against in the ACR Manual on MR Safety.

RF fields can also induce currents within the body, particularly when a “closed loop” is formed; for example, if there is skin-to-skin contact at the inner thighs. If there is only a

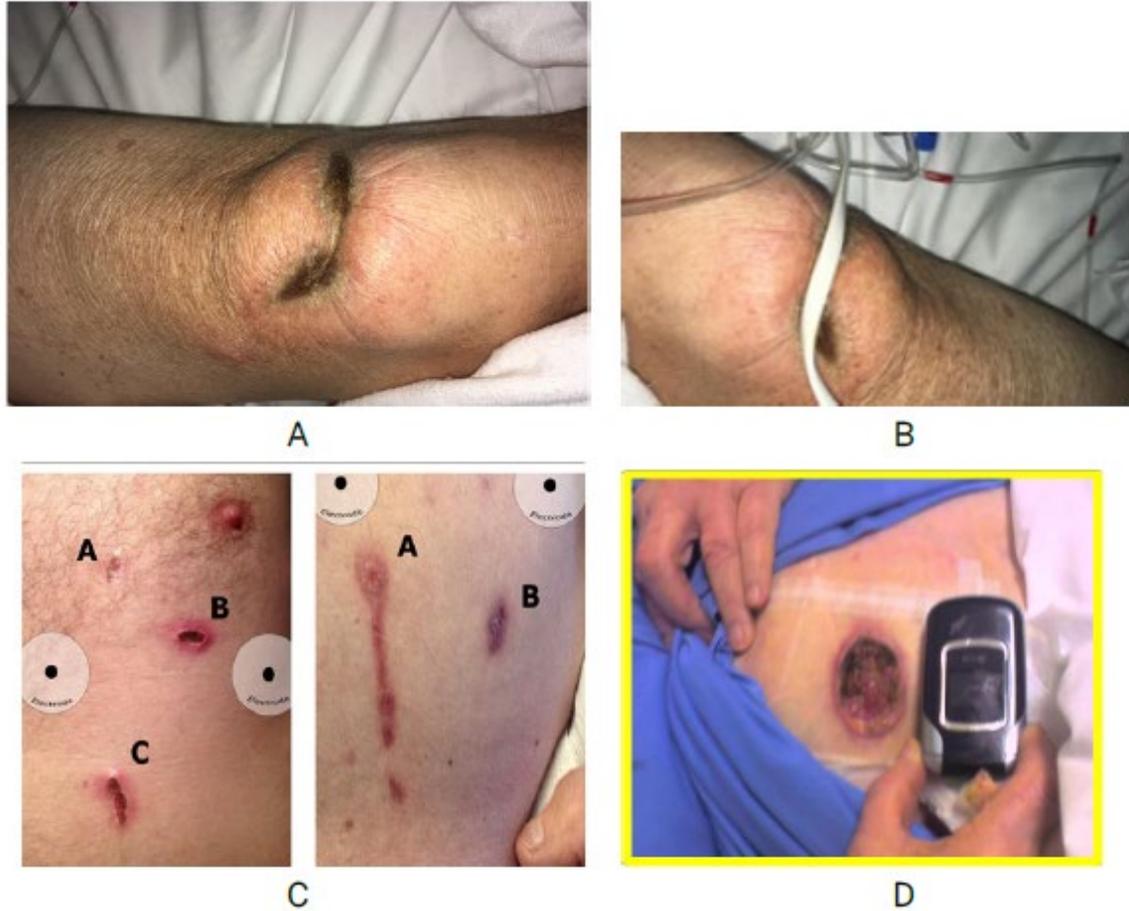


Figure 4.5 Examples of serious tissue burns resulting from RF-related heating during MRI exams. (A) Healing third degree burn at patient's knee. (B) Reenactment of path of an arterial pressure transducer extension cable within the RF field that crossed an anesthetized patient's knee during an interventional MR procedure. Subsequent testing with the cable in that configuration demonstrated that the turbo spin-echo pulse sequences with whole body-averaged SARs of approximately 2 W/kg produced localized heating approaching 30° Celsius. (C) Skin burns caused by ECG electrode lead heating during MRI. (D) Third degree burn resulting from RF-related heating of a material (i.e., cell phone) courtesy of Frank G. Shellock, PhD. *Figure from the ACR® Manual on MR Safety 2024, used with permission.*

small surface area of skin-to-skin contact, the concentrated current density and resistive heating can lead to burns. Skin-to-skin burns have also occurred when a finger contacts the thigh and when an overhanging abdominal panniculus contacts the upper thigh in obese patients. Care must be taken to ensure that

padding prevents such situations. Commercial pads with strategically placed notches to keep thighs separated are available, minimizing this skin-to-skin contact risk.

Patient clothing containing metal can also serve as a source of heating, placing the patient at risk for

burns, especially when the clothing is adjacent to the skin, such as underclothing. To minimize this risk, it is recommended that patients change out of street clothes into hospital gowns or similar MR-safe attire.

Loops of metallic wire (e.g., from electronic physiologic monitoring equipment), patches of metal (e.g., in foil backed transdermal medication patches), and other electrical conduction circuits may be rapidly heated by RF pulses during normal operation of an MRI system. Additionally, large tattoos may occasionally undergo heating and cause burns; application of a cold compress or an ice pack may be necessary to reduce the risk of skin burning. Since the RF resonant wavelength is a function of magnet field strength, leads or other conductors can have drastically different and unpredictable tendencies to heat in different magnets. Care must be taken to prevent wire loops or metallic patches from touching patients' skin during routine scanning.

When medication patches are removed for MRI scanning, there must be a clear line of communication to ensure medication replacement after the MRI, particularly for critical medications (e.g., clonidine foil-backed patches).

4.1.5 Quenching (Emergency Magnet Shutoff)

When the presence of the magnetic field poses an immediate risk to human life or health—such as when personnel are pinned to the magnet by a ferromagnetic hospital gurney—the magnetic field must be eliminated by initiating an emergency magnet shutoff. MRI personnel must recognize that, unlike most medical equipment, an MRI magnet cannot simply be switched on and off.

Because the supercooled main magnetic coil is always on, the only way to turn off the main magnetic field is by initiating a “quench,” in which the magnetic coil abruptly loses its superconducting properties and associated magnetism. A quench may be deliberately

initiated by an operator using the emergency magnet shutoff (quench) button, or it may occur spontaneously and unintentionally as a result of equipment malfunction or system failure.

A magnetic quench is a significant event in which a cascade of physical processes unfolds in rapid succession. In normal operation, the main magnetic field is sustained by keeping the electromagnetic coils of the MR scanner immersed in large volumes (typically 1500 to 2000 L) of extremely cold liquid helium, cooled to approximately -269°C (4°K). When the temperature of the coils rises above the threshold required to maintain superconductivity, electrical resistance develops, generating additional heat and triggering a rapid, self-reinforcing loss of superconductivity. This process causes the liquid helium to boil violently into gas, expanding its volume by a factor of approximately 760.

To safely accommodate this expansion, MR systems are equipped with a dedicated quench pipe that vents helium gas directly to the external atmosphere. If the quench pipe fails or becomes obstructed during a quench, the rapidly expanding helium gas may be inadvertently released directly into the magnet room (Zone IV). Because helium is lighter than air, it rapidly displaces oxygen, particularly near the floor, creating an immediate risk of hypoxia and asphyxiation for anyone in the room. In addition, the sudden influx of extremely cold gas can produce dense condensation fog, severely reducing visibility and complicating safe egress. For these reasons, emergency procedures for a quench should always include immediate evacuation of Zone IV.

Architectural features of the magnet room can further influence safety during a quench. Inward-swinging doors may create a risk of positive-pressure entrapment during rapid gas expansion. Thus, most contemporary MRI installations incorporate pressure-equalization mechanisms designed to mitigate this hazard.

4.2 Management of Intravascular Contrast Media

4.2.1 Iodinated Contrast Media

Types of Iodinated Contrast Media

All iodinated contrast media are derived from tri-iodinated benzene rings. Iodinated contrast media can be classified as ionic or nonionic, and monomeric or dimeric.

Ionic contrast media dissociate into two particles in solution (an anion, which contains the tri-iodinated benzene ring, and a cation, consisting of sodium or methylglucamine [meglumine]). Nonionic contrast media are hydrophilic molecules that do not need to be conjugated with cations to be water soluble. They do not dissociate in solution.

Lipiodol is the only currently approved water-insoluble iodinated contrast media.

Monomeric contrast molecules contain only one tri-iodinated benzene ring, while dimeric contrast molecules contain two joined tri-iodinated benzene rings.

The concentration of iodinated contrast media is often associated with the name of the product. The higher the iodine concentration, the higher the osmolarity. For example, iohexol (Omnipaque®) 350 has 350 mg iodine/ml and has greater osmolarity than Omnipaque® 300, which has 300 mg iodine/ml. At standard iodine concentrations, ionic monomeric contrast media have the highest osmolality, roughly four times that of human serum. They are referred to as high-osmolality contrast media. These agents are not employed routinely for intravascular injection in the United States as they are associated with higher rates of adverse reactions than are nonionic monomeric or dimeric contrast media.

Nonionic monomeric contrast media have about half the osmolality of high-osmolality contrast media, and roughly twice that of serum.

Nonionic dimers have similar osmolality to that of plasma and are referred to as iso-osmolality

contrast media. Iso-osmolality media are sometimes used for intra-arterial injection (and uncommonly for intravenous injection), because they cause less discomfort than do nonionic monomers when injected into the arteries.

Many nonionic contrast media are approved for intravascular use in the United States, including the low-osmolality agents iohexol (Omnipaque®), iopamidol (Isovue®), iopromide (Ultravist®), ioversol (Optiray®), and ioxilan (Oxilan®). Only one iso-osmolality contrast agent has been approved for use: iodixanol (Visipaque®).

Adverse Reactions to Iodinated Contrast Media

Most patients who receive iodinated contrast media have no adverse effects. Adverse contrast reactions of any type have been reported in up to 3% of patients injected with nonionic contrast material, though some series have reported a much lower frequency.

Acute adverse reactions can be categorized as either physiologic or allergic-like. Physiologic reactions are dose related. These reactions are less likely to occur, and when they do occur, they are less likely to be severe when lower doses of contrast material are administered. They are believed to represent direct toxic effects of the injected contrast media.

The mechanism of allergic-like reactions is not understood in most patients. However, it is known that in most patients these reactions (especially those classified as mild or moderate) do not represent the antigen-IgE antibody response characteristic of typical allergic reactions, such as to penicillin. Therefore, sensitization due to prior exposure is not required for an allergic-like reaction to contrast material to occur. Thus, these reactions are generally considered to be “allergic-like” rather than “allergic.” Nonetheless, allergic-like reactions present with symptoms similar to those of true allergic reactions. These reactions are idiosyncratic and can occur from any

administered volume of contrast media.

