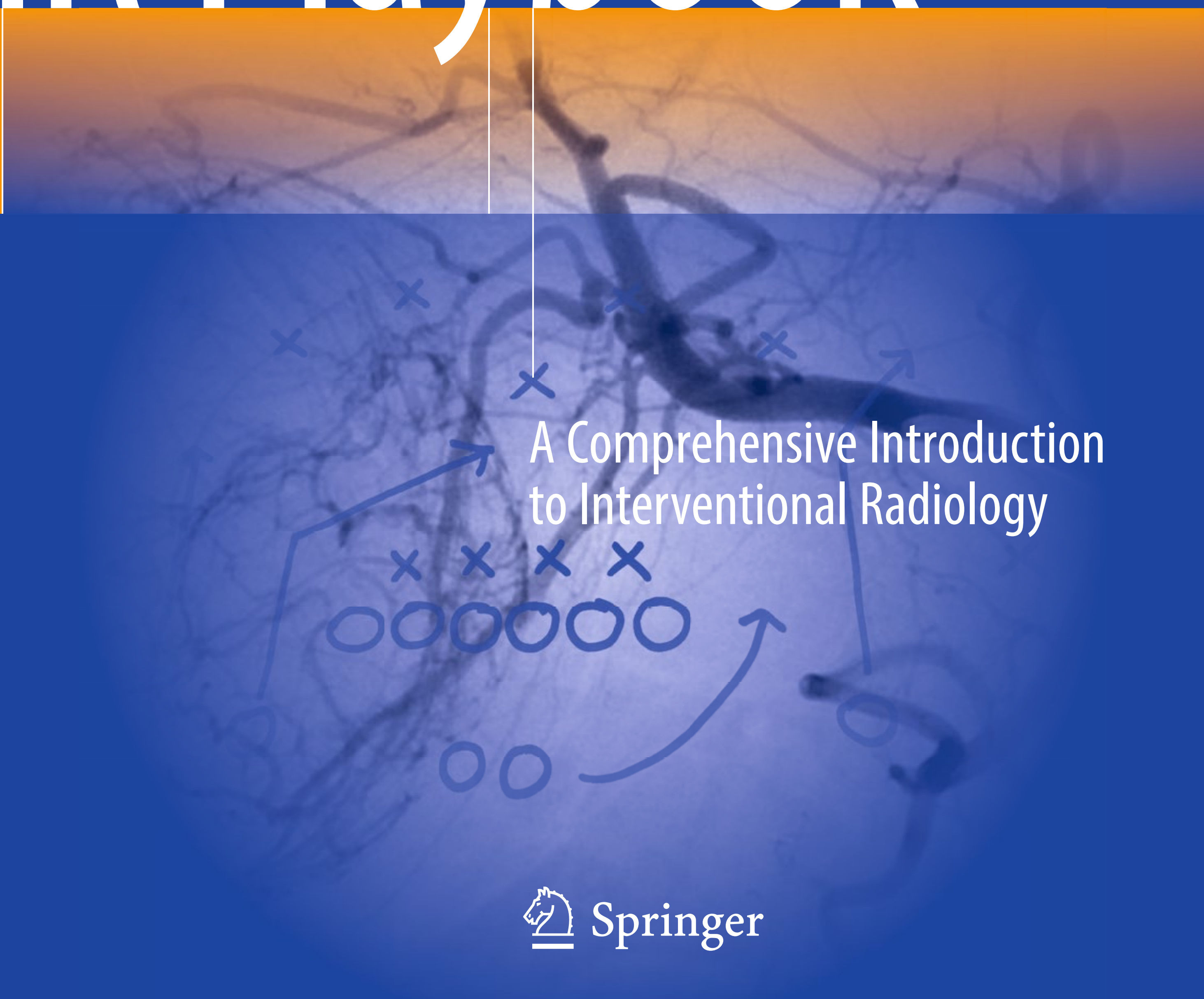
Nicole A. Keefe
Ziv J Haskal
Auh Whan Park
John F. Angle
Editors

IR Playbook



A Comprehensive Introduction to Interventional Radiology

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Editors
Nicole A. Keefe
Department of Radiology and Medical Imaging
University of Virginia
Charlottesville, VA, USA

Ziv J Haskal
Department of Radiology and Medical Imaging
University of Virginia
Charlottesville, VA, USA

Auh Whan Park
Department of Radiology and Medical Imaging
University of Virginia
Charlottesville, VA, USA

John F. Angle
Department of Radiology and Medical Imaging
University of Virginia
Charlottesville, VA, USA

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Thank you to my parents, Doug and Bridget, my sister, Sabrina, and my wonderful husband, Phil, for their unwavering support and sacrifice. Thank you to my numerous mentors, particularly Geogy Vatakencherry, Reza Rajebi, and my brilliant coeditors for always encouraging me to strive for more.

Nicole A. Keefe

To my wife, Dina, my daughters, Yael and Aliza, and my parents Ruth and Haim, who taught me that life does not follow a playbook. And to the newest members of the IR team: think, dream, inspire, and create. Write your own playbooks.

Ziv J Haskal

I would really like to express my heartfelt respect and gratitude to all of my patients who have always been great teachers in addition to the distinguished colleagues and faculty members at UVA, IR families and communities around the world (KSIR/SIR/Global IR). "We Are All Truly Connected."

Auh Whan Park

To my wife and children for all their support and to my parents for all their inspiration.

J. Fritz Angle

A Message to Students of IR[1]

There has never been a better time to become an interventional radiologist. But then, it has always been the "best time" to be one. The origins of the specialty can be traced to a cadre of early "cowboys" who often had to invent procedures and devices on the fly to treat patients. In some cases, this impulse solved unique anatomic or pathologic complexities, while in others, it created entirely new therapies—be it the first TIPS, prostate embolization, or radioembolization. The conditions we treat have changed as other specialties have embraced image-guided approaches or evidence has directed us to reevaluate ours. Twenty years ago, few of us might have imagined our essential involvement today in women's health, oncology, and venous disease or in managing clinics and clinical services.

