15 Minimally Invasive Image-Guided Procedures

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15.1 Introduction

The first significant advances that forged minimally invasive image-guided procedures (MIIPs) date back to the early 1950s and 1960s. In 1953, a Swedish-born physician first published a technique he pioneered that is known to this day as the "Seldinger technique" for accessing blood vessels without a surgical cut-down [1–4]. A decade later, Dr. Charles Dotter published his experience using this technique by introducing a series of dilating catheters to treat an atherosclerotic lesion in a femoral artery, a technique which became known as "Dottering" [5, 6]. In contrast to minimally invasive surgery, MIIPs do not use cameras inside the body. Instead, MIIPs utilize medical imaging technologies such as fluoroscopy, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US) to see inside the body from the outside avoiding the need for multiple larger incisions required to place cameras and surgical instruments into the body. Most procedures are performed on an outpatient basis or require a hospital stay that is considerably shorter than that following an open surgical procedure. General anesthesia is not usually required which makes MIIPs safer for patients with multiple comorbidities. In select cases, general anesthesia can be helpful or required, as in very lengthy, complex, or potentially painful procedures. Nurse-administered moderate sedation is usually utilized to keep the patient comfortable while maintaining their ability to respond to commands and protect their airway. MIIPs provide many benefits to patients and to the facilities that provide these services. Procedures may be performed on an outpatient basis using moderate sedation with recovery times that are significantly reduced. MIIPs are less invasive and less painful than open surgery, as they are performed through a very small hole that requires little or no stitches with significantly less scarring. The use of targeted image-guided treatment results in higher levels of safety and efficacy and reduces the risk of infection. By avoiding traditional surgery, reductions to the length of stay after procedures, improved patient outcomes, the ability to resume normal activities, and return to work sooner result in a reduction in costs for both the patient and the hospital. MIIPs contribute to higher patient satisfaction.

15.2 Principles

15.2.1 Evolution of Interventional Radiology as a Specialty

The practice pattern of interventional radiologists (IR) has evolved over the years since Dr. Charles

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K. A. Gross (ed.), *Advanced Practice and Leadership in Radiology Nursing*,
https://doi.org/10.1007/978-3-030-32679-1_15

Dotter performed the first percutaneous transluminal angioplasty (PTA) successfully dilating a tight stenosis of a superficial femoral artery on January 16, 1964. An 82-year-old female was suffering from painful gangrenous toes and refused to undergo an amputation [5, 6]. After the intervention, her pain subsided and she ultimately walked out of the hospital. Dr. Dotter was the first to lecture that the future of diagnostic angiography would not only provide an exact diagnosis but, in fact, would provide the means by which angiographers would be able to treat patients percutaneously with catheters and guide wires [5]. During the 1970s, the early pioneers applied their techniques to other conditions and expanded the indications for percutaneous procedures resulting in the introduction of coronary PTA, vena cava filters, and the use of the first micro coils and polyvinyl alcohol (PVA) for embolization in treating gastrointestinal bleeding. The early coronary balloon catheters were used to dilate peripheral arteries and an industry was born with multiple medical device companies improving upon the technology facilitating the expansion of MIIPs into other areas of the body. By the late 1980s, bare metal balloon-expandable stents became available for treating benign and malignant strictures in the biliary tree as well as coronary and peripheral vascular lesions. Patients with end-stage liver disease with significant morbidity suffering from esophageal bleeding and intractable ascites were very poor candidates for open surgery. These stents provided the solution to manage these patients as IRs were able to percutaneously create an internal shunt between the portal vein and hepatic vein, thus decompressing the liver preventing further bleeding and eliminating ascites. Catheter techniques learned from the treatment of gastrointestinal bleeding are used today in the treatment of liver cancer to deliver chemotherapy and radioactive spheres. Throughout the course of its history, IR has moved away from a diagnostic specialty to a clinical practice model. Increasingly, patients are being seen in clinic for evaluation and informed consent prior to admission for procedures. Advanced level practitioners often are found in clinics providing evaluation through history and physical exams and ordering pre-procedure testing, educating patients about a procedure and obtaining consents, and performing follow-up for patients. At some facilities radiologists may have admitting privileges should the patient need a 24-h stay or an overnight admission following a procedure. Advanced practice providers often are involved in the follow-up care of admitted patients.