Acute adverse reactions are categorized as being mild, moderate, or severe. Examples of some reactions of different types and severity as summarized in the *ACR Manual on Contrast Media* are as follows:

Mild Reactions: Signs and symptoms are self-limited and without progression.

1. **Mild Physiologic Reactions:** Nausea, vomiting, flushing, warmth, chills, headache, anxiety, altered taste, mild hypertension, and spontaneously resolving vasovagal reaction
2. **Mild Allergic-like Reactions:** Few hives, pruritus, limited cutaneous edema, itchy/scratchy throat, nasal congestion, repetitive sneezing, stuffy nose

Moderate Reactions: Signs and symptoms are more pronounced and commonly require medical management.

1. **Moderate Physiologic Reactions:** Protracted nausea, chest pain, vasovagal reaction that requires and is responsive to treatment
2. **Moderate Allergic-like Reactions:** Diffuse hives, diffuse erythema (with stable vital signs), facial edema without dyspnea, wheezing with mild or no hypoxia.

Severe Reactions: Signs and symptoms are potentially life threatening and can result in permanent morbidity or death if not managed appropriately.

1. **Severe Physiologic Reactions:** Vasovagal reaction resistant to treatment, arrhythmia, seizures, hypertensive crisis, pulmonary edema, cardiopulmonary arrest.
2. **Severe Allergic-like Reactions:** Diffuse edema or facial edema with dyspnea, erythema with hypotension, laryngeal edema with stridor and/or hypoxia, wheezing with hypoxia, severe

hypotension and tachycardia, pulmonary edema, cardiopulmonary arrest.

As noted above, pulmonary edema and cardiopulmonary arrest can be symptoms of either severe physiologic or severe allergic-like reactions.

Fortunately, a clear majority of acute adverse reactions to contrast media are physiologic, mild, and self-limiting, often consisting of warmth, metallic taste, and nausea. Allergic-like reactions are much less common, encountered in < 1% of injected patients. In one recent series, 0.6% of patients injected with low-osmolality contrast media had allergic-like reactions, most of which were mild. Severe life-threatening allergic-like reactions are extremely rare, with the incidence of such reactions estimated to be 0.01% to 0.04% of injected patients.

Risk Factors for Adverse Reactions

Several factors increase the likelihood of an adverse reaction to contrast media. Patients with a history of a prior allergic-like reaction to the same class of contrast media (iodinated or gadolinium-based) are believed to have approximately five times the risk of the general population for having another allergic-like reaction to that same class of contrast media.

Patients with other allergies and asthma are about two to three times as likely to have an allergic-like reaction. Allergies to shellfish or other iodine-containing products (such as povidone-iodine [Betadine®]) are not believed to increase the risk for an allergic-like contrast reaction beyond that of other allergies. Also, a history of a prior allergic-like reaction to gadolinium-based contrast media (GBCM) is not believed to increase the risk of an allergic-like reaction to iodinated contrast agents above that of other allergies and vice versa.

Some patients' underlying diseases may be exacerbated by administration of contrast

media. Such disease exacerbations are considered to be non-allergic-like reactions. These can occur in patients with severe chronic kidney disease (CKD) and acute kidney injury (AKI) (see section on contrast-associated AKI), cardiac arrhythmias, congestive heart failure, myasthenia gravis, and severe hyperthyroidism or hypothyroidism.

Additional attention should be paid to the use of intravascular iodinated contrast media in patients being considered for radioactive iodine therapy or undergoing radioactive iodine imaging of the thyroid gland. Administration of iodinated contrast medium can interfere with uptake of the treatment and diagnostic dose; therefore, washout periods of 3-4 weeks for patients with hyperthyroidism and 6 weeks for patients with hypothyroidism, respectively, are suggested.

Screening of Patients before Contrast Media Administration

Safe administration of contrast media begins with a focused patient history to identify the factors that may increase the likelihood of an adverse reaction to contrast media.

The likelihood of an allergic-like contrast reaction may be reduced by premedication.

Premedication

The utility of premedication in high-risk patients is uncertain based on best available evidence. Globally, there is widespread variability on recommending use of premedication for allergic-like reactions to contrast. For example, in Europe, premedication is NOT routinely advised. In the United States, the ACR Manual on Contrast Media (2024) suggests consideration of premedication only for patients who have had a prior allergic-like or unknown-type reaction to the same class of contrast media as that to be

administered. Currently, the ACR does NOT recommend routine premedication for patients with a history of allergies to substances other than contrast media, to patients with a history of asthma, or to patients with allergic-like reactions to other classes of contrast media, such as iodinated contrast in the setting of an allergic-like reaction to gadolinium-based contrast.

The only proven benefit of corticosteroid premedication regimens is a reduction in the number of mild reactions. Studies showing the reduction in the number of mild reactions after premedication did not have sufficient numbers of patients with moderate, severe, or life-threatening reactions to draw statistically significant conclusions about the ability of premedication to reduce those reaction rates. Thus, while there is no definite evidence that premedication protects against moderate, severe, or life-threatening reactions, it is typically assumed that there is a positive effect. The rarity of severe reactions makes it difficult to prove a benefit of premedication in this setting.

Premedication Regimens

The most widely accepted premedication regimens, or “preps,” involve the use of oral corticosteroids and an antihistamine, with the first steroid dose administered 12 to 13 hours before contrast media injection and the antihistamine given one hour before contrast media injection. One common adult regimen involves oral administration of 50 mg of prednisone 13, 7, and 1 hour(s) before contrast media injection, and oral administration of 50 mg of diphenhydramine (Benadryl®) 1 hour before injection. Another common regimen involves oral administration of 32 mg of methylprednisolone 12 and 2 hours before contrast media injection. While a 12- or 13-hour oral regimen has been proven effective, and

a 1- or 2-hour oral regimen has been proven to be ineffective, the precise minimum effective time for premedication is not known.

Premedication can also be administered to children who have had prior allergic-like contrast reactions. One recommended regimen calls for administration of 0.5-0.7 mg/kg of oral prednisone at 13, 7, and 1 hours prior to contrast injection, up to a maximum of 50 mg, with one dose of oral diphenhydramine (Benadryl®) one hour prior to injection, at a dose of 1 mg/kg, up to a maximum dose of 50 mg.

In some situations, patient health can be seriously jeopardized by having the patient wait 12 or more hours before a contrast-enhanced study. In these situations, “rapid” corticosteroid regimens may be utilized, with the understanding that limited evidence supports this approach. The ACR Manual on Contrast Media (2024) suggests using one of these regimens in inpatients and Emergency Room patients. One of the more commonly used rapid preps consists of intravenous (IV) administration of 200 mg of hydrocortisone every 4 hours until the study is performed, preferably deferring imaging until at least two doses of hydrocortisone have been administered (if safe and feasible). In this rapid prep, 50 mg of diphenhydramine is also administered 1 hour before contrast media injection. In the rare emergency situation where a contrast-enhanced examination must be performed immediately, the contrast media may have to be administered without premedication.

The greatest risk of corticosteroid premedication to patient health is probably the delay that it causes in the performance of an imaging study (which can delay disease diagnosis, increase cost, and, in inpatients, expose patients to the additional risk of hospital-acquired infections for longer periods of time). For such patients, use of the “rapid” prep has been recommended. While

transient hyperglycemia can occur from three doses of corticosteroids, it is usually mild and is rarely clinically significant. Other complications from a short burst of corticosteroids, such as exacerbation of infection and peptic ulcer disease, steroid psychosis, and tumor lysis syndromes, have been reported, but are very rare.

Premedication Break-Through Reactions

Premedication likely reduces the risk of a contrast reaction in high-risk patients, but it does not eliminate it. A contrast reaction that occurs despite premedication is called a “breakthrough reaction.”

Even with appropriate use of an accepted premedication regimen, breakthrough reactions occur in a small number of high-risk patients. When they do occur, they are of similar severity to the initial reaction about 80% of the time, less severe about 10% of the time, and more severe about 10% of the time.

A patient who has had an allergic-like reaction to contrast media despite steroid premedication can be reinjected in the future after being premedicated again, if clinical circumstances require reinjection. Many such patients will not have a repeat reaction, and if a repeat reaction occurs, it will most likely be of the same severity as the previous breakthrough reaction (e.g., mild subsequent breakthrough reaction if the previous breakthrough reaction was mild).

Contrast-associated Acute Kidney Injury and Contrast-induced Acute Kidney Injury

Contrast-associated acute kidney injury (CA-AKI) is a general term used to describe a sudden deterioration in renal function that occurs after the intravascular administration of iodinated contrast media (with clinical onset detectable within 48 hours as creatinine accumulates in the serum). Such

injury may occur whether or not the contrast medium is determined to have caused the deterioration in renal function. CA-AKI is a correlative diagnosis, meaning that AKI can be correlated to, but not proven to be caused by, the administration of IV contrast.

Contrast-induced acute kidney injury (CI-AKI) is defined as a sudden deterioration in renal function caused by intravascular administration of iodinated contrast media. CI-AKI is a subset of CA-AKI; that is, those cases of CA-AKI in which iodinated contrast media is proven or known to be the cause of the AKI. CI-AKI is more of a statistical concept because it is difficult in practice to identify which individual cases of CA-AKI can be proven to be caused by the contrast media. For example, if a group of patients who are administered iodinated contrast media have a higher rate of CA-AKI than a properly chosen control group of patients not receiving iodinated contrast media, then the excess rate is due to CI-AKI, but it is generally not possible to identify which patients have CA-AKI from CI-AKI and which have CA-AKI from causes other than contrast media.

Nearly all papers published on CI-AKI before 2006, and many afterwards, considered all CA-AKI to be CI-AKI. This error has led to substantially inflated estimates of the rate of CI-AKI. It is now known that most CA-AKI is not due to CI-AKI.

CI-AKI was previously believed to be common, because a clear majority of published studies that came to this conclusion did not include control groups of patients who did not receive contrast media. For this reason, distinction between CI-AKI and CA-AKI was not possible in these studies. Additionally, many previous publications studied patients who had undergone arteriography rather than IV contrast media injections. Catheter angiography may be associated with additional risks to the patient that

could also affect renal function, including catheter manipulation in the abdominal aorta (i.e., atheroemboli) and exposure of the kidneys to more concentrated contrast media.

With the recent performance of several large propensity-adjusted controlled retrospective studies, it is now understood that true CI-AKI is much less common than previously thought, and if CI-AKI occurs at all, it is most likely to develop in patients who have severe CKD (estimated glomerular filtration rate [eGFR] < 30 mL/min/1.73 m²) or AKI. CI-AKI occurring in patients with an eGFR of 45 mL/min/1.73 m² or higher is very unlikely, and in patients with an eGFR between 30 and 45 mL/min/1.73 m², it is questionable. As a result, special precautions for administering IV iodinated contrast media are advised only for patients with severe CKD or AKI. Administration of large or multiple doses of contrast media within 24 to 48 hours may also be a risk factor for AKI, although precise risk thresholds are not well defined and likely vary by patient condition, and whether the contrast medium is administered intra-arterially or intravenously.