The essential need for image-guided interventional services in any modern hospital is both established and recognized worldwide. The public will recognize your specialty. The American Board of Medical Specialties has acknowledged its value by approving it as a stand-alone specialty in American medicine. Other countries will inevitably follow this model.

What first draws most of us into the specialty? Is it a charismatic mentor, witnessing a defining medical case, or publishing a paper? Or is it the adrenaline thrill of getting to handle the tools and seeing the immediate effect? There is no discounting the endorphin thrill of deploying the stent graft or embolization coil; it is like playing video games with human stakes. Bleeding stops, blood pressure rises, pressors cease, and patients are extubated and go home—all these amazing facts accomplished just through thread-sized tubing. This intoxicating hunger doesn't dim with time—witness the enduring success of Extreme IR course, wherein standing-room-only crowds come to see an endless series of rapid-fire adventures that have gone well—or not so much.

But with maturity, one's satisfactions must shift from congratulatory cases to a profound belief that procedural medicine can be perfected while accepting that it cannot. And yet we must practice as if it can be, by constantly seeking to tune approaches, skills, techniques, and devices so that the most complex case appears controlled and mundane. Expertise means anticipating variance and controlling it to eliminate the drama. These satisfactions refocus us to the very reasons we chose medicine as a profession—the sustaining human interactions with our patients as we hopefully help them and as they buoy us by trusting and honoring while allowing us to participate in their care. Keep that ever in your minds.

We must evolve from cowboys to legionnaires. Where there is scientific evidence, we should methodically march in support of it, applying it to our own patients. This means maintaining a lifelong commitment to study, reading journals, attending congresses, and Socratic questioning—what is new, what has changed, and whether evidence supports clinical practice. Our literature reflects this evolution. It is gradually but definitively changing direction, from

[1] Reprinted from Haskal ZJ, From the Editor: A Message to Students of IR, Journal of Vascular and Interventional Radiology, Sept 2017, 28(9), with permission from Elsevier.

case reports and retrospective reviews to methodical prospective protocol-driven research and systematic analyses. The next generation of interventional radiologists and endovascular specialists will undoubtedly innovate—creating new procedures, expanding into unrecognized areas, and devising new devices. Equally, we must continue to drive up the levels of evidence, focus upon meaningful quality of research, and endlessly read, question, and adopt.

Ziv J Haskal, MD, FSIR, FACR, FAHA
Editor in Chief, *Journal of Vascular and Interventional Radiology*

Preface

Some specialties evolve to understand a disease state or organ. Others are born out of the revelation that imaging technology could guide the development of many procedures and revolutionize medicine. Since its genesis, interventional radiology (IR) has evolved to meet the growing demands of patient care by applying cutting-edge technology to minimally invasive image-guided procedures. Interventionalists thrive on the desire to innovate, replacing the outdated with the updated, acting as an adjuvant to the existing, and developing novel procedures where there was no previous treatment. We attract high-achieving, technology-loving, problem-solving medical professionals.

IR is a clinical specialty. We admit patients to the hospital, provide expert consultation, make hospital rounds, and maintain busy clinics. The vast and ever-changing scope of IR makes it difficult for patients and referring providers to grasp the breadth of our specialty. You will need to continuously educate those around you about IR. Don't be discouraged by this; instead, revel in the fact that we are at the forefront of medicine.

The foundation of IR builds upon a solid understanding of diagnostic radiology (DR), which distinguishes it from other specialties that perform image-guided procedures. While IR may seem far removed from the dark rooms of diagnostics, focus on your imaging training to master the specialty. Being dual certified in DR and IR allows interventionalists to accurately interpret the imaging our patients receive, recommend appropriate follow-up studies, and conceptually understand how to best utilize imaging to perform procedures. Continued innovation using different imaging modalities can only arise from understanding each modalities benefits and limitations.

A note to our future IR colleagues: though this textbook covers current IR procedures, remember that medicine is a holistic pursuit. You should learn from other specialties and look for opportunities to utilize IR procedures in novel ways. Good diagnostics, interventions, and outcomes for patients should always be the goal. Furthermore, get involved in IR at the local, regional, or national level and never lose sight of our foundation in innovation for the betterment of patient care.

With the advent of the IR pathway, the focus of education must shift to include medical students and residents. The IR/DR residency has established programs and criteria to meet the growing demand. When I was a medical student, I found a paucity of IR resources catered toward the student and young trainee. This textbook was developed to fill that void and serve as a much-needed resource for the future generation of interventional radiologists. The first section is designed to give readers an introduction to IR including radiation safety, commonly used devices, patient care, and anatomy. The remaining chapters cover procedures including pathophysiology, indications for treatment, as well as alternative treatments before delving into interventional therapy. If you only have a few minutes before a case starts, read the key point boxes which are high-yield pearls along with the "How To" before you step into the room.

The editors of this book have a passion for IR and trainee education. I hope this book spurs your enthusiasm for the field and serves as a springboard to launch your career in IR.

