Interventional Radiology Procedures: Addressing the Needs of the Cardiovascular Patient

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Interventional radiologists perform a wide range of procedures on virtually every organ system in the body. Technological advances continue to expand the repertoire of procedures in this field, challenging the frontiers of medical science and individual expertise. With cardiovascular disease being the number 1 cause of death in the United States and an aging population before us, physicians who perform minimally invasive procedures must be knowledgeable regarding unique aspects of cardiovascular management as it pertains to the catheterization laboratory. Specific areas addressed in this review include anesthesia, hypertension, and chronic kidney disease.
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In the current landscape where the rapid advancement of computing power meets with the ever-tightening economic constraints of managed health care, the opportunity for the development of minimally invasive, image-guided procedures is great. The promise of interventional radiology (IR) is to use cutting-edge technology to provide patients with safe and effective therapies that minimize their periprocedural discomfort, hospitalization time, and recovery time for a limitless host of conditions.

According to the American Heart Association (AHA), coronary heart disease is the leading cause of death in the United States and stroke is the third leading cause.[1] Diabetes mellitus affects 7%, nearly 21 million Americans, as of 2005

and by all accounts is on the rise. In a particularly alarming association, patients with diabetes have a 2- to 4-fold increased risk of stroke and heart related death compared with patients without diabetes.[2] With this magnitude of disease prevalence, it is incumbent upon the practitioner who endeavors to treat a broad variety of patients to be facile with the management of the cardiovascular patient.

The risk factors for cardiovascular disease are listed in Table 1.[3] The stereotypical patient that is seldom overlooked is an overweight, male smoker aged 65 years or greater. However, consistently successful clinical outcomes in a broad-based practice rely on identifying the uncharacteristic patient. With the well-established association between obesity, diabetes, and hypertension, it may be the middle-aged female who, when carefully questioned, relates that she also smokes and has a family history of heart disease. This woman may not be diagnosed with coronary artery disease (CAD) or peripheral arterial disease (PAD) simply because she has not undergone a thorough physical nor communicated a full health history. Identifying this patient in the interventional radiology clinic, applying appropriate medical management, and instituting lifestyle modification may save her significant risk for morbidity and mortality both periprocedurally and throughout her lifetime. After all, according to the National Institutes of Health, a person with PAD has a 6- to 7-fold increased risk of CAD, heart attack, stroke, or transient ischemic attack. Also, a person who has heart disease has a 33% chance of having lower extremity PAD.[4]

Table 1
Risk Factors for Cardiovascular Disease[3]

Fixed Risk Factors
Advanced age (> 65)
Male sex
Genetics
Modifiable Risk Factors
Tobacco
Cholesterol
Hypertension
Sedentary lifestyle
Obesity
Diabetes mellitus
Contributing Factors
Emotional stress
Excessive alcohol consumption

Cardiovascular Care in the IR Laboratory

Although it may seem obvious, the importance of spending a few extra minutes before a procedure to get to know a patient's history, particularly as it relates to cardiovascular disease or past cardiovascular events, cannot be overstated. Making this a mandatory part of the patient's preprocedural checklist does not guarantee a good clinical outcome, but it will undoubtedly aid in the detection of preventable catastrophes. However, forewarning of the patient's medical limitations will not typically result in the canceling of procedures. Rather, it will remind the operator to plan accordingly. This may be as simple as knowing how much a patient can tolerate in terms of pain, procedural duration, positioning, and so on. It may alert one to the need for added consultative support from the anesthesia department for particularly long or painfully stimulating procedures. For patients with congestive heart failure (CHF), careful monitoring of inputs and outputs during a long procedure may mean the difference between an uneventful recovery and a CHF exacerbation.

One of the aspects of IR that makes it so appealing is the constant technical and intellectual challenges that it presents. By its very nature, IR pushes the envelope of medical science. This may mean treating some of the hospital's sickest patients; those too sick to tolerate open surgery are frequently referred to IR. In these situations, regardless of the amount of preprocedural planning, cardiac emergencies will sometimes occur. In order to be fundamentally prepared to handle these situations, it is imperative that as many members of the IR team are not only certified but also adept at the AHA's curriculum on advanced cardiac life support.