This dose-toxicity relationship has been consistently shown after coronary arteriography, but has not been conclusively shown for IV administrations. From a practical standpoint, it is therefore unclear if small reductions in administered IV contrast volume has any actual benefit in further reducing risk of CI-AKI. It is therefore advised to always try to use the lowest dose of IV contrast needed to get a diagnostic exam for the clinical indication.

The Kidney Disease Improving Global Outcomes (KDIGO) organization has suggested that, regardless of the cause, AKI should be diagnosed whenever there is 1) an absolute serum creatinine increase of at least 0.3 mg/dL; 2) a percentage increase in serum creatinine of at least 50% (1.5-fold above baseline); or 3) a reduction in urine output to 0.5 mL/kg/h for at least 6 hours.

The usual clinical course of CA-AKI (including CI-AKI) is a rise in serum creatinine beginning within 24 hours of contrast media administration, peaking at about 4 days and then usually returning to baseline by 7 to 10 days. Most affected patients do not have oliguria, and it is extremely rare for IV iodinated contrast to cause permanent renal dysfunction.

In addition to severe renal dysfunction, other previously identified diseases or conditions may predispose patients to develop AKI, but most likely, in and of themselves, they do not specifically predispose patients to develop CI-AKI. These include diabetes mellitus, dehydration, cardiovascular disease, diuretic use, advanced age, multiple myeloma with high beta 2-microglobulin, and hypertension.

Although patients with end-stage renal disease who are on chronic hemodialysis could experience additional renal function compromise (resulting in a further decrease in any remaining urine output that might be helpful for managing electrolyte balance), such a risk is theoretical. Many nephrologists agree to inject these patients with intravascular contrast media if a contrast-enhanced study is necessary. There is also a possibility that such patients, if their fluid status is brittle, could develop fluid overload as a result of the administration of even a relatively small volume of hyperosmolality contrast media.

Because iodinated contrast media have no significant toxicity if retained in the body after injection, there is no requirement that chronic hemodialysis be timed to occur either immediately before or immediately after contrast media administration.

Some nephrologists advocate more caution in administering potential nephrotoxins such as intravascular iodinated contrast to patients on peritoneal dialysis because the urine output of

these patients may be more important to their well-being than for patients on chronic hemodialysis.

There is some controversy concerning screening of patients' renal function before contrast media administration if no recent eGFR level is available. Suggested indications for obtaining a serum creatinine, from which an eGFR can be determined, have included a history of renal disease (including dialysis, renal transplant, solitary kidney, renal cancer, or renal surgery), hypertension and diabetes mellitus. If a potentially at-risk patient's condition is stable, a creatinine value within 30 days of contrast administration is generally considered sufficient.

In patients with severe CKD or AKI who are considered at increased risk of developing CI-AKI, several prophylactic strategies should be considered. Since most iodinated contrast media are currently administered intravenously for CT scans, alternatives include performing only unenhanced scans or using other modalities such as ultrasound or MR (note that contrast-enhanced MR performed with certain MR contrast media is associated with a risk of nephrogenic systemic fibrosis [NSF] in patients with severe CKD or AKI —see separate section on NSF). When iodinated contrast media administration is deemed necessary in high-risk patients, the lowest possible dose needed to perform a diagnostic study should be used.

The most widely accepted strategy for minimizing the risk of CI-AKI in at-risk patients (typically those with AKI or eGFR < 30) is IV volume expansion with isotonic fluids, such as 0.9% saline or Lactated Ringer's solution. No standard volume expansion protocol has been established; therefore, the prescribed volume will vary by patient and institutional guidelines. However, for reference, an example approach might include administration of volumes of 100 mL/h for 6 to 12 hours before contrast administration and continued for 4

to 12 hours after contrast administration. Volume expansion with sodium bicarbonate solution instead of saline or Lactated Ringer's solution has been used, but it is not clear that this solution is any more efficacious for preventing AKI after IV iodinated contrast administration.

Multiple other drugs have been studied to assess if they can help reduce risk of CI-AKI. N-acetylcysteine, mannitol, furosemide, and theophylline have all been discredited as a means of preventing CI-AKI.

Metformin

Metformin-containing drugs are prescribed as oral agents of choice for treating many patients with diabetes mellitus. Metformin is contraindicated in patients with severe renal dysfunction because a very small percentage of these patients develop lactic acidosis, leading to a reported 50% mortality rate.

There is no direct interaction between iodinated contrast media and metformin; however, if a patient receiving metformin develops AKI, the possibility of developing lactic acidosis exists. The American College of Radiology Committee on Drugs and Contrast Media currently recommends that no precautions are necessary in diabetic patients taking metformin, unless the patient has CKD and the eGFR is $< 30 \text{ mL/min/1.73 m}^2$ (in which case the patient should not be taking metformin anyway), the patient has AKI, or the patient is undergoing arterial catheterization with the risk of emboli to the renal arteries. In the latter instances, the drug should be withheld for 48 hours after contrast media administration and only reinstated if the renal function is reassessed and found to be acceptable.

Thus, metformin itself is not a risk factor for the development of CI-AKI, but patients who develop renal failure while taking metformin are at risk of developing lactic acidosis.

Iodinated Contrast Media in Pregnancy

Although iodinated contrast media cross the placenta, there is no evidence that maternal exposure to intravascular iodinated contrast media is harmful to the fetus. Specifically, there is no evidence that fetal (in utero) exposure to iodinated contrast media given to the mother increases mutagenesis or fetal cancer risk or affects fetal renal function or fetal thyroid function.

Iodinated Contrast Media in Women Who Are Breastfeeding

Only 1% of maternally administered contrast media enters the milk of breastfeeding mothers and, of this, only 1% of the contrast media in breast milk is absorbed through an infant's gastrointestinal tract.

This represents less than 1% of the recommended infant dose of iodinated contrast media that could be used for a contrast-enhanced imaging study on that infant.

There is no evidence that this tiny amount of absorbed iodinated contrast media has any adverse effect on the infant. Although it is generally accepted that no precautions need to be taken, it is recommended that a lactating mother be informed that studies assessing the risks to an infant are limited. If concerned, the mother can abstain from breastfeeding for 12 to 24 hours after a contrast-enhanced study is performed and pump and discard breast milk that is produced during this time.

Iodinated contrast media in young children

In 2022, the FDA updated thyroid function monitoring guidelines for young children who received iodinated contrast media. The FDA has since updated their recommended for children under age 3 who receive intravascular iodinated contrast media that decisions to monitor thyroid function should be based on an individualized assessment

incorporating patient risk factors such as prematurity, very low birth weight, and other medical conditions that could affect thyroid function. However, these guidelines remain controversial and have not been endorsed by the ACR Committee on Drugs and Contrast Media.

Extravasation

Extravasation of IV-administered iodinated contrast media is an occasionally encountered complication of intravascular contrast media administration, usually occurring during CT. The reported overall rate of extravasation with power injection for CT ranges from 0.1% to 1.2%. While extravasations are more likely to occur when poor catheter insertion technique is utilized, they can be encountered even when proper technique is employed.

Extravasations are more common in patients who are uncommunicative, have altered circulation in the injected extremity, have had radiation to the injected extremity, and are injected in the hand, foot, or ankle.

Methods to help reduce risk of extravasation include using angiocatheters instead of butterfly needles, confirming the location of the line via blood aspiration and doing a small test injection, and carefully securing the inserted catheter. Injections into the antecubital or other large forearm veins are preferred.

Immediately after extravasation of contrast media occurs, most patients complain of swelling or tightness and/or stinging or burning pain at the site of extravasation. Edema, erythema, and tenderness may be found on physical examination. Ninety-eight percent of extravasation injuries resolve with no adverse sequelae. In the remaining 2% of injuries, some patient morbidity develops because contrast media can damage adjacent tissue, likely due to a combination of direct

toxic effects and its hyperosmolality. Adverse effects are usually self-limited, most commonly consisting of prolonged pain or swelling.

Severe extravasation injuries occur in < 1% of patients with extravasations. The most common and most potentially devastating severe injuries after extravasation of nonionic contrast media are compartment syndromes, which result from mechanical compression. Skin ulceration and tissue necrosis are less commonly encountered. Other complications, including lymphedema and reflex sympathetic dystrophy, are extremely rare.

Compartment syndromes are more likely to develop when large volume extravasations occur, especially into smaller compartments such as the hand, wrist, or foot, but even large-volume extravasations most often resolve without any adverse effects. The risk of a severe extravasation injury may also be increased in patients with arterial insufficiency or compromised venous or lymphatic drainage.

Severe symptoms may not be evident immediately after the extravasation occurs. They may develop gradually over time. For this reason, patients should be monitored to assure that minor symptoms remain stable or that minor or more significant symptoms are resolving or improving. When a symptomatically stable or improving patient is discharged from the radiology department, he or she must be given clear instructions concerning what new or recurring symptoms may indicate a severe injury and where and how to seek prompt additional treatment if necessary.

Little can be done to mitigate the effects of contrast extravasations after they occur. Elevation of the affected extremity above the level of the heart is recommended to decrease capillary hydrostatic pressure. This may promote resorption of the extravasated contrast media. Cold or warm compresses can be applied to the site of extravasation. Attempted aspiration of the

extravasated contrast media and injection of medications into the extravasation site (such as corticosteroids or hyaluronidase) are ineffective.

Surgical consultation should be obtained after an extravasation whenever there is concern for a developing compartment syndrome or for tissue necrosis. Ominous symptoms that indicate the need for prompt surgical consultation include progressive swelling or pain, decreased active or passive range of motion, altered tissue perfusion (manifested by decreased capillary refill), change in sensation or paresthesia development, or skin ulceration or blistering. In general, the earliest and most reliable sign of a severe injury is severe or progressive pain.

It should be noted that there is no extravasation volume threshold above which surgical consultation is considered mandatory.

4.2.2 Gadolinium-based Contrast Media (GBCM)

Classification of GBCM

Most contrast agents used for MRI contain gadolinium bound within a chemical moiety called a chelate.

Gadolinium-based contrast media (GBCM) are classified as linear or macrocyclic, and ionic or nonionic. In general, macrocyclic GBCM, in which the gadolinium ion is surrounded by a chelate ring, have more stable binding of the gadolinium ion within the chelate than do linear agents, in which the chelate is not in the form of a ring. Among the linear agents, the nonionic agents are less stable than the ionic agents. Table 4.1 summarizes the gadolinium-containing contrast agents currently available for use in the United States.

Acute adverse reactions to GBCM occur approximately two to four times less frequently

than acute adverse reactions to iodinated contrast media. In general, the physiologic and allergic-like reactions that occur after GBCM administration are similar to those that occur after injection of iodinated contrast agents. For this reason, treatment of contrast reactions to GBCM is similar to that of contrast reactions to iodinated contrast media (see separate section on treatment, to follow).