In 2017, IR gained official specialty status from the American Board of Medical Specialties (ABMS). The Society of Interventional Radiology has outlined IR training options [7] (see https://www.sirweb.org/learning-center/ir-residency/). As IR became more clinically oriented and patient acuity increased, more clinical radiology nurses were needed to care for the procedure patients, pre-, intra-, and post-procedure. The need for more radiology advanced practitioners has also increased. The Association for Radiologic and Imaging Nursing (ARIN, www.arinursing.org), which supports radiology nurses via education and networking, has grown in response to the needs of all radiology, especially IR (see Chaps. 1 and 2 for more information about the role of the advanced practice nurse in radiology).

15.2.2 The Interventional Initiative

The Interventional Initiative (the II, http://theii.org/miips/procedures) is a 501c3 not-for-profit charitable organization founded in 2015 by physicians, patients, and allied healthcare professionals who recognized a healthcare knowledge gap between the public and the availability of MIIPs.

It has been estimated that in the USA only 12% of adults have proficient health literacy, which means that nearly nine out of 10 adults may not have the skills needed to make informed decisions around their healthcare needs and choices [8]. What is striking is that according to the U.S. Bureau of Labor Statistics 12.2% of the nation's workforce reside in the healthcare industry, so a large percent of those who are deemed proficient likely are healthcare workers such as physicians, nurses, and allied health professionals [9] (https://www.bls.gov/emp/tables/employment-by-major-industry-sector.htm).

A study published by members of the II in 2017 found that 65% of radiology department outpatients in a single hospital setting had no prior knowledge of IR [10]. A survey of the general public found that 72% could not identify an interventional radiologist as a physician. Understanding that internet searches are one of the primary methods used by the public to learn about disease and treatment options, the authors also evaluated the activity of internet searches and IR-related coverage in the media and compared findings to those of medical specialties that also perform MIIPs such as cardiologists, vascular surgeons, and nephrologists and found that they were markedly lower.

Low health literacy coupled with a lack of knowledge of interventional radiology highlights the needs to engage the public about MIIPs providing education about the full breadth of diseases treated and empowering them to take an active role in their healthcare decision-making. Despite the general lack of awareness of IR, Heister and colleagues found that the majority of patients would prefer a MIIP to open surgery, especially if it is recommended by their physician [10]. It is therefore imperative that MIIPs providers make available opportunities to educate their referring physicians about the services they provide.

The II supports the beliefs that patients who are empowered to make informed healthcare decisions will have better outcomes [11]. The II produces informative content at the sixth grade health literacy level delivering it through a variety of platforms including visually engaging infographics, medical animation, and short-format video podcasts titled "Behind the Scrubs" and "Ask an IR." The documentary series "Without a Scalpel" (http://www.theii.org/the-docuseries) provides a glimpse inside MIIPs from both the patient and the interventional radiologist perspectives. The Centers for Disease Control (CDC) offers a variety of online health literacy courses including topics such as writing and speaking with the public [12]. For a list of courses see https://www.cdc.gov/healthliteracy/gettraining.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fhealthliteracy%2Fwriting-course%2Findex.html.

15.3 Description of Techniques and Indications

15.3.1 Percutaneous Access

The Seldinger technique provides the foundation of both percutaneous vascular and nonvascular access [1]. A small gauge needle is used to puncture a blood vessel, organ, or anatomical space. A guide wire is then threaded through the needle, the needle is withdrawn, and a catheter is then threaded over the guide wire. The guide wire is removed and contrast is injected to verify that the catheter is in the correct location. For vascular cases, common femoral artery access is often preferred. However, the transradial approach for both diagnostic and interventional procedures has gained popularity due to resulting shorter procedural recovery times and hospital stays, possible reductions in access-site complications, and improved patient satisfaction due to the ability to ambulate sooner.