With over 16 million Americans living with coronary heart disease, the likelihood of encountering such a patient on a routine basis in a typical IR practice is quite high, and even higher in hospital-based practices where the specialty prevails.[5] Although one of the fundamental tenets of image-guided, minimally invasive procedures is increased patient comfort, some procedures still cause painful stimuli and, at a minimum, evoke periprocedural patient anxiety. Both of these can lead to an increase in cardiac work with resultant adverse outcomes. However, appropriate procedural anesthesia can prevent some of these adverse events from occurring.

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Sedation and Analgesia

All patients should undergo a preprocedural evaluation and have their American Society of Anesthesiologists

Table 2
ASA Physical Status Classification System

P1	A normal healthy patient
P2	A patient with mild systemic disease
P3	A patient with severe systemic disease
P4	A patient with severe systemic disease that is a constant threat to life
P5	A moribund patient who is not expected to survive without the operation
P6	A declared brain-dead patient whose organs are being removed for donor purposes

ASA, American Society of Anesthesiologists. Reprinted with permission from the American Society of Anesthesiologists (520 N. Northwest Highway, Park Ridge, Illinois 60068-2573).[34]

(ASA) classification (Table 2) established. During this evaluation, specific attention should be directed toward cardiovascular risk factors, medications, prior cardiac events, and any prior requirement for cardiac intervention. These factors, among others, will help establish the patient's ASA category, which will help guide the level of sedation that is safely required and determine by whom it should be administered. Although most patients undergoing aortofemoral arteriography experience only mild discomfort,[6] those with limited cardiovascular reserve require careful handling. Individuals that may require anesthesia under the supervision of an anesthesiologist include those with severe cardiovascular disease, patients who have mild to moderate disease but are undergoing a more painful, noxious examination (eg, transjugular intrahepatic portosystemic shunt placement [Figure 1], biliary drainage, nephrostomy, vertebroplasty), or patients requiring significant diminution of motor activity to perform a satisfactory examination (many neurointerventional cases). Based on recommendations outlined in the ASA's Task Force on Sedation and Analgesia by Non-Anesthesiologists report, many institutions have established a moderate sedation (formerly referred to as *conscious sedation*) policy requiring that all patients in ASA category IV or V, as well as those considered a "difficult III," obtain consultation or supervision by an anesthesiologist.[7]

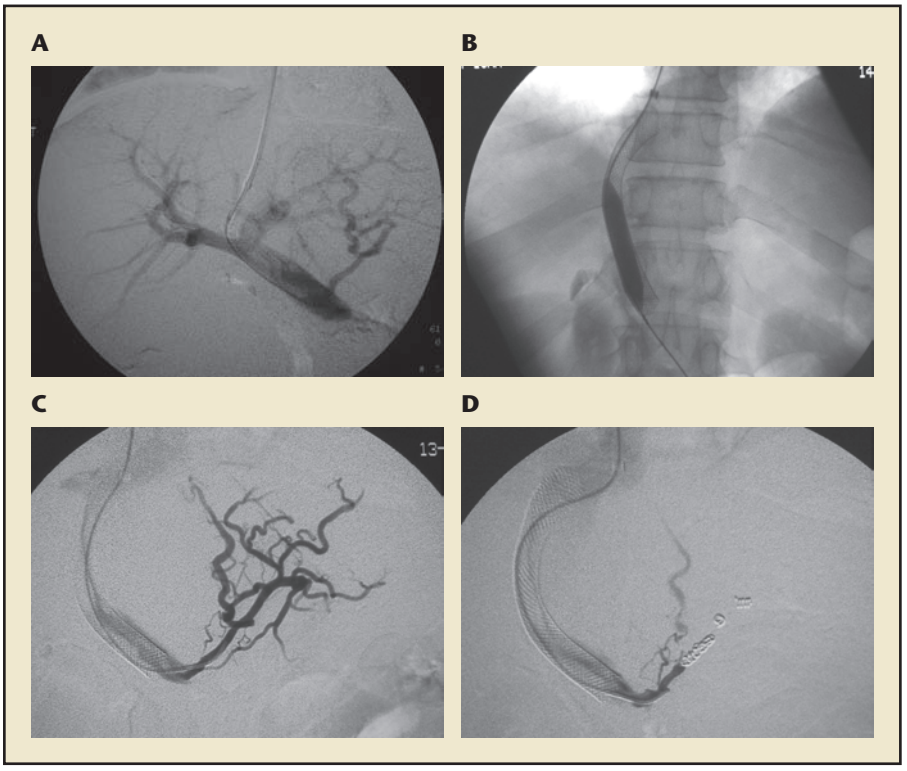
Moderate sedation is adequate for most procedures as it allows the patient to respond to verbal commands while still providing sufficient anxiolysis and analgesia. Additionally, patients who are moderately sedated remain capable of airway protection and baseline cardiovascular function is preserved.[8] As moderate sedation is typically administered by a sedation-qualified nurse (not an anesthesiologist) under the supervision of the physician performing the procedure, it is paramount that the medications likely to cause physiological derangements in cardiovascular function are well understood.