A clear majority of GBCM reactions are mild and non-allergic-like (i.e., physiologic), including coldness at the injection site, nausea with or without vomiting, headache, warmth or pain at the injection site, paresthesias, and dizziness. Rash, hives, and urticaria are the most frequent allergic-like symptoms; however, respiratory and cardiovascular reactions can occur. Fatal contrast reactions have been reported but are exceedingly rare.

A unique physiologic side effect of gadoxetate disodium (Eovist[®]) is transient tachypnea, which can cause motion artifact on arterial-phase MRI. It is more common with high volume, off-label administrations.

Patients at highest risk for adverse reactions to GBCM are those who have had previous reactions to these agents (even to different GBCM). Lesser risk factors include other allergies and asthma. A history of a prior allergic-like reaction to iodinated contrast media is not believed to increase the risk of an allergic-like reaction to GBCM above that of other allergies.

Some preventive measures can be considered in patients who have experienced previous adverse reactions to GBCM. This includes using a different gadolinium compound for reinjection. It should be noted that the FDA-approved package insert for one GBCM (gadobenate dimeglumine [MultiHance[®]]) states that use of this GBCM is specifically contraindicated in patients who have had prior allergic-like contrast reactions to

| Agent | Ionicity | Linear or macrocyclic |
|--|----------|-----------------------|
| Gadopentetate dimeglumine (Magnevist®) ¹ | Ionic | Linear |
| Gadobenate dimeglumine (MultiHance®) ² | Ionic | Linear |
| Gadoxetate disodium (Eovist®) ³ | Ionic | Linear |
| Gadodiamide (Omniscan®) ¹ | Nonionic | Linear |
| Gadoteridol (ProHance®) ² | Nonionic | Macrocyclic |
| Gadobutrol (Gadavist®) ² | Nonionic | Macrocyclic |
| Gadoterate meglumine (Dotarem®) ² (Clariscan®) ² | Ionic | Macrocyclic |
| Gadopiclesol (Elucirem®) ² (Vueway®) ² | Nonionic | Macrocyclic |

Table 4.1. Characteristics of approved gadolinium-containing contrast agents.

¹Indicates agents that have a higher risk for nephrogenic systemic fibrosis (NSF)

²Indicates agents that have a lower risk for nephrogenic systemic fibrosis (NSF)

³Indicates agent with limited evidence regarding association with nephrogenic systemic fibrosis (NSF).

ANY GBCM. Another preventive measure is premedicating patients with corticosteroids and antihistamines (using a regimen identical to that used for prophylaxis of adverse reactions to iodinated contrast media) before injection. The effectiveness of premedication before GBCM has not yet been determined, but premedication is still often performed, based on evidence extrapolated from experience with iodinated contrast media.

GBCM in Pregnancy

GBCM have been classified by the Food and Drug Administration as pregnancy class C drugs (no adequate and well-controlled studies in humans have been performed, although animal reproduction studies have shown an adverse effect on the fetus) and are therefore

relatively contraindicated in pregnant patients. These agents pass through the placental barrier and enter the fetal circulation. They are then filtered by the fetal kidneys and excreted into the amniotic fluid, where they may remain for a prolonged period. Prolonged presence of the agent in the amniotic fluid could theoretically increase the risk of dissociation from the chelate of the potentially toxic gadolinium ion (see separate section on nephrogenic systemic fibrosis, to follow). For this reason, GBCM should only be administered to pregnant patients in carefully selected situations in which the benefit is thought to outweigh the potential risk.

GBCM in Women Who Are Breastfeeding

Only tiny amounts (0.04%) of administered GBCM are excreted into the milk of breastfeeding mothers, and only a tiny

percentage of this (1%) GBCM is absorbed through an infant's gastrointestinal tract. This is much less than the allowed GBCM dose, when a contrast-enhanced imaging study is needed in an infant. There is no evidence that the tiny amount of absorbed GBCM has any adverse effect on a breastfed infant. Therefore, there is no need for a mother to stop breastfeeding after a GBCM-enhanced study. However, as with the administration of iodinated contrast media, if the mother is concerned, she can stop breastfeeding for 12 to 24 hours after the study, and pump and discard any milk produced during this time.

Nephrogenic Systemic Fibrosis (NSF)

Nephrogenic systemic fibrosis (NSF) is a fibrosing disease most evident in the skin and subcutaneous tissues, but it also may involve other organs, such as the lungs, esophagus, heart, and skeletal muscles. Initial symptoms typically include skin thickening with plaque formation. Symptoms and signs may progress rapidly, with some affected patients developing contractures and joint immobility. Occasionally, the disease may be fatal. There is no known effective treatment.

NSF occurs nearly exclusively in patients with severe CKD (eGFR < 30 mL/min/1.73 m²) or in patients with AKI who have been exposed to GBCM. Symptom onset can occur from days to years after GBCM administration. Identification of the GBCM responsible for the precipitation of this disease is sometimes difficult, because many patients have received multiple different MR contrast agents. GBCM agent exposure is considered to be "confounded" in patients with NSF who have been exposed to multiple GBCM; the exposure is considered to be "unconfounded" when a patient with NSF

has only been exposed to one agent.

NSF has been encountered almost exclusively after patient exposure to several specific linear GBCM, with the high-risk agents being gadodiamide (Omniscan[®]), gadoversetamide (OptiMark[®], no longer manufactured), and gadopentetate dimeglumine (Magnevist[®]).

Higher doses and multiple doses of the higher risk GBCM are believed to increase the likelihood of NSF, although cases have occurred after only a single administration of a standard dose of GBCM.

Few, if any, cases of unconfounded NSF have been reported with the lower-risk agents, which include gadobenate dimeglumine (MultiHance[®]), gadobutrol (Gadavist[®]), gadoterate meglumine (Dotarem[®] and Clariscan[®]), and gadoteridol (ProHance[®]).

Gadoxetate disodium (Eovist[®]) is a newer agent with limited information about its association with NSF; however, the risk of NSF developing after gadoxetate disodium administration has also been found to be very low.

Gadopicleonol (Elucirem[®] and Vueway[®]) was approved by the FDA in 2022. This agent is macrocyclic and has been classified in the lower-risk agent group for NSF development. The agent is unique in that it has the highest relaxivity values of any GBCM agent approved in the US. Based on non-inferiority trials, it was approved by the FDA at a dose that results in a 50% reduction in gadolinium dose (0.05 mmol/kg compared to most other GBCM agents which are dosed at 0.1 mmol/kg).

Because most patients with severe CKD who are exposed to NSF-associated GBCM do not develop NSF, other factors are believed to be required for disease development. Additional suggested risk factors for NSF have included metabolic acidosis or medications that predispose patients to acidosis; increased iron, calcium, and/or phosphate levels; high-dose erythropoietin therapy; immunosuppression; vasculopathy; an acute pro-inflammatory event; and infection. Unfortunately,

no consistent relationship between these factors and NSF has been identified.

The mechanism of NSF is unknown, although many experts have speculated that it may result from dissociation of the gadolinium ion from its chelate in vivo, with subsequent precipitation of gadolinium in tissue. This mechanism has been suggested because the three high-risk GBCM have lower stability of gadolinium ion binding to the chelate than do most of the nonimplicated GBCM. With high-risk GBCMs, a different ion is thought to be able to replace the gadolinium ion within the chelate more easily, thereby freeing up the toxic gadolinium atom. This replacement process is referred to as transmetallation.

In response to the emergence of NSF, radiologists have instituted a number of precautions that have been effective in nearly eliminating this disease. The most important precaution is avoiding the high-risk GBCM (gadodiamide [Omniscan®], gadoversetamide [OptiMark®], and gadopentetate dimeglumine [Magnevist®]) in any patients requiring contrast-enhanced MRI who might have severe CKD (eGFR < 30 mL/min/1.73 m²) or AKI. At institutions where high-risk GBCM are used, patients referred for contrast-enhanced MRI should be screened for renal disease (which may include obtaining eGFR levels in any patient with a history of a solitary kidney, kidney transplant, or renal neoplasm; or hypertension or diabetes mellitus). The three high-risk GBCM are absolutely contraindicated by the Food and Drug Administration when the eGFR is less than 30 mL/min/1.73 m².

There is no proof that immediate post-MRI dialysis reduces the risk of NSF in any high-risk GBCM-exposed patients.

Gadolinium Retention

Some administered gadolinium remains in the body after GBCM administration. It has long been known that this retention occurs in the skeleton and is greater with linear than macrocyclic agents.

More recently, investigators have found that gadolinium is also retained within the brain (particularly in the globus pallidus and dentate nucleus). This occurs even in patients with normal renal function. The amount of gadolinium accumulation is proportional to the amount of GBCM that a patient has received. It is not clear in what state the gadolinium is retained. As with retention in the bones, retention in the brain is greater with linear than with macrocyclic agents.

There is no evidence of any adverse neurologic effects of this accumulation (even after millions of GBCM administrations throughout the world); however, further study is necessary to determine long-term effects, if any, that gadolinium deposition in the brain may have.

4.2.3 Treatment of Acute Contrast Reactions

When an allergic-like reaction occurs, rapid recognition, patient assessment, and diagnosis are important so that appropriate treatment can be instituted rapidly.

A responding radiologist should assess the patient quickly. A brief discussion with the patient and any present healthcare providers, when possible, should provide the following information: the reason for the imaging study, a description of the patient's current symptoms, and a summary of the patient's health problems and medications. Vital signs should be obtained promptly. IV access should be secured. A pulse oximeter should be available. Oxygen should also be available and, if administered, should be given at high doses.

The examining radiologist should quickly determine the level of patient consciousness, the appearance of the skin, the quality of

phonation, and the presence or absence of respiratory and cardiovascular symptoms.

Mild reactions usually resolve within 20 to 30 minutes and do not require medical treatment; however, some patients with moderate and severe reactions may initially develop only mild symptoms. For this reason, all patients should be monitored until their symptoms have improved.

Aggressiveness in managing a contrast reaction depends on the type and severity of the reaction. Epinephrine comes in two concentrations: a higher concentration (1 mg/mL in a 1 mL vial) intended for intramuscular (IM) injection, and a more dilute concentration (1 mg/10 mL in a 10 mL vial) intended for intravenous (IV) use. Both contain the same total dose of 1 mg, but in different volumes, which is a frequent source of confusion—especially since both may be stocked in code carts and referenced in ACLS algorithms. The key point is that the concentrated 1 mg/mL formulation should be used only for IM injection, while the dilute 1 mg/10 mL formulation can be given as a slow IV push into a running infusion of fluids. EpiPen® contains 0.3 mL of 1 mg/1 mL concentration epinephrine, and the pediatric version (EpiPen Jr®) contains 0.15 mL of 1 mg/1 mL concentration epinephrine, both for IM administration. In practice, IM epinephrine is the first-line treatment in emergent situations without IV access, whereas IV epinephrine should be reserved for patients who are severely unstable and already have a running IV line.

Treatments recommended in the *ACR Manual on Contrast Media* (2024) for different types of reactions in **adults** are condensed and summarized below.