Charlottesville, VA, USA — Nicole A. Keefe

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Part XII Neuro-IR

Contributors

Solomon Abay University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Nadine Abi-Jaoudeh University of California Irvine, Department of Radiological Sciences, Orange, CA, USA

Siobhan E. Alexander University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

John F. Angle Division of Interventional Radiology, University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Bulent Arslan Rush University Medical Center, Department of Radiology, Division of Interventional Radiology, Chicago, IL, USA

Gabriel Bartal Diagnostic and Interventional Radiology, Meir Medical Center, Kfar Saba, Sackler Medical School, Tel Aviv University, Tel Aviv, Israel

James F. Benenati Miami Cardiac and Vascular Institute, Baptist Hospital of Miami, Department of Interventional Radiology, Miami, FL, USA

Alok B. Bhatt Miami Cardiac and Vascular Institute, Baptist Hospital of Miami, Department of Interventional Radiology, Miami, FL, USA

Vivian Lee Bishay Icahn School of Medicine at Mount Sinai, Divisions of Interventional Radiology, New York, NY, USA

Luke A. Byers University of Colorado, Department of Radiology, Aurora, CO, USA

James Chen Division of Interventional Radiology, Perelman School of Medicine at the University of Pennsylvania, Department of Radiology, Philadelphia, PA, USA

Andrew Chi University of Colorado, Department of Radiology, Denver, CO, USA

Benjamin N. Contrella University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Allan M. Conway The AVM Center of New York at Lenox Hill, Lenox Hill Hospital, Northwell Health, New York, NY, USA

Michael D. Dake Stanford University Medical Center, Department of Cardiothoracic Surgery, Stanford, CA, USA

Michael Darcy Chief of Interventional Radiolgy, Mallinckrodt Institute of Radiology, Washington University in St Louis, St. Louis, MO, USA

Mitchell Daun University of California, Irvine Medical Center, Department of Radiology, Orange, CA, USA

Daniel M. DePietro Perelman School of Medicine of the University of Pennsylvania, Philadelphia, PA, USA

Arya F. Derakhshani NYU Langone Medical Center, Department of Radiology, New York, NY, USA

Adam Donithan University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Yasser J. El-Abd University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Aaron M. Fischman Icahn School of Medicine at Mount Sinai, Department of Radiology, New York, NY, USA

Ron C. Gaba University of Illinois Hospital, Department of Radiology, Chicago, IL, USA

Brian C. Gardner University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Joseph J. Gemmete University of Michigan Hospitals, Department of Radiology and Neurosurgery, Ann Arbor, MI, USA

Julius Griauzde University of Michigan Hospitals, Department of Radiology, Ann Arbor, MI, USA

Michael J. Hagar George Washington University Hospital, Department of Diagnostic Radiology, Washington, DC, USA

Klaus D. Hagspiel Division of Noninvasive Cardiovascular Imaging, Department of Radiology and Medical Imaging, University of Virginia Health System, Charlottesville, VA, USA

Ziv J Haskal University of Virginia School of Medicine, Department of Radiology and Medical Imaging, Interventional Radiology Division, Charlottesville, VA, USA

Paul Haste Indiana University School of Medicine, Department of Radiology, Indianapolis, IN, USA

Stephen Haug University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Ryan Hickey New York University Langone School of Medicine, Department of Radiology, Division of Vascular & Interventional Radiology, New York, NY, USA

Timothy C. Huber University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Ross B. Ingber SUNY Downstate Medical Center, College of Medicine, Brooklyn, NY, USA

Maxim Itkin Perelman School of Medicine of the University of Pennsylvania, Diagnostic Imaging, Philadelphia, PA, USA

Jessie Jahjah University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Mary E. Jensen University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Matthew S. Johnson Department of Radiology and Imaging Sciences, Indiana University School of Medicine, Indianapolis, IN, USA

John A. Kaufman Department of Interventional Radiology, Oregon Health & Science University/Dotter Interventional Institute, Portland, OR, USA

Nicole A. Keefe University of Virginia Health System, Department of Radiology and Medical Imaging, Diagnostic and Interventional Radiology, Charlottesville, VA, USA

Robert K. Kerlan Jr. Emeritus Professor of Clinical Radiology and Surgery, Department of Radiology and Biomedical Imaging, University of California, San Francisco, CA, USA

Minhaj S. Khaja University of Michigan Hospital and Health Systems, Department of Radiology, Ann Arbor, MI, USA

Akhil Khetarpal VCU Health System, Department of Radiology, Richmond, VA, USA

Christopher Kim University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Rohit Koppula University of Virginia, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Arun Krishnaraj Division of Body Imaging, UVA School of Medicine, University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Edward Kuoy University of California Irvine, Department of Radiological Sciences, Orange, CA, USA

Jeanne LaBerge Emeritus Professor of Radiology, Department of Radiology and Biomedical Imaging, University of California, San Francisco, CA, USA

Andy Lee Beth Israel Deaconess Medical Center, Department of Vascular Surgery, Boston, MA, USA

Robert J. Lewandowski Northwestern University, Feinberg School of Medicine, Department of Radiology, Division of Vascular and Interventional Radiology, Chicago, IL, USA

Andrew J. Lipnik University of Illinois Hospital, Department of Radiology, Chicago, IL, USA

Alan H. Matsumoto University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

David M. Mauro University of North Carolina, Department of Radiology, Chapel Hill, NC, USA

Nasya Mendoza-Elias University of Illinois Hospital, Department of Radiology, Chicago, IL, USA

Gregory J. Nadolski II Perelman School of Medicine of the University of Pennsylvania, Diagnostic Imaging, Philadelphia, PA, USA

Kari J. Nelson Vascular and Interventional Radiology, University of California, Irvine Medical Center, Department of Radiological Sciences, Orange, CA, USA

Patrick T. Norton University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Paul J. O'Connor Icahn School of Medicine at Mount Sinai, Divisions of Interventional Radiology, New York, NY, USA

Amish Patel NYU Langone Medical Center, Department of Radiology/Vascular and Interventional Radiology, New York, NY, USA

Jeffrey S. Pollak Yale University School of Medicine and Yale-New Haven Hospital, Department of Radiology and Biomedical Imaging, Section of Vascular and Interventional Radiology, New Haven, CT, USA

Dheeraj K. Rajan University Health Network, University of Toronto, Medical Imaging, Toronto, ON, Canada

Howard M. Richard University of Maryland School of Medicine, University of Maryland Medical Center, Division of Interventional Radiology, Department of Diagnostic Radiology and Nuclear Medicine, Baltimore, MD, USA