15.3.2 Imaging Equipment

Improvements in the imaging equipment designed specifically for the angiography suite incorporating C-arm technology and digital subtraction angiography (DSA) and adoption of low and iso-osmolar contrast media to improve visibility have significantly improved the patient experience and procedural success. DSA is a technique used in MIIPs to allow the interventionalist to clearly visualize blood vessels that are in close proximity to bone or within dense soft tissue environments. This is accomplished by digitally subtracting an image that was acquired before contrast came into contact with the area under investigation. DSA decreases the procedure time, radiation dose, and the amount of contrast required. Three-dimensional (3D) technologies include "road mapping" which allows the interventionalist to overlay a DSA-acquired image of the area to be treated or integrate a 3D "reconstructed" image of structures attained during rotational angiography, CT or MRI over live images to help navigate guide wires and catheters

Table 15.1 Equipment/supplies

Puncture needle
Guide wire(s)
Introducer sheath/peel-away sheath
Syringes
Contrast media
Power injector
Diagnostic catheter(s)
Guiding catheter(s)
Balloon catheter(s)
Stent(s)
Vascular closure device (VCD)

across complex lesions or vascular structures. See Table 15.1 for a list of equipment and supplies utilized in a typical IR procedure.

15.3.3 Vascular Interventions

"Lower extremity PAD is a common cardiovascular disease that is estimated to affect approximately 8.5 million Americans above the age of 40 and is associated with significant morbidity, mortality, and quality of life impairment. It has been estimated that 202 million people worldwide have PAD" [13] (https://www.ahajournals.org/doi/full/10.1161/CIR.0000000000000470). Vascular intervention is not limited to the lower extremities. The same techniques for accessing blood vessels in the lower extremity are used to provide interventions in the brain, chest, and abdomen. See Table 15.2 for a list of common vascular intervention procedures.

Table 15.2 List of common vascular interventions

Balloon angioplasty
Central line placement
Dialysis graft or stent maintenance
Foreign body retrieval
Inferior vena cava (IVC) filter placement
IVC filter removal
Mechanical thrombectomy
Stent and stent graft placement
Thrombolysis
Transarterial embolization
Transjugular intrahepatic portosystemic shunt (TIPS)
Transjugular biopsy
Vein ablation
Vein embolization

15.3.3.1 Balloon Angioplasty

Percutaneous balloon angioplasty is utilized to open a blood vessel and is performed utilizing a catheter with a balloon mounted on the distal end. Once inflated, the balloon will open a blocked or narrowed blood vessel by stretching the walls of the vessel. However, the resulting injury to the vessel may lead to an inflammatory response known as intimal hyperplasia which has been shown to cause narrowing in the vessel or in the stent, called in-stent restenosis [14, 15]. Subsequent endothelial growth may necessitate later interventions such as angioplasty, stenting, or surgical bypass. A number of therapies are available to use in conjunction with or as an alternative to angioplasty in an effort to minimize the incidence of in-stent restenosis including drug-coated balloons, drug-eluting stents, and atherectomy [16, 17].

15.3.3.2 Endovascular Stents

Stents are permanent tubes made of metal mesh. Stents are deployed to open vessels that do not respond sufficiently to angioplasty. Stents can be self-expandable, which have the benefit of exerting high radial force, or balloon-expandable, which have the benefit of precise placement. Stents can be bare metal or covered. Stents covered by material such as polytetrafluoroethylene (PTFE) are called stent grafts. Stent grafts create a barrier to intimal hyperplasia and leaks. They are commonly used to treat aneurysms in the iliac arteries and abdominal aorta. The choice of stent size, deployment, and type depends on the indication and anatomy (Fig. 15.1).