Hives (Urticaria)

- No treatment is needed in most cases.
- If symptomatic, administer diphenhydramine (Benadryl®), 25 to 50 mg orally (PO), intra-muscularly (IM), or intravenously (IV). Alternatively, use fexofenadine (Allegra®), 180 mg PO.

Diffuse Erythema

- Preserve IV access, monitor vitals, and use a pulse oximeter.
- Give O₂, 6 to 10 L/min (via mask).
- If the patient is normotensive, no further treatment is usually needed; note that antihistamines should be administered with caution, as they may exacerbate existing or developing hypotension.
- If the patient is hypotensive, give 1 L of IV fluids rapidly, either 0.9% normal saline or Lactated Ringer's solution.
- If hypotension is profound or does not respond to IV fluids, consider epinephrine IV (1 mg/10 mL), 1 mL (0.1 mg) slowly into a running infusion of IV fluids. Repeat as needed at 5- to 10-minute intervals up to 10 mL total. In the absence of IV access, consider epinephrine IM (1 mg/mL), 0.3 mL (0.3 mg), or IM EpiPen® or equivalent (usually 0.3 mL). IM epinephrine may be repeated up to 1 mg total.
- Consider calling an emergency response team or 911 based on the severity of the reaction and the completeness of patient response to treatment.

Laryngeal Edema

- Preserve IV access, monitor vitals, and use a pulse oximeter.
- Give O₂, 6 to 10 L/min (via mask).

- Give epinephrine IM (1 mg/mL), 0.3 mL (0.3 mg), or IM EpiPen® or equivalent (0.3 mL), or, especially if hypotensive, epinephrine IV (1 mg/10 mL), 1 mL (0.1 mg) slowly into a running infusion of IV fluids.
- Repeat epinephrine as needed up to a maximum of 1 mg.
- Consider calling an emergency response team or 911 based on the severity of the reaction and the completeness of patient response to treatment

Bronchospasm

- Preserve IV access, monitor vitals, and use a pulse oximeter.
- Give O₂, 6 to 10 L/min (via mask).
- Give beta-agonist inhaler albuterol, 2 puffs (90 mcg per puff); can repeat up to three times. In cases in which bronchospasm is severe and/or unresponsive to an inhaler, consider adding epinephrine IM (1 mg/mL), 0.3 mL (0.3 mg), or IM EpiPen® or equivalent (0.3 mL), or epinephrine IV (1 mg/10 mL), 1 mL (0.1 mg) slowly into a running infusion of IV fluids.
- Repeat epinephrine as needed up to a maximum of 1 mg.
- Consider calling an emergency response team or 911 based on the completeness of patient response to treatment.

Hypotension, Any Cause (systolic blood pressure < 90 mm Hg)

- Preserve IV access, monitor vitals, and use a pulse oximeter.
- Elevate legs at least 60 degrees (Trendelenburg position).

- Give O₂, 6 to 10 L/min (via mask).
- Consider rapid administration of 1 L of IV fluids, 0.9% normal saline or Lactated Ringer's solution.

Hypotension with Bradycardia (pulse < 60 bpm) (Vagal Reaction)

- If mild, no additional treatment is usually needed beyond that listed above for any cause of hypotension.
- If severe (patient remains unresponsive to above measures), give atropine, 0.6 to 1.0 mg IV, into a running infusion of IV fluids. (Note: lower doses of atropine may exacerbate bradycardia.)
- May repeat atropine up to a total dose of 3 mg.
- Consider calling an emergency response team or 911.

Hypotension with Tachycardia (pulse > 100 bpm) (Allergic-like Reaction)

- If hypotension persists after the basic treatment listed above for any cause of hypotension, can give 0.3 mL IM epinephrine (0.3 mg) of 1 mg/ml solution, or IM EpiPen® or equivalent (0.3 mL). IM epinephrine may be repeated up to 1 mg total. If the patient is unresponsive to IM dose, can give epinephrine IV (1 mg/10 mL solution), 1 mL (0.1 mg) slowly into a running infusion of IV fluids. Can repeat as needed up to 10 mL (1 mg) total.
- Consider calling an emergency response team or 911 based on the severity of the reaction and the completeness of patient response to treatment.

Unresponsive and Pulseless

- Check for responsiveness.
- Activate emergency response team or call

911.

- Perform CPR per American Heart Association protocols.
- Defibrillate as indicated if equipment is available.
- May administer epinephrine IV 1 mg/10 mL, full 10 mL (1 mg) dose, between 2-minute cycles of CPR.

Reaction Rebound Prevention

- IV corticosteroids are not useful in acute treatment of any reaction.
- However, IV corticosteroids help prevent a short-term recurrence of an allergic-like reaction and may be considered for a patient having a severe allergic-like reaction before transportation to the emergency department.
- Give hydrocortisone, 5 mg/kg IV over 1 to 2 minutes, or methylprednisolone, 1 mg/kg IV over 1 to 2 minutes.

Hypertensive crisis, pulmonary edema, seizures or convulsions, and hypoglycemia are uncommon reactions. If these occur, the radiologist should refer to standard treatment sources, including the *ACR Manual on Contrast Media*.

Pediatric Dosing

Pediatric dosing for some of the interventions/medications utilized for treating allergic-like contrast reactions are provided as follows:

- Isotonic fluid: 10-20 mL/kg of 0.9% normal saline or Lactated Ringers up to a maximum volume of 500-1,000 mL
- Diphenhydramine (Benadryl®): 1 mg/kg up to a maximum of 50 mg

- Beta agonist inhaler (Albuterol®): 2 puffs (90 mcg/puff) for a total of 180 mcg; can repeat up to three times
- Epinephrine:
 - IM dosing: (up to 30 kg): epinephrine autoinjector (EpiPen Jr®) single dose of (0.15 mg)
 - IM dosing: (over 30 kg patient weight): use adult autoinjector; or 0.01 mL/kg (0.01 mg/kg) of 1 mg/mL solution (maximum single dose of 0.3 mL [0.3 mg]); repeated every 5-15 minutes needed up to a maximum dose of 1 mg (1 mL)
 - IV dosing: 0.1 mL/kg (0.01 mg/kg) of 1 mg/10 mL solution (maximum single dose of 1 mL [0.1 mg]), repeated every 5 – 15 minutes, as needed up to a maximum dose of 1 mg (10 mL).

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Chapter 5: Reimbursement, Regulatory Compliance, and Legal Considerations in Radiology

5.1 Reimbursement and Regulatory Compliance

5.1.1 Coding, Billing, and Reimbursement

Appropriate reimbursement for healthcare services involves a series of complex and interconnected steps that often vary depending on the payer. A number of generalizable principles based on Medicare rules should guide best practice efforts to optimize revenue and compliance activities. These principles of reimbursement are also important to understand as they often serve as the basis for how third-party payors structure their reimbursement. Traditionally, physician services and procedures are reimbursed on a fee-for-service basis. Although this fee-for-service system of reimbursement forms the basis for physician reimbursement today, it is important to recognize that especially with primary care models, there is a clear shift away from a volume-based form of reimbursement (i.e., fee-for-service) towards more value-based payments requiring attainment of certain quality measures.

Each service or procedure that a physician provides is given a unique code called a Current Procedural Terminology code (CPT) that in turn is assigned a specific reimbursement amount. The first step in obtaining reimbursement for a new service or procedure is to have it assigned a unique CPT code. The American Medical Association (AMA) CPT Editorial Panel, is responsible for maintaining the CPT code set, including authorizing new codes, modification of existing codes, and deletion of codes no longer relevant.

The CPT Editorial Panel is composed of physicians nominated by national medical societies, CMS, and other industry leaders. A separate committee, the AMA CPT Advisory Committee, assists the CPT Editorial Panel by making recommendations regarding new codes and existing codes. The CPT Advisory Committee is composed of representatives nominated by national medical societies. For example, national radiology societies designate representatives to serve on the CPT Advisory Committee who then advocate for radiologists by making recommendations for new or existing radiology CPT codes.

Each CPT code is assigned a value called the Relative Value Unit (RVU) based on the Resource Based Relative Value Scale. This value is relative in that each value reflects its relative value compared to other services or procedures within the specialty as well other medical specialties. The AMA RBRVS Update Committee (also known as “The RUC”), makes recommendations to CMS for RVU valuation for each CPT code, and is predominantly composed of physicians representing various medical societies. The AMA RUC Advisory Committee, supports the RUC by making recommendations just as the CPT Advisory Committee supports the CPT Editorial Panel. National medical societies can nominate representatives to the RUC Advisory Committee who then advocate for their membership by recommending specific RVU valuations to the RUC, which in turn makes its final recommendations to CMS.

Each service or procedure’s total RVUs reflect the amount of 1) encounter time, intensity,

effort, and skill (the work RVU); 2) costs of maintaining a practice, such as equipment, supplies, and nonphysician staff (practice expense RVU); and 3) professional liability expenses (malpractice RVU). Work RVU is used by many practices to track physician productivity. Although the Centers for Medicare and Medicaid Services (CMS) ultimately sets the valuation of RVUs, it has historically accepted the AMA RUC recommendations in the vast majority of cases.

Once an RVU is determined for a specific service or procedure designated by its CPT code, a multiplier called the Conversion Factor (CF) is used to determine the actual reimbursement. Thus, to obtain the actual reimbursement for a specific procedure, the RVU for that procedure is multiplied by the CF.

$$\text{Payment} = \text{RVU} \times \text{CF}$$

The conversion factor is set annually by CMS in Final Rule of the Medicare Physician fee schedule. For example, the CF for 2020 was set by CMS at \$36.09 and in 2021 this fell to \$34.89.

CMS and private insurers generally pay only for services deemed medically necessary. CMS defines medical necessity as “healthcare services or supplies needed to prevent, diagnose, or treat an illness, injury, condition, disease, or its symptoms and that meet accepted standards of medicine.” In practicality, the determination of medical necessity is usually a rules-based administrative exercise performed at the time a claim is submitted to a payer, wherein a CPT service code must match a pre-approved diagnosis code list. Those diagnosis codes must be in the form of the *International Classification of Diseases* (ICD) system, established by the World Health Organization, currently in its 10th revision (ICD-10). ICD-10 codes describe the signs, symptoms, or specific diagnosis of a patient that form the indication for a healthcare

service. Terms such as “rule out” or “consistent with” are not capable of being coded by ICD-10, and therefore do not meet medical necessity criteria.

Reimbursement for radiology services is largely predicated on the adequacy of documentation within the physician report. Professional coders, assisted by software tools, extract information from radiology reports to assign both ICD-10 and CPT codes. The Radiology Coding Certification Board is the primary organization that credentials professional medical imaging coders. These individuals extract ICD-10 information from radiology reports using any statements 1) about examination indication and clinical history provided by the referring physician or patient and 2) from any specific diagnostic information located in the findings section or (preferably) in the impression section of the radiologist’s report. CPT codes are assigned based on the specific details of the described service. For radiography, more views generally translate to higher complexity codes. For ultrasound, organ inventory “checklists” apply to abdominal, pelvic, obstetrical, and extremity imaging. For CT and MRI, details of contrast administration (i.e., without, with, or without and with contrast) determine the CPT code for a specific body part. Structured template reporting helps radiologists comply with many of these reporting requirements, facilitating appropriate reimbursement and regulatory compliance.