Anne Roberts UC San Diego Medical Center, Department of Radiology, La Jolla, CA, USA

Paul J. Rochon University of Colorado, Department of Radiology, Aurora, CO, USA

Robert J. Rosen The AVM Center of New York at Lenox Hill, Lenox Hill Hospital, Northwell Health, New York, NY, USA

John H. Rundback Holy Name Medical Center, Interventional Institute, Teaneck, NJ, USA

Saher S. Sabri University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Abhijit L. Salaskar George Washington University Hospital, Department of Interventional Radiology, Washington, DC, USA

Riad Salem Northwestern University, Feinberg School of Medicine, Department of Radiology, Division of Vascular and Interventional Radiology, Chicago, IL, USA

Shawn Sarin George Washington University Hospital, Department of Vascular and Interventional Radiology, Washington, DC, USA

John H. Schilling University of Illinois Hospital, Department of Radiology, Chicago, IL, USA

Sandra L. Schwaner University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

William M. Sherk University of Michigan Health System, Department of Radiology, Ann Arbor, MI, USA

Ji Hoon Shin University of Ulsan College of Medicine, Asan Medical Center, Department of Radiology, Seoul, Republic of Korea

Akhilesh Sista NYU Langone Medical Center, Department of Radiology/Vascular and Interventional Radiology, New York, NY, USA

S. William Stavropoulos Division of Interventional Radiology, Perelman School of Medicine at the University of Pennsylvania, Department of Radiology, Philadelphia, PA, USA

Katherine Sterner University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

James R. Stone University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Dylan Suttle University of Virginia Health System, Department of Radiology and Medical Imaging, Interventional Radiology, Charlottesville, VA, USA

Malcolm K. Sydnor VCU Health System, Department of Radiology, Richmond, VA, USA

Jordan Tasse Rush University Medical Center, Department of Radiology, Division of Interventional Radiology, Chicago, IL, USA

Jimmy Ton University of California Irvine, Department of Radiological Sciences, Orange, CA, USA

Scott O. Trerotola Perelman School of Medicine of the University of Pennsylvania, Philadelphia, PA, USA

Ulku Cenk Turba Rush University Medical Center, Department of Radiology, Division of Interventional Radiology, Chicago, IL, USA

Andre Uflacker University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Leonardo I. Valentin Massachusetts General Hospital, Division of Interventional Radiology, Boston, MA, USA

Eliseo Vano Department of Medical Physics, San Carlos University Hospital – Complutense University, Madrid, Spain

T. Gregory Walker Massachusetts General Hospital, Division of Interventional Radiology, Boston, MA, USA

Luke R. Wilkins University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

David M. Williams University of Michigan Hospital and Health Systems, Department of Radiology, Ann Arbor, MI, USA

Adam B. Winick University of Virginia Health System, Department of Radiology and Medical Imaging, Charlottesville, VA, USA

Part I

Radiology Basics

1 Evolution of IR Training

John A. Kaufman

The most important individuals in any specialty are its trainees. Although medical students, residents, and fellows often feel that they are at the low end of the professional hierarchy, they are in reality far more valuable than their teachers. Without trainees there is no future. At any given moment, these are the people who have the most potential to make the greatest contributions over time. For this reason, training in interventional radiology (IR) has been a major focus of the specialty since its earliest years and continues to evolve and grow in importance. The purpose of this chapter is to briefly review the history of IR training as the backdrop for the latest step in evolution, the IR residency.

IR was not fully conceptualized or formed at a specific time or place but was gradually defined by many different individuals all over the world. The history of the specialty in the United States is just one of many histories, all equally fascinating and instructive. For the purposes of this chapter, training as it evolved in the United States will be discussed.

The influence of Europe on IR in the United States cannot be understated. Sven Seldinger (of the Karolinska Institutet in Sweden) invented percutaneous catheterization in 1953 [1]. Previous to that Berberich and Hirsch had demonstrated peripheral angiography and venography (1923), Egas Moniz of Portugal had described cerebral angiography (1927), Reynaldo dos Santos performed direct puncture aortography (1929), and Werner Forssmann of Germany catheterized his own heart (1929) [2, 3]. As a result, Europe was an early destination for radiologists seeking training in invasive diagnostic techniques [4].

In the 1960s, training in angiography could be obtained in only a few US centers. Among the first programs were those located at the University of Oregon (Charles Dotter), Stanford University in California (Herbert Abrams), and the University of Minnesota (Kurt Amplatz) [4]. Training was not standardized, and there was no formal regulation or certification. The length of training was also variable, with some programs requiring a 2-year commitment. Most trainees had already completed a diagnostic radiology (DR) residency. The graduates of these programs, as well as individuals originally from Europe, Latin America, and Asia created new training programs in other cities such that by the 1980s the then Society of Cardiovascular and Interventional Radiology (SCVIR, now Society of Interventional Radiology, SIR) recognized the need to develop a standardized curriculum. The SCVIR formed a committee to seek formal recognition of these training programs by the Accreditation Council of Graduate Medical Education (ACGME) [5].

Accreditation for Vascular and Interventional Radiology fellowships first became available from the ACGME in 1991. Eligibility for the fellowship required completion of a diagnostic radiology residency, with a fellowship duration of 1 year in length. Standards for faculty, resources, didactics, and clinical content had to be met in order for a program to receive accreditation. This was a new concept for IR fellowships, which had been used to self-regulation at the program level for many decades. In 1994, the American Board of Medical Specialties (ABMS) recognized Vascular and Interventional Radiology (VIR) as a subspecialty of Diagnostic Radiology, and the American Board of Radiology (ABR) began offering subspecialty certification in VIR by examination. Eligibility for examination was initially open to both interventionalists who had completed an ACGME fellowship and those who had not but was later restricted to graduates of accredited VIR fellowships. As a result, all VIR fellowships became accredited by the ACGME.