The 2 primary classes of medication that are typically administered during moderate sedation are sedatives or hypnotics and analgesics.

Sedatives/Hypnotics

Benzodiazepines are the most commonly used class of sedative or hypnotic agents used for moderate sedation. They have anxiolytic, antegrade amnestic, anticonvulsant, and skeletal muscle relaxant properties and work on the central nervous system (CNS) by interacting with gamma-aminobutyric acid receptors. They are metabolized in the liver by hepatic microsomal enzymes.[9] In the

Figure 1. *Transjugular intrahepatic portosystemic shunt formation for upper gastrointestinal bleed.* **(A)** *Portal venogram following successful transhepatic traversal from right hepatic to right portal vein.* **(B)** *Parenchymal tract dilated to 8 mm.* **(C)** *Following shunt formation, residual gastroesophageal varices visualized.* **(D)** *Varices eliminated by coil embolization of coronary vein.*



elderly and in those with chronic obstructive pulmonary disease (COPD), respiratory depression, including apnea, can be elicited at lower doses.[10] Although there are numerous agents, midazolam is the most commonly used in the IR suite owing to its rapid onset of action (within 2 minutes when given intravenously) and its duration of effect (lasting between 45 and 60 min). It has a low risk of respiratory depression, although there have been over 80 deaths reported with its use in a variety of procedures. Most of these deaths were the result of a respiratory cause, and in 57% of cases an opioid had also been administered.[11]

Propofol is a potent sedative usually reserved for use by anesthesiologists. It is given by continuous intravenous infusion, has a very rapid onset of action, and has a short duration of activity. Comparisons with midazolam, primarily in the gastroenterology field, have shown a side effect profile favoring propofol. However, propofol's increased propensity to cause hemodynamic depression, apnea, and loss of protective airway reflexes relegates it primarily to use under the supervision of an anesthesiologist, particularly in high-risk patients with cardiovascular and pulmonary risk factors.[8]

Analgesics

Although there is a vast universe of analgesic agents commercially available, opioids are predominantly used during moderate sedation. Specifically, fentanyl and morphine (morphine sulfate) are the most commonly employed. Fentanyl is a short-acting synthetic opioid that is roughly 80 times as potent as morphine. It has a rapid onset and short duration of action that make it well suited to providing a titratable effect during moderate sedation procedures. Because fentanyl causes respiratory depression and has a synergistic effect with benzodiazepines, it should be administered in incremental doses. The depressive effect on the respiratory system can last as long as 4 hours more than the analgesic effect, which makes postprocedure monitoring important in vulnerable patients.[9] Morphine is the prototype opioid, and it is typically given in incremental doses of 2 mg. Compared with fentanyl, morphine is less suited for use in moderate sedation because of its long duration of activity and difficulty in titration.

A thorough understanding of the pharmacology of sedative agents is critical to ensuring favorable procedural outcomes. An important step toward this understanding is recognizing the patients who have increased susceptibility to adverse outcomes as they pertain to the medications already discussed. The cardiovascular patient possesses unique risk factors related to CAD and PAD, and often carries other associated risk factors such as obesity, emphysema, CHF, and chronic kidney disease (CKD). For intuitive reasons, obese patients are at increased risk of gastroesophageal reflux and airway obstruction during sedation procedures, but they are also at increased risk of oversedation. Therefore, these patients should be dosed according to lean body mass rather than total body mass. Adjunctive measures such as periprocedural administration of an H_2 blocker or metoclopramide may also help obviate gastrointestinal complications.