Many private payers, Medicaid plans, and Medicare Advantage (i.e., not traditional Medicare indemnity) payers contract with radiology benefit management (RBM) companies, and require preauthorization (also known as precertification) as a condition for reimbursement for any elective outpatient advanced imaging service. Before performing advanced imaging services such as CT, MRI,

and PET/CT, radiology facilities should determine whether preauthorization is required for a particular service for a particular patient and, if so, whether such preauthorization has been obtained. Although a necessary condition for payment, preauthorization by an outsourced RBM does not always guarantee a subsequent favorable medical necessity determination by the insurer itself when a claim is filed. As a general rule, preauthorization requirements do not apply to emergency department and inpatient services.

The consultation of software for imaging Clinical Decision Support software (CDS) is technically required for all Medicare outpatient and certain ED patients when ordering advanced imaging tests (CT, MRI, and Nuclear Medicine), although payment consequences have not yet been defined. This software further scores appropriateness of imaging orders in 8 clinical priority conditions; Coronary artery disease (suspected or diagnosed), Suspected pulmonary embolism, Headache (traumatic and nontraumatic), Hip pain, Low back pain, Shoulder pain (including suspected rotator cuff injury), cancer of the lung (primary or metastatic, suspected or diagnosed) and cervical or neck pain. These initial 8 clinical priority conditions were designated by the CMS in 2016 with scores now being transmitted on provider claims. The list is likely to grow in future years after the initial operations testing period. These software systems are to use appropriate imaging recommendations from Qualified Provider Led Entities (QPLEs) which include national medical societies. The intent is to guide ordering physicians to the most appropriate studies for their patients, and this approach is being attempted by CMS as an alternative to the pre-authorization process.

The False Claims Act (FCA) protects the

government from being overcharged or sold substandard goods or services. A false claim is generally defined as a request for payment for services that a provider knew or should have known was false or fraudulent. While the U.S. Department of Justice does not expect physicians to be experts in all of these nuanced matters, it has set an expectation that radiology practice processes, structures, and cultures be oriented toward optimizing the integrity of revenue cycle operations. Best practice techniques call for formal compliance plans, with a formally designated compliance officer and compliance committee appropriately empowered to oversee these activities. A false claim ruling can result in fines of up to three times the billed amount plus \$11,000 *per claim filed*, because each single exam or service billed to Medicare or Medicaid counts as a claim. In 2014, the largest radiology practice settlement occurred for \$15.5 Million based upon allegations at a diagnostic testing facility that it falsely billed federal and state health care programs for tests that were not performed or not medically necessary and paid kickbacks to physicians. Multi-million dollar settlements occur almost annually with \$5 million being paid in 2020 to resolve allegations of unsupervised radiology services and services provided at unaccredited facilities.

5.1.2 Patient Privacy and HIPAA

Respect for patient privacy is a core responsibility of a medical professional. The Privacy and the Security rules of the Health Insurance Portability and Accountability Act of 1996 (HIPAA) represent a codification of this principle in the law. They provide a set of national privacy standards and bring with them the power of law. As such, compliance activities must prioritize patient privacy. HIPAA rules apply to healthcare providers, plans, and clearinghouses alike.

The Privacy Rule establishes national standards for the protection of individually identifiable health information, referred to as protected health information (PHI). The Security Rule establishes a national set of security standards for securing PHI when held or transferred in electronic form. It operationalizes the protections contained in the Privacy Rule by addressing both technical and nontechnical safeguards that organizations must put in place to secure individuals' electronic PHI (e-PHI). Within the U.S. Department of Health and Human Services, the Office for Civil Rights (OCR) has responsibility for enforcing these rules with civil money penalties.

The major goals of the HIPAA rules are to assure appropriate protection of each individual's PHI while still permitting the flow of information necessary to provide and promote quality healthcare. The following identifiers are included in the definition of PHI: 1) names; 2) geographic subdivisions smaller than a state (except for the first three digits of a ZIP code representing a population greater than 20,000); 3) all elements of dates (except year) related to an individual, such as birthdate, admission date, discharge date, and date of death; 4) phone numbers; 5) fax numbers; 6) email addresses; 7) Social Security numbers; 8) medical record numbers; 9) health plan beneficiary numbers; 10) account numbers; 11) certificate and license numbers; 12) vehicle identification and license plate numbers; 13) device identifiers and serial numbers; webpage universal resource locators (URLs); Internet Protocol (IP) addresses; 16) biometric identifiers such as finger- and voice-prints; 17) full face or similar photographs; and 18) any other unique identifier, characteristic, or code.

As a general rule, an individual's PHI cannot be disclosed or transmitted to anyone other than the individual without that individual's

authorization. Exceptions include information disclosed or transmitted when necessary for 1) the delivery of care or treatment, 2) payment activities, and 3) healthcare operations involving quality or competency assurance, fraud or abuse detection, or compliance. In addition, when required by law, information can be released 1) to public health authorities, 2) during investigation of abuse, neglect, or domestic violence, 3) to oversight agencies, 4) for judicial and administrative proceeding, 5) for law enforcement purposes, and 6) for worker's compensation.

5.1.3 Human Subjects Research

Properly controlled biomedical research involving human subjects is essential to advancing medical knowledge and care. Unfortunately, human cruelty has occasionally been perpetrated in the name of research, and not all human studies have been either justifiable or useful. The discoveries of such abuses during Nazi Germany were the basis for the development of the Nuremberg Code, which represented the first international codification of minimal expectations for the conduct of ethical research involving human subjects. The Code's most important principles were that experiments involving human subjects should occur only with subjects who have freely chosen to participate, and in the context of a clear scientific rationale. The subsequent Declaration of Helsinki, now widely regarded as the cornerstone of human research ethics, has recommended that all research protocols be reviewed by an independent committee prior to initiation.

That recommendation led to the development of the Institutional Review Board (IRB) system currently in place in the United States, wherein appropriately constituted groups, usually at the university or health system level, are formally designated to review and monitor biomedical

research involving human subjects. In accordance with Food and Drug Administration (FDA) regulations, an IRB has the authority to approve, require modifications in order to secure approval, or deny approval for proposed research protocols. These review groups serve important roles in the protection of the rights and welfare of human research subjects.

IRBs are required to ensure a “diversity of members, including consideration of race, gender, cultural backgrounds, and sensitivity to such issues as “community attitudes” and to register with the Department of Health and Human Services (HHS). Institutions engaged in research involving human subjects usually have their own IRBs to oversee research conducted within the institution or by its staff. However, institutions without an IRB are permitted to arrange for an outside IRB to assume oversight responsibilities.

Because the free choice of research subject participation is a fundamental prerequisite to ethical research, an IRB carefully scrutinizes all aspects of consent. The research informed consent process involves 1) providing adequate information about a study to potential subjects, 2) providing an adequate opportunity for subjects to consider all options, 3) responding adequately to all subject questions, 4) ensuring that the subject comprehends all necessary information, 5) obtaining the subject’s voluntary agreement to participate, and 6) providing ongoing information as the subject or situation so requires. In some situations (such as many studies involving the retrospective review of imaging), an IRB may waive the requirement for informed consent when the research involves no more than minimal risks to participants, and cannot be practically carried out without such a waiver. IRBs typically provide an exemption from formal

protocol review when a project constitutes a quality improvement activity, as long as the primary objective is to improve local practice rather than to create generalizable knowledge. IRB approval is not required for studies that do not meet federal definitions of human subjects research (e.g., studies that utilize open source public datasets).

5.2 Malpractice and Risk Management

5.2.1 General Principles of Malpractice

Malpractice fears have been cited as a cause of physician burnout and distress, including in radiology.

Approximately 7% of all radiologists are named in a medical malpractice lawsuit each year; radiology indemnity payments in malpractice cases average approximately \$480,000. The average radiologist spends approximately 19 months of his or her career with an unresolved open malpractice claim. Malpractice concerns have also been identified as a cause of overutilization of services; more than 90% of physicians report that they at least sometimes engage in the practice of defensive medicine.

Malpractice insurance coverage is usually mandated as a condition of state licensure and hospital credentialing. “Claims-made” policies are the most common types of policies and protect physicians from personal financial liability, up to a predetermined policy cap, but only while the policy is in effect. Physicians with claims-made policies thus usually need to arrange for tail insurance when changing jobs or retiring to ensure continued financial protection. “Occurrence” policies cover any claim for an event that took place during the period of coverage, even if a claim is filed after the policy lapses.

Medical malpractice lawsuits are based on the tort of negligence, and require four elements:

1. The physician must have an *established duty* to a patient. For example, duty would exist for a radiologist to provide treatment for a patient undergoing a contrast reaction in the radiology department but not for interpreting the contents of a CT scan on a CD in a patient's purse in her ICU room unless those images were submitted for formal review under established hospital policy.
2. There must have been a *breach of duty*, which usually involves a failure to meet the standard of care. The definition of standard of care varies by jurisdiction, but is generally how a reasonable, prudent, or ordinary physician of a similar specialty would have acted in similar circumstances.
3. *Causation* must exist, in that the breach must have been the proximate cause of injuries. A radiologist, for example, may have negligently missed a lung mass on a chest radiograph, but establishing that as the proximate cause of a hemorrhagic stroke the next day would be difficult.
4. The negligence must result in *damages*. In many jurisdictions, emotional distress, pain, and suffering are frequently considered remunerative damages.

Claims of negligence against radiologists generally fall into 3 categories: 1) diagnostic errors, 2) procedural complications, and 3) communication deficiencies.

5.2.2 Malpractice Related to Diagnostic Errors

The most common cause of malpractice lawsuits against radiologists is for alleged

errors in diagnosis. Depending on the clinical indication and modality, the sensitivity of imaging in detecting disease is highly variable, and plaintiff lawyers frequently contend that any false negative interpretation represents medical negligence. In considering a chest radiograph with missed lung cancer, for example, as many as 90% of cancers are identifiable in retrospect; a radiologist's potential legal exposure is not insignificant. Hindsight bias represents the tendency for people with a knowledge of the actual outcome of a case to believe falsely that they would have predicted its outcome. This jury bias makes defending such cases difficult.

Negligent diagnosis claims can be categorized as related to 1) failures of perception (i.e., not identifying a finding), 2) failures of interpretation (i.e., identifying a finding but not appropriately appreciating or adequately communicating its significance), or 3) combinations of both. Diagnostic errors can also be categorized as 1) cognitive errors (e.g., not identifying a lung nodule when interpreting a chest radiograph), which are usually errors of visual perception (scanning, recognition, and interpretation), or 2) system errors (e.g., failure to adequately communicate the presence of that nodule), which are usually attributed to health system issues or context of care delivery problems.