The impact of this first step, accreditation, was enormous. There was initially much controversy over the concept of any sort of specialization in diagnostic radiology and subsequently over certification of special competence. The issues of disenfranchisement of diagnostic radiologists performing interventional procedures who were not trained in VIR fellowships and the potential weakening of the structure of diagnostic radiology by differentiated subgroups were of great concern to both interventionalists and

J. A. Kaufman (✉)
Department of Interventional Radiology, Oregon Health & Science University/Dotter Interventional Institute, Portland, OR, USA
e-mail: kaufmajo@ohsu.edu

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non-interventionalists alike. However, the uniformity of training brought by accreditation also solidified the educational community of IR. Without this initial unification, all subsequent changes would have been impossible.

Shortly after the recognition of VIR as a subspecialty, efforts to modify training were already underway. The primary intent of these efforts was to enhance training in non-procedural patient care. By the year 2000, becoming an IR required an internship (PGY 1), diagnostic radiology residency (PGY 2–5), and then a VIR fellowship (PGY 6). Even individuals with great interest in non-procedural care had little direct exposure to patient management during the 4 years between internship and fellowship. As IR practice was increasingly intervention based, with the interventions becoming more complex, the importance of this skill set was anticipated to grow with time.

The first attempt to provide more training in non-procedural patient care was the clinical pathway, proposed by the SIR in 2000 [6]. This 6-year program consisted of 16 months of training in non-radiology patient care specialties, 29 months of DR, 24 months of VIR, and 3 months of research. There was only limited implementation of this pathway, although it was successful in the few programs that offered it.

In 2005, the DIRECT (Diagnostic and Interventional Radiology-Enhanced Clinical Training) pathway was approved by the ABR as a pathway to specialty board certification in DR and subspecialty certification in VIR. This pathway, which required individual approval by the ABR, allowed for 24 months of training in non-procedural patient care, 27 months of DR, and 21 months of VIR. The initial intent of this pathway was to permit individuals transferring from other specialties into DR to apply 2 years of their other training toward the usual total of 6 years by reducing the DR rotations and to have more exposure to VIR. Several institutions developed successful programs that began at the PGY1 level, but overall the implementation of this pathway was also limited.

In 2006, the SIR initiated development of a proposal to further modify training as well as transition VIR from a subspecialty of DR to a primary specialty. As had been anticipated, IR was continuing to expand in breadth and complexity and with it the importance of non-procedural patient care. Practicing IRs were developing levels of content expertise that went well beyond their training in imaging and procedures, functioning as integral members of the clinical patient care team. The classic example was the IR who focused on cancer and was viewed first as a member of the cancer team and second as an IR.

A proposal for a new specialty and training program was presented to the ABR in 2007, which then worked with the SIR and multiple other stakeholders in DR over the next 5 years. A refined and carefully vetted proposal was ultimately approved by the member boards of the ABMS in 2012. The fundamental feature of the proposal was the unique combination of imaging expertise, procedural expertise, and non-procedural patient care that differentiated IR from all other primary specialties. The ABMS approved a new ABR certificate that included both IR and DR (the IR/DR certificate). With approval of the new certificate, the ABMS also approved the concept of a dedicated residency. The overarching significance of the ABMS approval of IR as a primary specialty of medicine was the affirmation by all other ABMS boards that competency in non-procedural patient care was not only a unique feature of IR but expected of individuals trained in IR. In essence, from the outside looking in, non-procedural patient care was recognized as an essential part of IR.

In 2015, the ACGME approved the structure of the training that fulfilled the requirements for IR/DR certification and began accrediting the first programs. Termed the IR residency, this training will have replaced all current VIR fellowships by the year 2020. As this training results in eligibility for a single certificate that includes two specialties (IR and DR), there are several features that are unique to these training programs. For example, the majority of these programs reside in DR departments and have shared leadership between DR (for the DR portions of the training) and IR (for the IR years). There are two basic configurations, the integrated and independent programs.

The integrated program requires a 1-year internship, preferably in surgery, followed by 5 years in a single department. The first 3 years are identical to the first 3 years of DR training, after which the resident spends the majority of the next 2 years in IR or IR-related rotations. One rotation in an ICU is mandated. Entry into integrated residencies is from medical school. This is a major change from the traditional entry from DR residency. For the first time, medical students who are procedurally oriented can consider IR as a career option directly from medical school (although they still must complete an internship).

The independent programs require a 1 year internship and completion of a DR residency. The standard independent IR residency is 2 years in length and also requires one ICU rotation. However, residents who receive extra IR training during DR residency in a formal early specialization in IR (ESIR) pathway are eligible for advanced placement into the second year of the IR residency. The independent program provides great flexibility, as residents can move between institutions (DR residency in one place, IR residency in another), whereas integrated residents much complete both DR and IR in the same institution. The independent pathway allows DR programs without IR residencies to remain competitive, as their graduates can still train in IR. If these programs can offer ESIR, their residents will be able to complete all of their training in the same time frame as integrated residents.

Lastly, this pathway provides a training option in IR for those who develop and interest after starting DR.

The certification process is the same regardless of the residency, in that IR residents in both the integrated and independent programs take the same DR core examination as the DR residents. Subsequently, certification in IR/DR requires passing a combined computerized and oral examination after completion of training. The oral examination is considered an essential tool for assessing competency in IR, and was therefore retained for this certificate, although it has been dropped for DR.

The IR/DR certificate is unusual in that it indicates competency in two ABR primary specialties, IR and DR. This is a foundational concept, in that the IR/DR certificate can be used as the parent specialty certificate for other DR subspecialties, such as pediatric radiology or neuroradiology. More important, it emphasizes that general imaging competency is unique to IR compared to all other specialties that perform image-guided interventions. This competency is the special feature that IR brings to medicine and which all of the ABMS member boards wanted preserved in the IR specialty certificate.