For patients with COPD and/or CHF, patient positioning can be a critical consideration. Even though the supine position can be challenging enough for many of these patients, some interventional procedures, such as nephrostomy tube placement, spine intervention, or biopsy, require prone positioning. For patients with these conditions, particularly those who are obese, it is often extremely difficult to sustain respiratory and hemodynamic homeostasis. Because their respiratory efforts are severely impaired, it can lead to hypoxia precipitated by anxiety and tachycardia. This, coupled with the effects of sedation, can lead to precipitous respiratory compromise and even collapse. These circumstances necessitate careful planning and consideration. They can often be optimized with support of an anesthesiologist who will take positive control of the airway and has the ability to carefully regulate the hemodynamic parameters that can become deranged during these procedures. Steady-state analgesia can also be used, which reduces cardiac work and preserves consistent myocardial oxygen delivery.

Chronic Kidney Disease

A major subgroup of the IR patient population includes patients with CKD. The number of Americans who rely on hemodialysis (stage V CKD) is markedly on the rise, which also means that patients with stage III and IV CKD are increasingly becoming prevalent. This makes it incumbent upon the procedural physician to take advantage of all renoprotective measures available to stem the growth of the dialysis population. Kidney disease is an independent risk factor for cardiovascular disease, and when paired with hypertension and diabetes it places a person at a substantially increased risk of cardiac death. In fact, according to the American Society of Nephrology, patients with end-stage renal disease are 10 times to 30 times more likely to die of cardiovascular disease than patients without renal failure.[12]

Resulting from the nearly ubiquitous use of iodinated contrast in interventional radiology, contrast-induced acute kidney injury (CIAKI) plays a substantial role in potential renal morbidity. Although other factors such as hypotension and atheroembolic phenomena can play a role in iatrogenic renal dysfunction, CIAKI is the largest single contributor to hospital-acquired renal failure in the IR patient. This problem is critical because multiple studies have demonstrated increased in-hospital and 1-year mortality in percutaneous coronary intervention patients who develop CIAKI.[13] The recent literature is confusingly rife with studies that have endeavored to find an effective and practical solution to this problem. The leading strategies are presented in Table 3,[14-21] but are limited by the fact that, with the exception of a normal saline hydration protocol, consistently favorable results have been difficult to reproduce.

The CIN Consensus Working Panel has advocated a few strategies for the prevention of contrast-induced nephropathy. These include no special precautions for patients with estimated glomerular filtration rate (eGFR) > 60 mL/min; hospital admission, nephrology consultation, and dialysis planning for patients with eGFR > 30 mL/min; and, for patients with eGFR between 30 mL/min and 60 mL/min, intravenous volume expansion, limited volume of contrast media (CM), consideration of choice of CM osmolality (low osmolal vs iso-osmolal), and use of potentially beneficial pharmacological agents.[22]

Table 3
Leading Strategies for Prevention of Contrast-Induced Nephropathy

Hydration with normal saline
Administration of N-acetylcysteine
Sodium bicarbonate infusion
Use of nonionic, low osmolal, or isosmolal contrast
Limit contrast volume
Other antioxidants (theophylline, ascorbic acid)

Another consideration in the precipitation of renal dysfunction in the IR suite is hypotension. However, a more common scenario is related to induction of a pre-renal state during preprocedural fasting and inadequate attention to periprocedural hydration. As patients are routinely instructed to take nothing by mouth after midnight before their procedure, it is worrisome that they may actually be dehydrated at the time they receive an iodinated contrast load and blood pressure reducing sedation agents. These factors result in a perfect storm that can have disastrous consequences in both the short and long term. Surgical data confirms that hypotension is the leading cause of hospital-acquired renal failure,[23] and we have already discussed how hydration is the only undisputed strategy for prevention of CIAKI. Thus, it stands to reason that we should embrace a more liberal policy of oral preprocedural hydration and should in fact strive for a urine output of 150 cm^3/h at the time of the procedure to confirm adequate blood volume. It is important to note, however, that studies have shown oral hydration with hypotonic solutions, such as water, are potentially deleterious, and that oral hydration should be done with isotonic solutions.[24]

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Hypertension

Hypertension is defined as systolic blood pressure greater than 140 mm Hg and/or diastolic blood pressure greater than 90 mm Hg. It affects more than 40 million Americans and is the most common reason for physician office visits in the United States.[25] As a result of its high prevalence and direct correlation with CAD and stroke, the United States Preventive Services Task Force recommends that all patients aged 21 years or older be screened when visiting a physician.[26] Even though the burden of hypertension diagnosis and management resides with the primary care physician, it is well accepted that a high association with cardiovascular disease remains, and inadequate management of hypertension may be associated with the increasing incidences of CHF and stage V CKD.[27,28]