As in other medical disciplines, errors in diagnosis in radiology often result from a combination or interaction between cognitive and system errors, such as preliminary reports by residents that are revised in a final report but not fully communicated to care teams. Certain system factors, such as lighting conditions, shift length, or pace of interpretation, have been shown to increase the likelihood of diagnostic errors. Enhanced awareness of these types of errors helps

radiologists identify areas of diagnostic vulnerability and institute interventions to improve patient care and mitigate their own potential risks.

5.2.3 Malpractice Related to Procedural Complications

Any invasive procedure has a risk of complication. Such complications vary in type and severity based on the procedure, and can similarly serve as the grounds for medical negligence claims. Despite what some plaintiff lawyers might contend, complications by themselves do not indicate negligence. Lawsuits based on procedural complications, however, are more successfully argued in scenarios in which a radiologist did not exercise appropriate care in 1) minimizing the risk of the complication, 2) identifying complication once it occurred, or 3) treating the complication. In the instance of the very common complication of pneumothorax after a lung biopsy, for example, a radiologist's malpractice risk would increase if he or she 1) used an overly large needle or chose a trajectory unnecessarily crossing an aerated lung, 2) did not obtain a postprocedural chest radiograph, or 3) discharged the patient to home in the setting of an enlarging pneumothorax.

Patients and their families are more likely to sue physicians for damages related to complications if they believe that details of their care were withheld. As a result, most risk managers advocate full and prompt disclosure of any untoward events, and ongoing communication about decision-making and treatment. Detailed and contemporaneous documentation of events, discussions, and rationale for decisions in the radiology report and/or elsewhere in the medical record may prove helpful in court.

Engaging patients (and their families, when appropriate) in decision-making before a

procedure also helps set realistic expectations. The doctrine of informed consent has been codified in the U.S. courts as a basic right of self-determination: "Any human being of adult years and sound mind has a right to determine what shall be done with his body; and a surgeon who performs an operation without his patient's consent commits an assault." Courts have subsequently expanded that decision to apply to procedures other than open operations and those performed by nonsurgeon physicians. Necessary elements of informed consent are described in Section 3.2.1 of this study guide. Although most hospitals have standard consent forms in place, additional detailed documentation in procedure reports may prove helpful in a claim of negligence.

5.2.4 Malpractice Related to Communications Deficiencies

Appropriate communication of actionable information from radiologists to clinical caregivers is a critical component of patient care. Both courts and regulatory agencies are increasingly holding radiologists to higher standards of ensuring prompt communication of diagnostic information. In fact, a number of court decisions have focused not only on a radiologist's duty to communicate important or critical findings with referring physicians, but also on communications with patients themselves when their treating physicians may not be available.

Routine Communication

In radiology, routine communication refers to the creation and delivery of written reports. The ACR Practice Parameter for Communication of Diagnostic Imaging Findings outlines suggested formatting for reports, which includes relevant demographic information (e.g., patient name and identifying information, referring physician, facility information), examination details (e.g., type and time of

examination including contrast administration information, time of dictation), and report content recommendations (e.g., findings, impressions, limitations, complications). It is acceptable for demographic information and examination details to be contained in the metadata associated with the report (rather than in the dictated report body itself). Radiology reports are now typically generated and transmitted electronically.

The final report represents the definitive documentation of the results of an imaging examination or procedure. It should be proofread to minimize typographical errors and confusing or conflicting statements. The use of abbreviations or acronyms should be limited to avoid ambiguity. The final report should be completed in accordance with all appropriate state and federal requirements (e.g., Mammography Quality Standards Act). A copy of the final report should be archived by the imaging facility as part of the patient's medical record and be retrievable for future reference. Retention and distribution must be in accordance with all state and federal regulations and facility policies.

Nonroutine Communication

While routine communication is typically carried out through institutionally established final reporting mechanisms, certain circumstances dictate alternative communication mechanisms to ensure timely receipt of important diagnostic information. These include situations warranting preliminary reports and results of an urgent or other significantly important nature.

Occasionally, a preliminary report is issued before the final report, and may be rendered for the purpose of directing immediate patient management (e.g., when old comparison images are not yet available but reporting cannot wait) or to meet the needs of a particular

practice environment (e.g., by a trainee in a teaching institution or by a general practice radiologist when a subspecialist radiologist is not immediately available). Such preliminary communications should be archived, since they may have served as the basis of immediate clinical decisions. Institutions are expected to maintain policies for reconciling discrepancies between preliminary and final reports and for discrepancies encountered upon subsequent review of a final report. Any clinically significant variation in findings or impression between a preliminary and final interpretation should be clearly documented and reported as soon as possible and in a manner that ensures receipt by the ordering or treating physician.

Clinical situations that may warrant nonroutine communication include the following:

- 1. Findings that warrant immediate or urgent intervention.** These are generally new or unexpected findings on an imaging study that suggest life-threatening conditions or those that may require an immediate change in patient management. Aside from risk management imperatives, The Joint Commission (TJC) requires that professionals "report critical results of tests and diagnostic procedures on a timely basis." TJC-accredited facilities are required to define critical tests and critical results and monitor performance in reporting those results. A critical result is defined as "any result or finding that may be considered life threatening or that could result in severe morbidity and require urgent or emergent clinical attention." Examples include tension pneumothorax, ruptured aortic aneurysm, acute intracerebral hemorrhage, and pneumoperitoneum. Each facility has leeway in defining its own critical tests and critical results; there is no standard list for either category. For all critical results,

communication requires direct contact between the radiologist and the requesting or responding clinician or another licensed healthcare provider responsible for that patient's care. In addition, communication is generally expected to occur within 60 minutes of the time that the observation is made, and it must be documented. When the ordering physician or healthcare provider cannot be contacted expeditiously, it may be appropriate to convey results directly to the patient, depending on the nature of the findings. At some institutions, these critical results are deemed "Level 1 results."

2. Findings that may not require immediate attention but nonetheless may seriously impact a patient's health, worsen over time, or result in an adverse outcome.

These include the following: 1) New or unexpected findings that could result in mortality or significant morbidity if not treated in a timely manner. Referred to as "Level 2 results" by some institutions, these are less dire than critical results and generally warrant communication within 12 hours. For such findings, the radiologist might call the care team directly, or might request a call service or assistant to call on his or her behalf. Examples include intra-abdominal abscess or impending pathological hip fracture. 2) New or unexpected findings on an imaging study that could result in significant but not immediate morbidity if not appropriately treated. Deemed "Level 3 results" by some institutions, communication is not particularly time sensitive but mechanisms must be in place to ensure that these important or potentially important findings are not overlooked. Examples include a newly identified lung nodule or solid renal mass. These findings may be reported

electronically when electronic messaging tracking mechanisms are in place to make sure that information was successfully received and, when necessary, supplemented by telephone confirmation.

Documentation of all nonroutine communication should include the date and time of the communication, the person reporting the information, the person receiving the information, and a summary of or reference to the information that was conveyed.

Informal Communication

Radiologists may occasionally be asked to provide interpretations that do not result in a formal report but are nonetheless used to make treatment decisions.

Such communications may take the form of a "curbside consult" that may occur informally in the reading room or during a clinical conference. These circumstances often preclude immediate documentation and may also occur in suboptimal viewing conditions (e.g., no comparison studies, no original reports, or inadequate incomplete history). Informal communications carry additional inherent risk since the documentation of the clinician initiating the informal consultation may constitute the only written record of that communication. For these reasons, informal communications are largely discouraged; when such communications do occur, radiologists should document them independently from the referring clinician's documentation.

Radiology departments are encouraged to establish processes and policies for reporting studies performed at outside institutions. Radiologists who provide consultations of this nature are encouraged to document any information conveyed, including formal interpretations. Although formal second opinion interpretations are historically non-

payable, Medicare and private payers are increasingly reimbursing radiologists for them when they are medically necessary and are billed in accordance with payer rules.

5.2.5 Discoverability of Communications

In malpractice lawsuits, most communication related to any part of the case—whether written or oral—is considered discoverable and can be used as evidence at trial. However, certain important exceptions apply. The attorney–client privilege is one of the oldest recognized privileges for confidential communications. It encourages clients in all legal matters (not just malpractice cases) to make full and frank disclosures to their attorneys, who should then be better able to provide candid advice and effective representation. Nearly all communication between a client and his or her attorney is protected from discovery. For this reason, physicians involved in lawsuits are strongly discouraged from speaking with any parties other than their attorneys about any elements of their cases.

Most jurisdictions also protect certain peer review activities from legal discovery. Peer review protection laws are designed to provide an incentive for healthcare providers to perform ongoing quality improvement activities without fear of increased tort risk. As a general rule, no person who participates in any approved peer review process shall be permitted or required to testify in any civil action as to the findings, recommendations, evaluations, opinions, or other actions of the peer review process. However, communications are only protected if they occur within established peer review processes; informal conversations with colleagues outside established peer review processes, for example, are typically not protected from legal discovery.

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Chapter 6: Core Concepts of Imaging Informatics

6.1 Standards

DICOM

The Digital Imaging and Communications in Medicine (DICOM) standard (<http://dicom.nema.org>) is the international standard that specifies protocols for display, transfer, storage, and processing of medical images. The DICOM standard applies to storage of both pixel-based image data and metadata. The metadata, located in the “DICOM header” of the image, contains information about the image, series, exam, patient, imaging facility, and scanner. The data are organized into separate fields, each of which has a unique identifier so that it can be queried directly. DICOM transactions enable data to be queried, retrieved, and transmitted between systems in an organized fashion. They also allow for information about an order to be transmitted between the radiology information system (RIS) and the modality (e.g., the CT, MR, or ultrasound machine) rather than having to be manually entered by the technologist and risking incorrect data entry.

Standard DICOM data elements are required to contain specific information while private data elements can be defined by the vendor. To enable interoperability between systems, vendors who implement products that use DICOM are expected to provide customers with conformance statements that detail their use of the DICOM standard.

HL7

HL7 (<http://www.hl7.org>) is the international standards organization responsible for developing and maintaining standards for the exchange, integration, sharing, and retrieval of medical information (i.e., nonimage data). The

primary HL7 standards are the ones most frequently used to achieve systems interoperability.

The HL7 V2 messaging standard is generally considered to be the most widely implemented healthcare-related standard in the world. This text-based standard facilitates the exchange of medical data by enabling interoperability between many types of electronic medical systems that need to communicate. HL7 V3, while more human-readable, has been less widely adopted in the industry because of its increased complexity. The newer HL7 Fast Healthcare Interoperability Resources (FHIR®) standard allows software developers to use internet transactions to exchange medical data between systems, increasing the potential for data exchange between systems.

Ontologies

Ontologies are formal collections of terms and their inherited or causal relationships. RadLex (<http://www.radlex.org>) is the largest radiology-specific lexicon. It contains more than 68,000 terms that describe imaging anatomy, procedures, and pathology. A special portion of the RadLex ontology, the RadLex Playbook, defines standard imaging exam names, descriptions, and codes. The RadLex Playbook has been merged with LOINC (Logical Observation Identifiers Names and Codes), the international standard nomenclature for health measurements, observations, and documents.