IR training has been evolving for the entire history of the specialty and will continue to evolve. With each change new opportunities arise, as well as challenges. Initial accreditation of fellowships unified training programs and made system-wide changes feasible. Recognition as a specialty was based on the importance of non-procedural patient care and maintaining imaging competency. The next steps may be development of areas of content expertise to a level that would benefit from training beyond residency. Perhaps oncology or vascular fellowships would produce individuals with special competency in these areas. However, the very same issues that arose when the idea of recognized VIR fellowships was debated in the 1980s are likely to surface again; concerns about disenfranchising IRs who do not seek additional training or weakening of the structure of IR by allowing subgroups to differentiate. As in the past, IR will find a way, and this exciting specialty will continue to innovate, advance care, and lead in image-guided interventions.

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2 Simulation Training in Interventional Radiology

Gabriel Bartal and John H. Rundback

Introduction

Medical simulation is a cross-disciplinary realistic and economical training and feedback method, in which learners can repeatedly practice and review tasks and processes using physical or virtual reality models. Simulation allows trainees to learn, develop, maintain, and improve skills in virtual environments or on models. They can be used until required proficiency is achieved, without harming the patients. Moreover, simulation-based education facilitates knowledge, ability, and approach that can be safely and efficiently acquired by student and/or physician. Simulated procedure-based skills and team working can be learnt, rehearsed, and measured, thus providing a base for certification in specific fields of medical practice.

Medicine has traditionally relied on a "see one, do one" approach to learning and experience. This exposes patients to inexperienced health-care practitioners, and the dangers and harm associated with this are increasingly unacceptable [1]. It is essential to explore, define, and implement models of physicians training models that do not expose the patient to preventable errors [2]. One such model is simulation-based training [1, 2].

Simulation is a model of an object, process, or system that can be manipulated in some way. It replicates some aspects of reality known as the "simuland" (i.e., the object, process, or system that is simulated). The value of simulation is a function of its ability to stand for the "simuland" with sufficient fidelity (accuracy) to serve trainee's purpose.

With recent advances in medical imaging technologies like CT angiography and MR angiography, most of the diagnostic angiographic procedures (i.e., peripheral angiography, angiography in a bleeding patient, and almost any kind of diagnostic angiography) have become less common, reducing the number of occasions to learn basic catheter manipulation skills [2]. Nevertheless, gaining selective catheterization skills is necessary for therapeutic endovascular interventions.

The RSNA (Radiological Society of North America), SIR (Society of Interventional Radiology) and CIRSE (Cardiovascular Interventional Radiology Society of Europe) established a joint medical simulation task force in order to improve patient care by guiding the implementation of simulation in IR [3]. The United States Food and Drug Administration (FDA) also promotes adoption and implementation of simulation training in IR. For example, FDA requires mandatory proficiency training in a simulator before prior to performing carotid artery stenting (CAS) on patients [4].

Medical Error

Medical error is one of the most challenging problems of modern medicine. It is also one of the drivers to develop reliable and cost-effective best tools for simulation. Here are some examples of the scope of the problem:

- 1997: 180,000 deaths annually from medication errors and adverse reactions [5].
- 1999: 44,000 to 98,000 deaths annually from medical errors [6].
- 2000: 225,000 deaths annually from medical errors, including 106,000 deaths due to "non-error adverse events of medications" [7].
- 2010: The Office of Inspector General for Health and Human Services said that bad hospital care contributed to the deaths of 180,000 patients in Medicare alone in a given year.
- 2013: Serious harm seems to be 10- to 20-fold more common than lethal harm.

G. Bartal (✉)
Diagnostic and Interventional Radiology, Meir Medical Center, Kfar Saba, Sackler Medical School, Tel Aviv University, Tel Aviv, Israel

J. H. Rundback
Holy Name Medical Center, Interventional Institute, Teaneck, NJ, USA
e-mail: jrundback@airsllp.com

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- According to the *Journal of Patient Safety*, the numbers may be between 210,000 and 440,000 patients. These numbers make medical errors the third medical cause of death.

These sobering facts emphasize the need for methodical and standardized practitioner training to reduce error.

History of Medical Simulation

Medical simulation has a very long history; the first evidence comes from ancient Egypt, around 2000 BC, where surgeon priests simulated surgical procedures (e.g., rhinoplasty) on cadavers. Parisian Dr. Gregoire in the seventeenth century created a manikin from cadaver pelvis with skin stretched across it to simulate an abdomen and with the help of a dead fetus explained assisted complicated deliveries. In 1739 Dr. William Smellie introduced a mechanical labor device by creating female models from a real pelvis, with ligaments, muscles, skin, artificial materials, and cloth dolls to simulate the fetus. By 1747, he had three machines, with six "artificial children."

In the modern era, simulation in medical education started with the use of standardized patients. For interventional radiologists, the case conference has been a long-standing form of simulation. Today, simulation training using devices and technology is becoming more common. Initially, simulation training used computer-based training modules such as RSNA's Medical Imaging Resource Center and the AuntMinnie.com Case of the Day [2].

Professions that require precise cognitive and physical tasks in high-risk environments are the best candidates for simulation training. Medical simulation is often used as a tool to assist a fellow or resident to practice performing a given procedure to improve proficiency. It can be practiced either under the guidance of a mentor, with performance feedback being provided by the mentor, or in a self-directed mode, with self-assessment coming from the learner. Recently, with implementation of computer-based training, the performance data is provided by the simulator.