Although cardiovascular disease is a multifactorial entity, hypertension plays a substantial role in 3 end-organ complications: cardiac disease, stroke, and CKD. In the case of cardiac disease, hypertension is associated with CAD, left ventricular hypertrophy with subsequent CHF, arrhythmias, and sudden cardiac death.[29,30] Moreover, it is the leading risk factor for cerebrovascular accident and is also a risk factor for intracerebral hemorrhage.[27] Concerning the role of hypertension in CKD, hypertension and diabetes are the leading causes of end-stage renal disease in America.[12]

Clearly these 3 categories of patients make up a large proportion of the individuals seen in a typical IR practice. Therefore, understanding

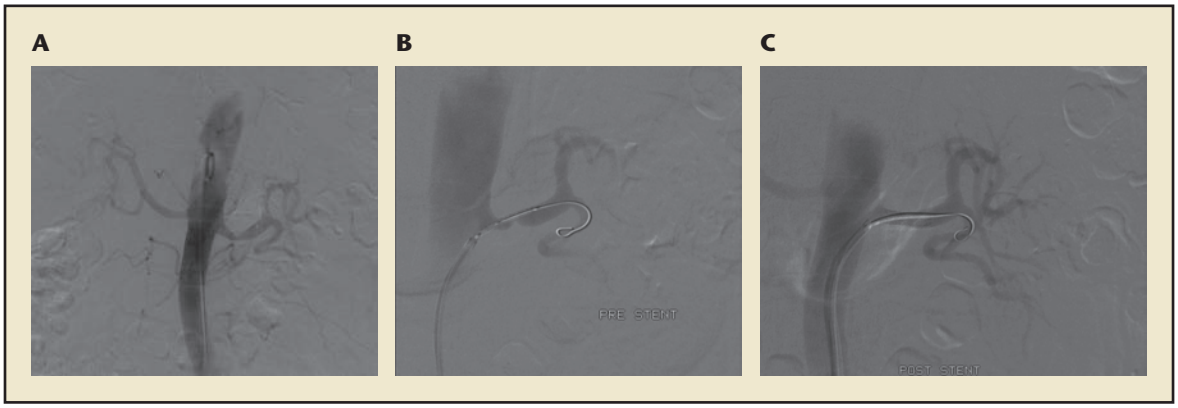
how to manage the blood pressure of these patients while they are undergoing image-guided procedures is of paramount importance. With a few rare exceptions, hypertensive patients are instructed to continue taking their outpatient oral antihypertensive regimen up to the time of their procedure. This is of greater importance in patients who take beta-blockers or central sympatholytics, such as clonidine, as abrupt cessation can result in rebound hypertension and myocardial ischemia.[27]

Special consideration is reserved for patients undergoing renal artery revascularization procedures, including angioplasty for conditions such as fibromuscular dysplasia or angioplasty with stenting for renal artery stenosis secondary to atherosclerosis (Figure 2). These patients are unique in that the procedure causes abrupt changes in the renin-angiotensin-aldosterone axis, which can lead to erratic blood pressure control in the immediate postprocedural period. Hypotension is usually successfully managed with intravenous fluid boluses, but considering the suspension of diuretics and angiotensin-converting enzyme inhibitors before the procedure is warranted. [27]

Carotid artery stenting procedures also present a unique category for blood pressure management both during and following the procedure (Figure 3). In the patient who has not previously undergone carotid endarterectomy, stretching of the carotid bulb during balloon dilatation causes sympathetic inhibition, which results in bradycardia and hypotension. Paying particularly close attention to hemodynamic monitoring during this phase of the procedure is mandatory, often requiring expeditious administration of intravenous atropine. Patients who have already undergone ipsilateral carotid artery revascularization, particularly by endarterectomy, have a much lower incidence of bradycardia or hypotension than their primary treatment counterparts.[31] This may result from denervation of the sinus nerve of Hering, a branch of the glossopharyngeal nerve. When intact, this stimulates a reflex arc resulting in reciprocal change in peripheral sympathetic and vagal neural activity, thereby causing bradycardia and hypotension. Stent placement may promote persistent stimulation of these receptors.[32] Additionally, as a result of their underlying condition, patients with carotid artery stenosis are also more prone to hemodynamic lability following revascularization. This means they require careful and ongoing hemodynamic monitoring to ensure appropriate cerebral perfusion. Intraprocedural hemodynamic lability appears to be predictive of postprocedural lability, and intensive care unit management may help identify these patients to limit potential complications.[33]