15.3.3.3 Transcatheter Arterial Embolization

Embolization is the intentional closure of a bleeding or diseased blood vessel using any of a variety of materials delivered through a catheter. Embolization techniques were first utilized by interventional radiologists in the early 1970s to treat gastrointestinal bleeding and spinal vascular malformations [2]. Embolic agents include small particles, coils, plugs, and glue. The choice of

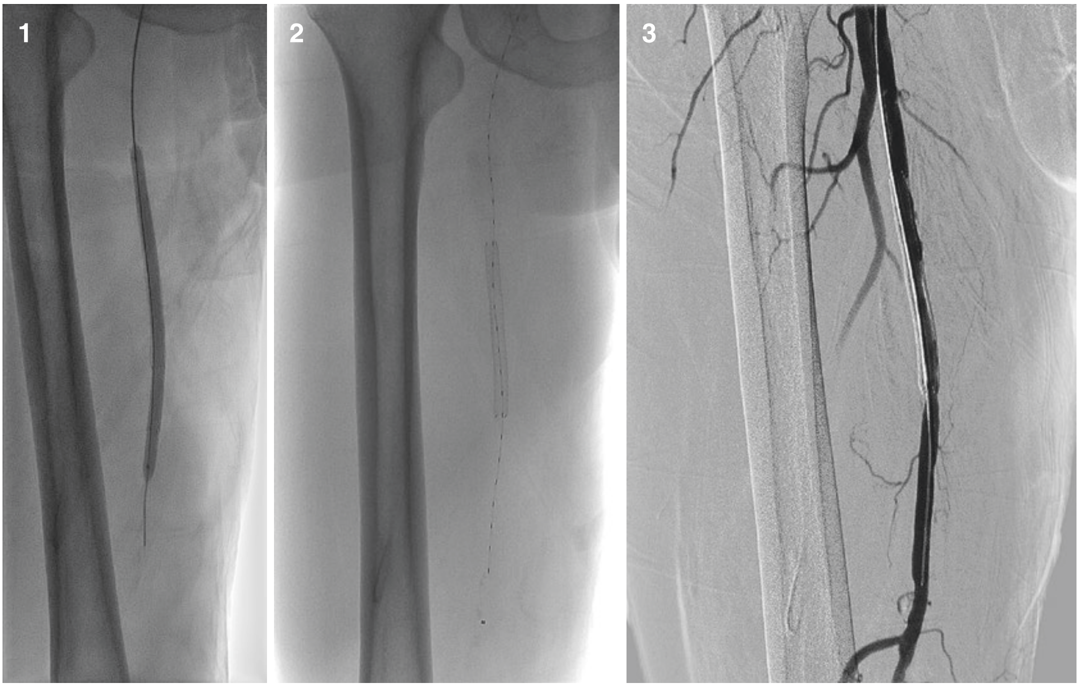

Fig. 15.1 Seventy-one-year-old male with claudication due to narrowing in the superficial femoral artery (SFA). Image 1 shows percutaneous balloon angioplasty of SFA. Image 2 shows a metal stent with guide wire in SFA. Image 3 with contrast flow through SFA stent

agent depends on several factors: the vascular territory to be treated, the type of abnormality being treated, the possibility of superselective delivery of an occlusive agent, the goal of the procedure, and the permanence of the occlusion [18, 19]. Careful placement of the correct catheter is essential to decrease the risk of complications from embolization of nontarget vessels.

15.3.3.4 Vascular Closure Devices

Manual compression of the vascular entry site can be utilized to achieve hemostasis. A mechanical device can be used to maintain pressure but should be attended by personnel who can verify correct placement without slippage of the device and possible hemorrhage. Compression of arterial access points typically takes 20 min whereas compression of venous access site typically takes less than 5 min. After arterial access, patients are required to stay on bed rest with the affected limb immobilized for a length of time depending on the point of access. All manufacturer recommendations should be followed after deployment of a vascular closure device. Some products include a “sticker” of identification that can be temporarily placed at the puncture site to inform staff of the device used. There has been a shift from the femoral artery access to the radial artery approach (see Chap. 9); however, a percentage of cases will require a crossover to the femoral approach either due to failed radial access or to perform an intervention. The utilization of vascular closure devices provides an alternative to manual compression with the benefit of shorter time to hemostasis and ambulation [20, 21].