Traditional Training

Training based on the current "see one, do one, teach one" model is insufficient as trainees learn by practicing on real patients, which can be an issue when performing interventional procedures. Modern hands-on medical and procedural training is limited by duty hour restrictions, intolerance for the use of live animal, medicolegal concerns, and the increasing range and complexity of procedures and instruments that must be mastered. Indeed, residents have expressed feeling inadequately trained to perform unsupervised procedures safely exposing patients to unnecessary harm [7]. Equally, mature practitioners have an ongoing need for maintaining familiarity with infrequently used devices or new devices and procedures.

Two categories of skills that may benefit from simulation training: procedural and non-procedural. Procedural ones include the physical skills a physician requires to complete an interventional procedure. Non-procedural skills encompass interpersonal, cognitive, or interpretive competencies.

Types of Simulators

1. *Phantoms or Part Task Trainers: Models of Anatomical Regions Aimed to Teach Specific Skills*

Low-tech task trainers remain at the heart of clinical skills and procedural instruction. They are fundamental in the teaching of anatomic landmarks and in enabling learners to acquire, develop, and maintain the necessary motor skills required to perform specific tasks.

For example, realistic 3D patient-specific renal biopsy phantoms have been created using CT data, manufactured from an organ mold and casted thereafter (Fig. 2.1). Using gelatin gel materials with calibrated parameters allows phantoms to provide realistic mechanical, ultrasound, and CT properties and mimics various pathologies (Fig. 2.2) [8].

For biopsies, practice is important for maintaining and improving skills [6], yielding faster performance, reducing the number of missed target lesions [1], lowering procedure room time [7], and improving success rates [8]. Even experienced radiologists face a learning curve when equipment changes are made [7]. Thus, realistic phantoms can be useful for both practicing radiologists and trainees.

2. *Computer-based learning modules* are digital simulations on the computer.
3. *Computer-assisted mannequins* are full body models that can simulate physiological responses.
4. *Virtual reality simulators* are immersive environments simulating live experience for the user and resembling the "real world." For instance, Mentice AB (Gothenburg, Sweden) has created virtual reality simulation platforms for both uterine artery and prostatic artery embolization.
5. *Augmented reality simulators* use the existing environment, overlay digital information on top of it, and then integrate digital simulation with physical simulator's environment in real time.

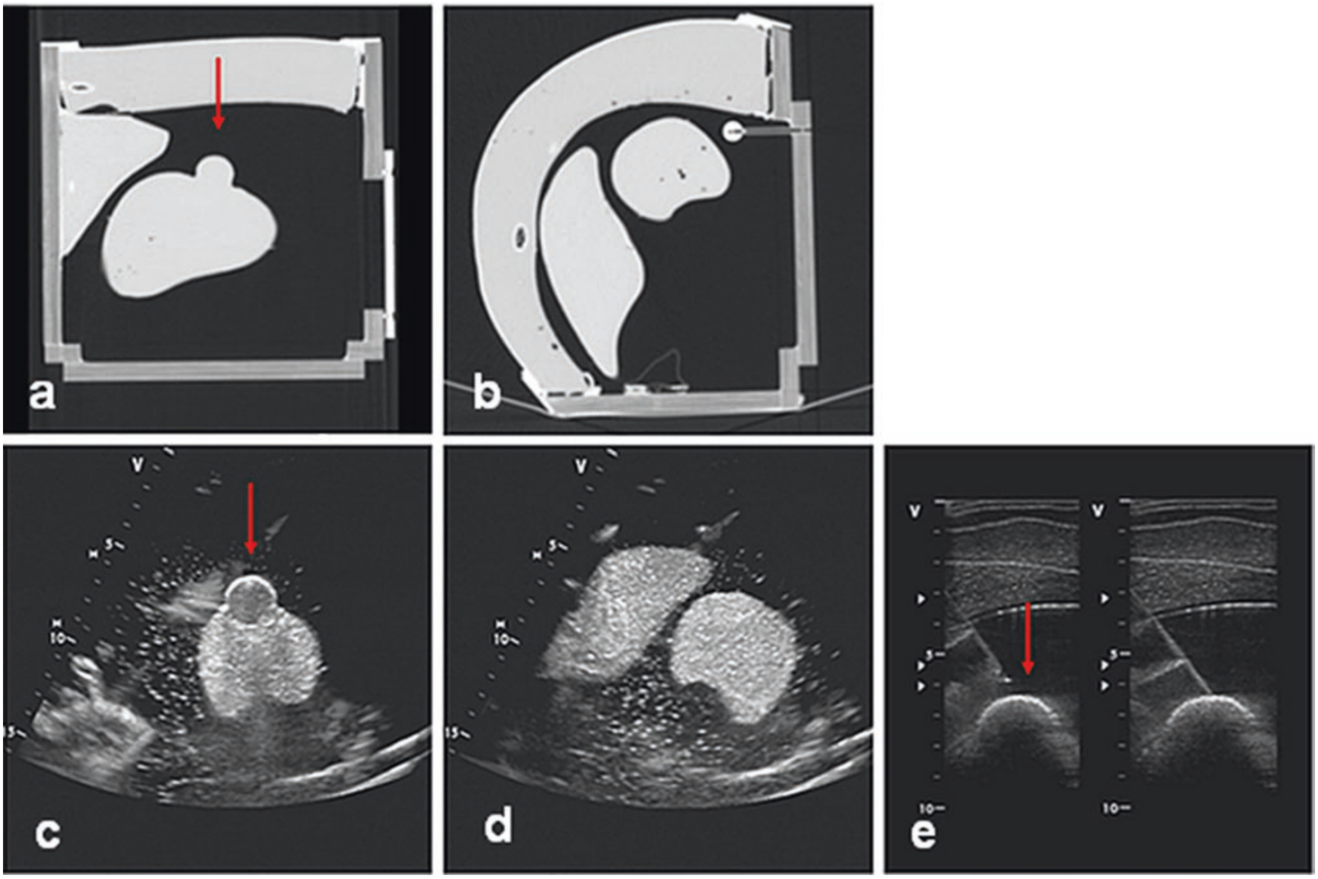

Fig. 2.1 Kidney box phantom CT scan (upper row) and US images (lower row) [8]. (**a**, **c**) Phantom and ultrasound demonstrating a focal lesion (red arrow) within the lower pole of the right kidney. (**b**, **d**) The kidney is visualized in relation to the liver for ablation planning. (**e**) The 10 L ablation probe is visualized adjacent to and then within the renal lesion. The phantom box can aid in procedural planning in order to avoid vital structures and practice technique (Reprinted by permission from SafeToAct Ltd. © 2017)