The remainder of IR patients who are not undergoing carotid or renal revascularization still generally receive moderate sedation to facilitate their procedure. The typical agents, midazolam (most common) and propofol, are each vasoactive and can result in unpredictable changes in blood pressure, particularly in patients who take antihypertensives. As discussed earlier, it is imperative that the individual administering the medication and the supervising physician have a thorough understanding of its hemodynamic effects in order to maintain a safe and effective level of sedation. For this reason, in IR these medications are generally administered in incremental doses rather than boluses to titrate to the desired effect and minimize the likelihood of a severe derangement in blood pressure or CNS depression.

Figure 2. *Left renal artery stent placement for hypertension.* **(A)** *Anteroposterior abdominal aortogram reveals high-grade stenosis of left renal artery.* **(B)** *Selective left renal arteriogram prior to stent placement.* **(C)** *Left renal arteriogram following balloon expandable stent placement.*



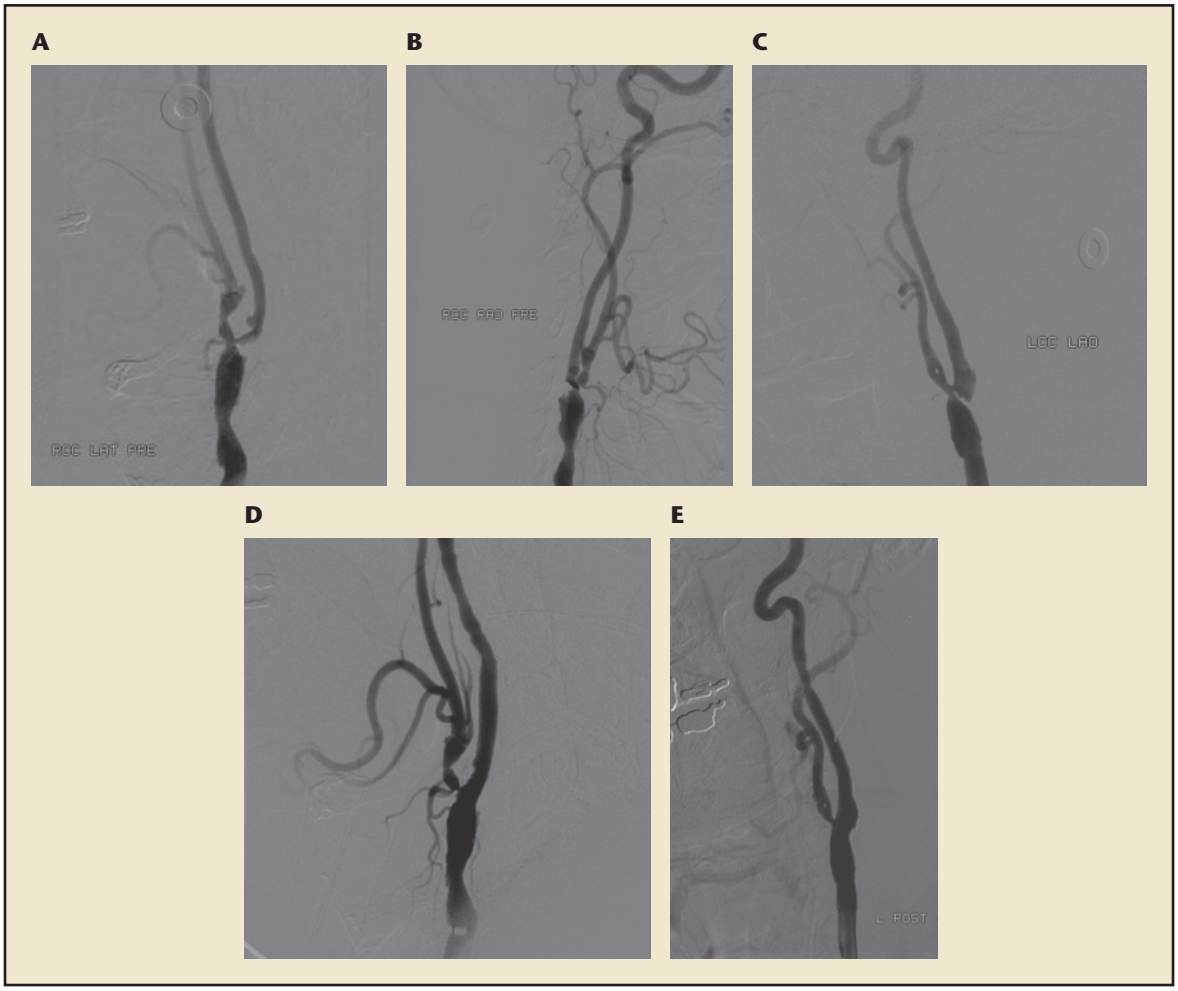


Figure 3. *Man aged 62 years status post bilateral carotid endarterectomy.* **(A)** *Right anterior oblique, and* **(B)** *lateral common carotid arteriograms reveal high-grade irregular stenosis of proximal right ICA.* **(C)** *Left anterior oblique common carotid arteriogram reveals high-grade proximal left ICA stenosis.* **(D)** *Right carotid arteriogram following stent placement.* **(E)** *Left carotid arteriogram following stent placement performed 1 month following right-sided stent placement. ICA, internal carotid artery.*

In patients with elevated, difficult to control hypertension, some advocate minor technical modifications, such as the use of a single-wall access needle or maintaining a smaller arteriotomy, when feasible. Seldom is a procedure cancelled or postponed as a result of poor blood pressure control. However, a non-emergent procedure in a symptomatic patient would certainly present an exception. Some suggest that with a persistent systolic blood pressure $>$ 180 mm Hg or diastolic blood pressure $>$ 100 mm Hg following administration of sedation medications and antihypertensives, postponement of the procedure or a more thorough investigation for possible alternative imaging modalities should be considered.[27]

Conclusions

In the 1960s, a visionary named Charles Dotter effectively founded a new specialty: interventional radiology. Today, IR is at the center of an ongoing medical revolution in which image-guided, minimally invasive procedures have supplanted many traditional, open, and more-invasive therapies for conditions ranging from CAD and PAD to portal hypertension. Patients today are sophisticated consumers who research their disease and demand the latest, most cutting-edge treatments, which must be safe, effective, and allow them to return to their active lifestyles with minimal morbidity. It has therefore become incumbent on the traditional players in this arena (such as radiologists and cardiologists), as well as the relative newcomers (including nephrologists and