6.2 The Reading Room Environment

PACS

The PACS (picture archiving and communication system) is the radiologist’s

primary tool for imaging viewing and interpretation. Basic components of PACS include a workstation, display, short-term storage, and long-term archive. PACS communicates with imaging modalities using DICOM transactions, and with the RIS and/or EMR using HL7 transactions that are translated to and from DICOM. Unlike original PACS implementations that required a physical workstation to run, the modern PACS can be entirely web-based and accessible on mobile devices as well as on desktop thin clients.

VNA

The development of the vendor-neutral archive (VNA) allows data to be stored in a central archive that may support viewers for multiple types of DICOM images (e.g., radiology, cardiology, operating room, etc.), as well as for non-DICOM data, including photographs and pathology slides. Enterprise imaging relies heavily on VNA technology to facilitate dissemination, viewing, and storage of medical imaging data beyond radiology. Determining how best to format and exchange the metadata (e.g., patient information, body part, date of acquisition, etc.) accompanying a non-DICOM image is a major challenge in enterprise imaging.

RIS

The radiology information system (RIS) is a software application that manages all aspects of an imaging exam, including order reconciliation, patient scheduling and tracking, communication with modalities and PACS, reporting, results notification, and billing. The RIS may be a standalone application or a component of the electronic medical record (EMR) application. Both PACS and RIS can be used to drive clinical workflow.

Image Displays

The ACR-AAPM-SIIM technical standard

recommends that ideal reading room ambient lighting fall in the range of 25 to 50 lux. This level of lighting is similar to standing under a street light at night in dark surroundings. The maximum gray value luminance for diagnostic monitors is recommended to be at least 350 cd/m² for nonmammographic interpretation and 420 cd/m² for mammographic interpretation. By way of reference, top-performing flat screen televisions on the market in 2017 have a peak luminance upwards of 400 cd/m².

Compression

Compression is used to decrease image file size to speed up transfer and decrease storage requirements. Lossless compression is achieved by decreasing redundant image information (e.g., the black background of a CT image). Because image content is preserved, lossless compression can only reduce image file size by approximately 3:1. Lossy compression allows for more substantial image size compression (on the order of 10:1) by irreversibly discarding unnecessary or minimally important image information without significantly compromising diagnostic quality.

Ergonomics

Like all individuals who spend many hours working on a computer, radiologists are susceptible to repetitive strain injuries (RSI). For example, carpal tunnel syndrome (involving the median nerve) often occurs due to dorsiflexion of the wrist from upward angulation of the wrist while typing. Cubital tunnel syndrome (involving the ulnar nerve) can occur due to RSI at either the wrist or the elbow. DeQuervain tenosynovitis occurs secondary to RSI of the thumb.

Workstation configurations that promote a neutral body position with the forearm, wrist, and hand parallel to the floor, lumbar support,

and appropriate distance between the user and the display can help to decrease the incidence of RSI among radiologists.

6.3 From Order to Report: Workflow Considerations

Workflow Steps

Medical imaging depends on interoperability between many systems, including PACS, RIS, EMR and imaging modalities, as data are transferred via DICOM and HL7 transactions. The process begins with an order placed in the EMR. HL7 transactions communicate the order to the RIS (if it is a separate system). The RIS communicates order information to the relevant imaging modality (meaning the machine) via the DICOM Modality Work List, and the modality communicates with the PACS via DICOM transactions. The radiologist views the images on PACS and dictates the report using voice recognition. The reporting software then sends the report to the RIS and EMR via HL7 transactions.

Downtime Procedures

Downtime procedures include disaster recovery (DR) and business continuity (BC) procedures. DR policies direct activities that should be followed in the event of a disaster, such as a large-scale, unexpected, highly disruptive event, whether natural or human in origin.

DR policies typically include a description of off-site data backup systems, including the frequency of backup cycles, and the steps required to restore critical data in the event of a disruption. BC policies refer to the necessary systematic precautions, backups, and failover routines required to continue to care for patients when a system failure (such as a power outage) occurs under otherwise routine working conditions.

Radiology systems are considered to be high-availability (HA) systems. HA systems must have the ability to perform automated recovery and failover operations in the event of service disruption. The uptime expectations of an HA system can be expressed as a “number of nines.” For example, PACS is generally expected to perform at “four nines”, or 99.99% uptime, which translates to no more than approximately 50 minutes of downtime a year. Fault tolerance (FT) refers to the ability of a system to continue to function if one of its components fails. To avoid single points of failure, redundancy is built into essential components of a system (e.g., servers, network connections, data archives, etc.) to achieve a high FT.

6.4 Data Privacy and Security

De-identification of Images

De-identification involves removing protected health information (PHI), as defined by HIPAA, from an imaging examination such that the identity of the patient cannot be directly determined based on information contained in the images or the metadata. However, de-identified images may contain information that enables an approved entity to identify the patient using a key. In contrast, anonymization involves removing all PHI and other identifiable data from an imaging examination such that the identity of the patient is not revealed and cannot be re-established in the future. PHI contained in the metadata can typically be removed via automated de-identification processes. In some cases, “burned-in” PHI (such as in ultrasound images) also must be removed to fully de-identify medical images. Because the contours of a patient’s face can be reconstructed from CT or MRI of the head, imaging that includes the face is also considered PHI.

De-identification of Report Text

De-identification of report data is less straightforward than de-identification of image data, because PHI does not occur in radiology reports in the same form or with the same consistency. De-identification of report data often requires manual review or application of specialized algorithms.

Tools for de-identification of other medical text, such as encounter notes or progress notes, generally do not work as well for radiology reports, because of the less frequent appearance of PHI in radiology reports compared to medical text.

Cybersecurity

Ransomware attacks occur when bad actors encrypt files and systems and demand a ransom in exchange for the decryption key. Such attacks can be catastrophic to a radiology practice and its associated hospital or health system. Typical downtime procedures may not be sufficient for recovery. Instead, a long-term analog (e.g., paper-based) workflow may be necessary to maintain business continuity while compromised files and systems are isolated and data recovery is attempted. Eventually, any recovered data will have to be reconciled with new data collected after the attack.

6.5 Image Post-Processing

Post-processing refers to image transformations performed after acquisition. These transformations may occur before image display, interpretation, or quantitative analysis. Post-processing includes techniques such as image segmentation, registration, and three-dimensional (3-D) post-processing using maximum intensity projections (MIPs), multiplanar reformats (MPRs), or volume rendering.

Segmentation involves isolating or extracting a

region of interest from an image or extracting a subset of images from an image stack for further analysis. For example, segmentation of gray matter and white matter from MRI of the brain may be the first step to a more advanced analysis of atrophy in neurodegenerative disorders.

Image registration involves aligning one image set onto the coordinate space of another image set to allow a more direct comparison of the two image sets. Deformations can be rigid (translation, scaling), affine (shearing), or elastic. Elastic deformation involves local warping of an image to better align the target image with the reference image. Elastic deformation is one type of image registration that can accommodate changes such as patient position, lung expansion, or soft tissue shape changes in aligning image sets.

3-D post-processing is a required component of CT and MR angiography and can supplement other advanced imaging, such as cardiac MRI and brain MRI for tumor analysis. Simple 3-D post-processing, such as MPRs, MIPs, and volume rendering, can be performed on most modern versions of PACS. More elaborate analysis such as curved planar reformats (CPRs), functional analysis, and cinematic rendering, however, may require additional thin-client software and may be supported by a dedicated team of experts, such as a 3-D lab.

6.6 Artificial Intelligence

Artificial intelligence (AI) is the field of computer science that gives computers the ability to mimic human intelligence. Machine learning (ML) is a subfield of AI that enables computers to learn a task without an explicit set of instructions. Deep learning (DL) uses multi-layered neural networks with weighted connections to analyze data, and works with both images and text. AI serves as an adjunct to the human radiologist; at present, few autonomous AI applications exist for radiology.

Supervised and Unsupervised Learning

Supervised learning exposes an algorithm to a labeled set of training data and then evaluates how well the resulting model predicts labels on a different set of test data. It is important that the test set data not overlap the training data, so that model performance is not artificially exaggerated.

Unsupervised learning exposes an algorithm to a set of data without pre-defined labels or categories and expects the algorithm to organize the data.

Unsupervised learning models must be validated and may not perform as well as supervised models without further training.

Training AI Models

Generating training data for radiology requires experts to label images or text, which is time- and resource- intensive. A common pitfall in model training is overfitting the model to the data, such that it performs very well on similar data (e.g., at the organization where it was trained), but does not perform as well on data that are different in some way (e.g., data from another organization). Labeling images is task specific and can be as simple as assigning a label to an entire image or study (e.g., “normal”, “abnormal”), or it may require an expert to use segmentation tools to identify an anatomic structure or disease process. As with de-identification, labeling text data or workflow data requires different tools than labeling image data.

Deep Learning for Images

Deep learning models use neural networks with an input layer, multiple hidden layers, and an output layer to perform inference or make predictions. Convolutional neural networks and recurrent neural networks are DL algorithms often used in radiology applications. Image data are pre-processed

before use for training or inference to make them suitable for input to an AI algorithm; this may include rescaling, cropping, denoising, histogram equalization, and often downsampling (sometimes by as much as 10x). This decrease in image resolution may reduce the conspicuity of subtle findings in images unless sufficient training examples are provided.

Natural Language Processing

Natural language processing (NLP) is the analysis of human language data. Common uses in radiology reports include detection of critical findings or follow-up recommendations, longitudinal lesion monitoring, assessment of report compliance with practice requirements, or radiology-pathology correlation. Text documents are also pre-processed like images, with removal of stop words and punctuation, conversion to lower case, and tokenization. Text data can be tokenized by converting words and phrases to numeric representations for input into deep learning models through a process known as embedding.

Deployment Challenges

Major challenges in deploying AI for radiology include understanding how the “black box” model produces its results, ensuring that the model performs reliably in all potential applied settings and conditions, and efficiently integrating the model into the clinical workflow. Once deployed, models should be monitored to identify data drift, in which model performance degrades over time due to gradual changes in the data it processes. Additionally, the way that radiologists interact with AI should be monitored to guard against automation bias, in which the computer is always assumed to be more correct than the human practitioner.

Bias in AI

Bias in AI can occur due to the training data, the model architecture, or the conclusions drawn by end users based on model outputs. Statistical bias results when a model does not represent the true

features of the population. One example of statistical bias is sampling bias, in which the data used to train the model do not represent the patients to whom the model will ultimately be applied. Social bias has the potential to exacerbate health disparities by adversely affecting underrepresented populations. For example, a model may predict better health outcomes in a patient population that does not use healthcare resources as frequently, but may overlook the fact that the use or lack thereof is related to access to care rather than their state of health.

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