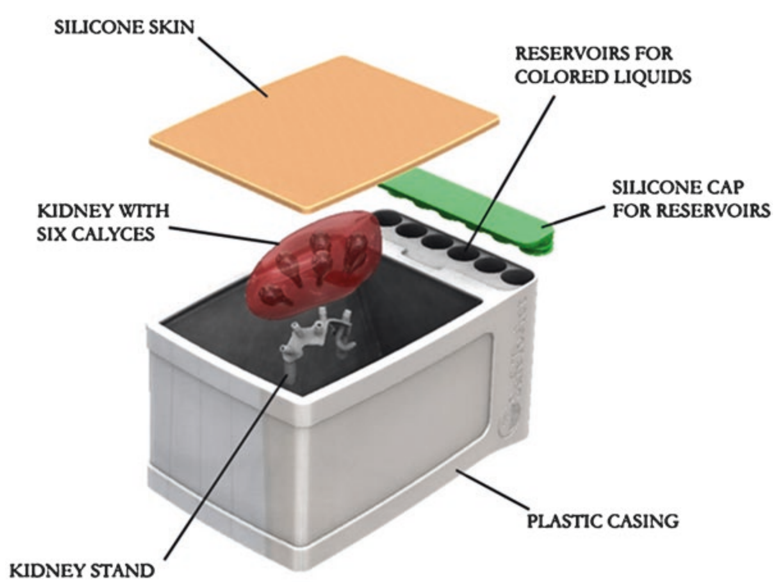

Fig. 2.2 Schematic presentation of the kidney phantom [8] (Reprinted by permission from SafeToAct Ltd. © 2017)

The educational validity of simulators is evaluated based on five aspects [9–11]:

1. *Face validity* evaluates how well a simulator mirrors real life. This is easiest to assess and is done by surveying participants regarding the realism of the simulator.
2. *Content validity* measures of how well a simulator tests knowledge; it is intended to show how well the simulator trains one in the expected skills. This can be assessed by pre- and post-knowledge test to determine improvements in test score.
3. *Construct validity* determines how well a simulator can differentiate participants by skill level. This can be assessed by including trainees of different experience levels in order to determine whether the final scores differ.
4. *Concurrent validity* compares simulators with standard methods. This compares the simulation and the apprenticeship or didactic model.
5. *Predictive validity* evaluates how well performance on a simulator predicts performance in real case. This is the hardest validity to determine.

Challenges in Interventional Radiologist's Training

Training in IR is inherently visual and requires "hands-on" experience. Residents or fellows are usually trained 1:1 or 2:1 with a scrubbed supervisor. A senior operator's view is an ideal additional teaching tool as he or she can comment in real time and impart specific valuable knowledge. Senior trainees do require supervision but also require a degree of independence to make decisions. This balance is hard to achieve as patient safety is overriding.

One of the limiting factors for many young IR physicians is a fear of personal radiation exposure (refer to Chap. 3 for more information on radiation safety). One of the important sources of personnel exposure is fluoroscopy time. Medical simulation allows practitioners to improve their performance in radiation-free conditions. Better and efficient performance of procedures will reduce fluoroscopy time and radiation exposure.

One of the most important guidance tools in image-guided interventions is ultrasound; this requires skill in scanning, image interpretation, and needle guidance [1]. Ultrasound-guided procedure simulations have shown improvement in knowledge maintenance, skills, and self-confidence, compared to pre-simulation training achievements [12]. Currently, most simulation is directed toward the vascular field, which is more complex and requires a very skilled operator.

Animal Simulation Labs

The use of animals for research and clinical training is both expensive and limited for one-time training events. Supply, ethical, and legal limitations support the use of non-animal alternatives (i.e., simulators). Several professional societies no longer allow the use of live animals in clinical training programs but endorse simulators instead [13].

Virtual Reality Simulation

This is a sophisticated and complex algorithm-based digital visualization of a medical procedure manipulated by a hardware component that an operator can interactively use in real time to accurately practice and test a surgical procedure [14, 15]. It contains all the benefits of a box/endo trainer, provides an added value of practicing full procedures, and allows learning the anatomy from different perspectives and practicing and managing complications. It can also provide accurate feedback on performance.

Catheterization and Angiography

Catheterization and angiography are basic and important skills that one must master in order to become a competent interventional radiologist. Different techniques including fluoroscopy, road mapping and DSA (Digital Subtraction Angiography) can be practiced on simulators. Simulation can both shorten the training time and improve catheter skills [16]. It has been shown to effectively train catheter-based endovascular skills to residents without any experience [17].

Angioplasty and Stent Placement

Angioplasty and stenting are core procedures in vascular interventions. Training of renal angioplasty and stenting using the VIST-Lab (Mentice) simulator has been shown to accelerate an apprentices' learning curve to reach proficient levels [15, 18]. Moreover, renal stenting outcomes when tested on the ANGIO Mentor (Simbionix 3D Systems simulator) improved after training on the simulator, showing technical skill improvement and increased patient safety [19]. All main vendors developed simulation training programs for major vasculature stenting. For example, carotid artery stenting results evaluated with the VIST-Lab (Mentice) simulator improved after novices' simulation training [20].

Simulator training should be performed in a stepwise fashion, from the basic to more complex procedure. For example, the trainee will practice iliac artery stenting prior to