15.4 Nonvascular Interventions

Nonvascular MIIP treatments have emerged as an alternative to open surgery through the application of techniques that were utilized in the early vascular MIIPs. MIIPs can be performed on essentially any organ or location in the body, depending on the disease process and the patient's clinical presentation including laboratory workup and imaging findings. Under real-time imaging guidance, IRs insert a small gauge needle into the structure of interest, such as dilated biliary ducts, a dilated ureteral system, or a pocket of abnormal fluid. Once placement is confirmed fluid is aspirated. If the fluid is infected or expected to recur, a catheter can be inserted to provide external drainage (Fig. 15.2). In the case of biliary or ureteral obstruction, temporary drainage catheters can be exchanged for chronic or permanent stents to treat benign and malignant strictures. See Table 15.3 for a list of common nonvascular interventions.

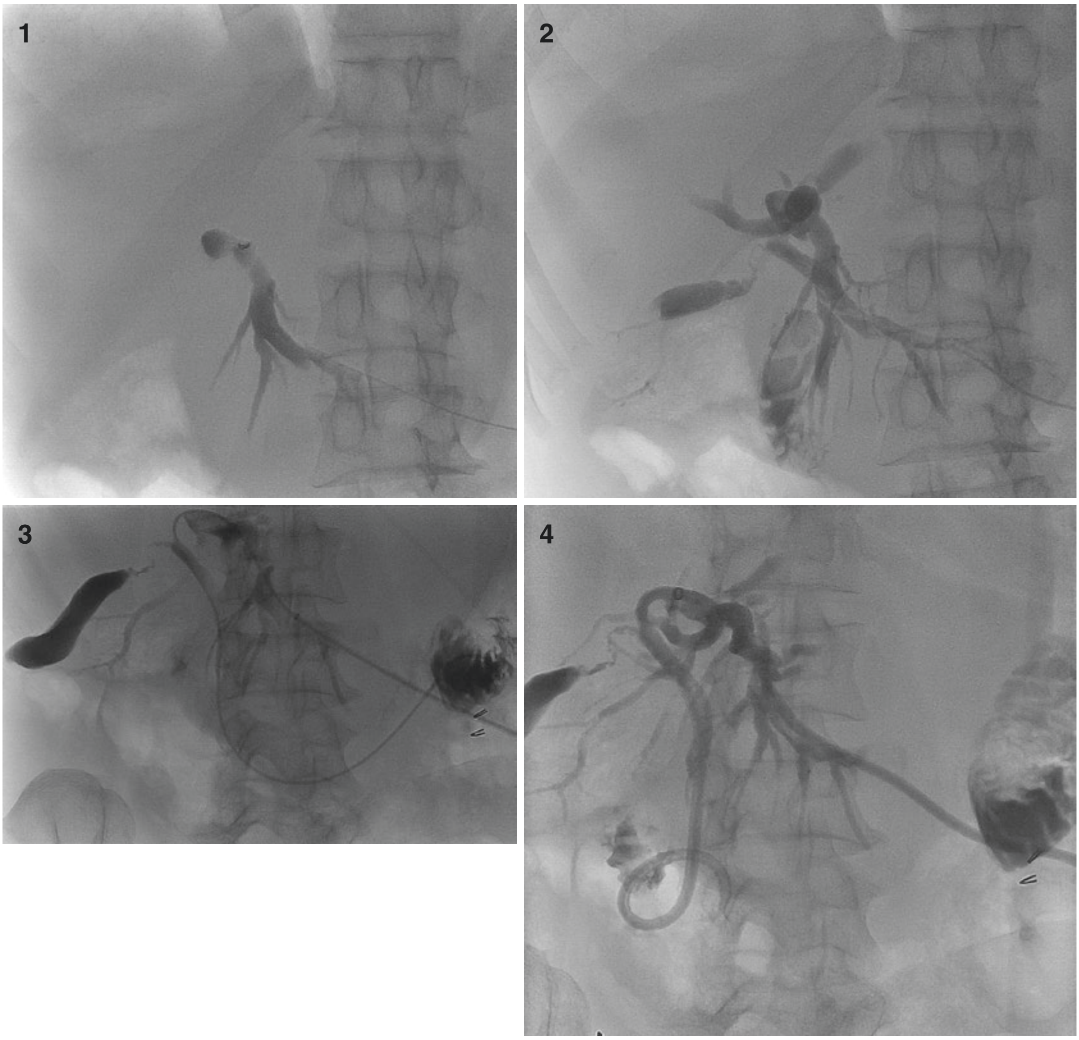

Fig. 15.2 Sixty-eight-year-old male with pancreatic cancer. Image 1 shows percutaneous transhepatic cholangiogram using a left side or anterior approach with contrast filling of left biliary duct. Image 2 shows further filling of the biliary tree, gall bladder with flow into the duodenum. Image 3 shows guide wire through left biliary duct, common bile duct into duodenum. Image 4 shows an internal/external biliary drainage catheter. The drainage catheter has side holes that allow bile to drain internally to the duodenum and externally to a drainage bag

Table 15.3 Common nonvascular interventions

Percutaneous biopsy	Abdominal
	Lung and mediastinum
	Neck
Percutaneous ablation (alcohol, heat-based [radiofrequency or microwave ablation], Cryoablation)	Liver, lung, kidney, bone
Percutaneous abscess and fluid collection/drainage	Throughout the body
Biliary duct intervention	Percutaneous transhepatic cholangiography
	Biliary drainage for benign and malignant obstructions