neurologists), to become adept at periprocedural practices and ongoing medical management of patients with a host of comorbidities. These include patients with diabetes, hypertension, CKD, cerebrovascular disease, cirrhosis, and a myriad of others. Cardiovascular disease is a common thread among this group and can be a source of devastating complications when not managed properly. Although the minimally invasive approach to these procedures promises less morbidity, high-risk patients and high-risk procedures will always exist. Optimal outcomes are ensured by doing what our surgical colleagues have done for decades prior to an open procedure: get to know patients thoroughly ahead of time, formulate risk stratification, and obtain consultation from appropriate medical specialists when necessary. ■

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Main Points

- Interventional radiology (IR) uses cutting-edge technology to provide patients with safe and effective therapies that minimize their periprocedural discomfort, hospitalization time, and recovery for a limitless host of conditions.
- Consistently successful clinical outcomes rely on identifying the uncharacteristic patient. It may be someone undiagnosed simply because he or she has not undergone a thorough physical nor communicated a full health history.
- Although image-guided, minimally invasive procedures promise increased patient comfort, some procedures still cause painful stimuli and cause periprocedural patient anxiety. Both of these can lead to an increase in cardiac work with resultant adverse outcomes.
- The 2 primary classes of medication that are typically administered during moderate sedation are sedatives or hypnotics and analgesics. A thorough understanding of the pharmacology of sedative agents is critical to ensuring favorable procedural outcomes.
- A major subgroup of the IR patient population includes patients with chronic kidney disease (CKD). Given the widespread use of iodinated contrast in IR, contrast-induced nephropathy plays a substantial role in potential morbidity. The leading strategies are limited by the difficulty of producing consistently favorable results.
- Although cardiovascular disease is a multifactorial entity, hypertension plays a substantial role in 3 end-organ complications: cardiac disease, stroke, and CKD. Patients with these conditions make up a large proportion of the individuals seen in a typical IR practice. Therefore, it is paramount to understand how to manage the blood pressure of these patients while they are undergoing image-guided procedures.

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