	Common bile duct stent placement
Gallbladder intervention	Percutaneous cholecystostomy
	Percutaneous cholecystolithotomy
	Gall bladder ablation
Percutaneous genitourinary intervention	Percutaneous nephrostomy, nephroureteral stent, or ureteral stent
	Percutaneous lithotripsy and nephrolithotomy
	Percutaneous stent placement and removal
	Ureteral brush biopsy
	Ureteral stricture dilatation
	Suprapubic cystostomy
Musculoskeletal intervention	Biopsy
	Facet joint infiltration
	Percutaneous epidural/nerve root block
	Percutaneous kyphoplasty/vertebroplasty/sacroplasty
	Thermal ablation of bone tumors
Image-guided breast intervention	Breast biopsy
Gastrointestinal tract intervention	Percutaneous gastrostomy
	Percutaneous gastrojejunostomy
	Percutaneous jejunostomy or cecostomy
	Stricture dilatation

15.5 Interventional Oncology

Interventional oncology (IO) is a subspecialty of IR that utilizes image guidance for cancer care across the continuum. This includes diagnosis through biopsy, MIIPs such as ablation and embolization, and the palliation of symptoms such as those which accompany obstructive jaundice with biliary drainage and stenting. Ablation and embolization procedures allow for selective targeted distribution of therapy to cure or control the spread of tumors, relieving symptoms while sparing normal organ tissue, preserving organ function and causing as little collateral damage to nearby structures and minimizing the body's exposure to therapy, as in systemic approaches [22, 23].

15.5.1 Tumor Ablation

Ablations are accomplished through the image-guided delivery of energy via a probe inserted directly into the tumor to destroy the tissue in situ through cytotoxic high or low temperatures to either burn or freeze the tumor using US or CT guidance. Success is dependent upon the size of the tumor and the accessibility of the probes. The most common forms of ablation are radiofrequency ablation (RFA), microwave ablation (MWA), cryoablation, and high-intensity focused ultrasound (HIFU).

15.5.2 Tumor Embolization

The two most common forms of IO embolization are transarterial chemoembolization (TACE) and transarterial radioembolization (TARE). In both procedures, a small catheter is carefully placed into the artery feeding the tumor and small particles are delivered. In TACE, the small particles are either mixed with or conjugated to chemotherapy agents. Iodinated poppy seed oil, which treats liver cancer and is also visible on fluoroscopy and CT, may or may not be included in TACE. Real-time fluoroscopic imaging is used to determine when the procedure has successfully disrupted blood flow to the tumor(s). In TARE, the microspheres are about ten times smaller than those in TACE. The TARE microspheres are loaded with a beta-emitting form of radioactivity.

15.6 Patient Considerations

It is important to determine that the planned procedure is the most appropriate one for the patient. The American College of Radiology (ACR) has established appropriateness criteria to assist clinicians in determining the right procedure for the patient. “The ACR Appropriateness Criteria are evidence-based guidelines funded solely by the American College of Radiology to assist referring physicians and other providers in making the most appropriate imaging or treatment decision for the specific clinical condition. By employing these guidelines, providers enhance quality of care and contribute to the most efficacious use of radiology” [24] (https://www.acr.org/Clinical-Resources/ACR-Appropriateness-Criteria/About-the-ACR-AC). The Society of Interventional Radiology (SIR) has published a number of evidence-based clinical practice guidelines with the goal of safeguarding patient safety and the delivery of patient care [25]. See the following for a list of practice guidelines by topic of interest https://www.sirweb.org/practice-resources/guidelines-by-document-type/guidelines-by-service-line/.

15.6.1 The American Medical Association (AMA) Implementation and Clinical Decision Support

“Overuse and inappropriate use of many imaging tests may cause harm by unnecessarily exposing patients to excess radiation; they can also impact patient outcomes when incidental findings are present and can increase healthcare costs” [26] (https://edhub.ama-assn.org/steps-forward/module/2702161). Beginning January 1, 2020, in the USA, the Protecting Access to Medicare Act (PAMA) requires referring providers to consult appropriate use criteria (AUC) prior to ordering advanced diagnostic imaging services (ADIS) including CT, MRI, Nuclear Medicine, and positron emission tomography (PET) for Medicare patients. MIIPs providers will be required to include evidence that AUC were used at the time of billing otherwise Medicare will not reimburse for the services rendered [27]. See the ACR clinical decision support page for further information (https://www.acr.org/Clinical-Resources/Clinical-Decision-Support). Appropriate pre-procedure consults should be done to ensure patient safety.

15.7 Complications

MIIP procedures provide less risk than open surgical procedures. However, there is still a potential for complications that can range from access site pain to life-threatening bleeding or respiratory complications. Careful planning including a review of the patient history and laboratory results as well as screening for appropriateness of moderate sedation is essential for the prevention or mitigation of complications. Table 15.4 includes a list of potential complications arising from MIIPs.

Table 15.4 Complications of MIIPs

Vascular	Bleeding
	Dissection
	Hematoma
	Perforation
	Pseudoaneurysm
	Reocclusion/intimal hyperplasia
	Thrombosis
	Vasospasm
	Off-target embolization
Contrast media	Allergic response/anaphylaxis
	Renal impairment/failure
Infection/sepsis	Iatrogenic
	Spread of infection from abscess or infected viscus
Over-sedation	Respiratory depression
	Need for reversal agents
Stroke	Embolic
	Hemorrhagic
Death	

15.8 Personnel

Radiology nurses are an integral part of the MIIPs team which includes the radiologist (or other provider), technologists, and, when needed, anesthesia personnel. In the case of hybrid procedures, other medical specialists may also be involved in the procedure. From the advanced practice nurse to the clinical nurse, their involvement facilitates the planning, performance, patient recovery, and follow-up for the procedures.

15.9 Conclusion

MIIPs have emerged through a rich history of innovation and disruptive technology that has created the opportunity to cure diseases virtually through a pinhole. The continued proliferation and adaptation of technology to new indications, especially to critically ill patients, will provide new challenges to nursing to keep step and provide informed care to patients across the MIIPs continuum.

Acknowledgments In appreciation for the images provided by Christopher J. Friend, MD, MBA.

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