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## Core Curriculum

# The Current State of Medical Simulation in Interventional Cardiology: A Clinical Document from the Society for Cardiovascular Angiography and Intervention's (SCAI) Simulation Committee

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**Objectives: To assess the current use and application of simulators in interventional cardiology. Background: Despite a paucity of data on the efficacy of simulation in medicine, cardiovascular simulation training is now a mandated part of cardiovascular fellowship training. Additionally, simulators have been endorsed by the Food and Drug Administration as a way to teach physicians new and novel procedures. We sought to establish the current use of simulators in cardiovascular medicine. Methods: A systematic review was done of available training programs, and currently existing data regarding simulation training. A panel of experts was convened to review this data and provide recommendations as how simulation should be used in the field of interventional cardiology. Results: This document provides a comprehensive review of the current state of simulation and how we as a society must formulate well validated studies to more closely examine and explore how this technology can be further studied and validated. Conclusions: Simulation will likely take on a larger role in cardiovascular training and maintenance of certification, but at the current time lacks a large body of evidence for its use.** 

**Key words: angiography coronary; percutaneous coronary; intervention; transradial cath; valvular heart disease; vascular access complications**

## INTRODUCTION

Simulation has a long history of use in training for professions that require precise cognitive and physical tasks in high risk environments [1–4]. Currently many non-medical professions require simulation as part of routine training or maintenance of competency and annual skills training [5]. Studies in non-medical fields have shown that high-fidelity simulations are effective

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teaching tools and enable repetitive practice of tasks in a range of conditions, and can improve learner success and satisfaction along with task safety [2,5–9]. Over the past decade, multiple high-fidelity medical simulators have been developed to address the numerous challenges of 21st century medicine which include the rapid expansion of new techniques, work hour restrictions and a demand by numerous regulatory bodies for the expansion of simulation in medicine.

Interventional cardiology is a field well suited for simulation. The procedures performed today have a wide range of complexity, have well-documented steep learning curves and have the potential for life threatening complications. The American Board of Internal Medicine was an early adopter of simulation in the field of interventional cardiology, using simulation to provide maintenance of certification (MOC) credits in the self-assessment portion of the program. When applied as a learning or testing tool, simulation has been used to both educate and improve performance in both medical and non-medical fields by enabling repetitive practice of tasks across a broad range of conditions [10–12], which is particularly applicable to interventional cardiology. The role of these advanced simulators in fellow training, post-graduate training, board certification, and maintenance of certification in procedure-based fields has yet to be clearly determined. This, coupled with the high cost of simulation and the lack of large studies showing improved patient outcomes, has led to the relatively slow adoption of simulation nationwide. Governing bodies including the Accreditation Council for Graduate Medical Education (ACGME), National Board of Medical Examiners (NBME), and American Board of Internal Medicine (ABIM) are closely examining simulation and exploring ways simulation may be used to assure physical procedural competency and patient safety, with ACGME now mandating that simulation be incorporated into cardiology training. In this article, we will attempt to review the current state of medical simulation in interventional cardiology. We report on the current use of simulation in training programs in the US, and highlight the capabilities of commercially available endovascular simulators and simulation programs, as well as provide recommendations for the use of simulation for interventional cardiology for the future.

## SIMULATION SURVEY

In order to evaluate the current role of simulation in training programs, a simulation survey was created by the ABIM in conjunction with SCAI and the American College of Cardiology (ACC). This survey was sent out to all ACGME accredited interventional cardiology programs in the United States ($n = 132$; complete survey data in online appendix) to ascertain the current use of simulation in programs across the nation and evaluate their perceived effectiveness as a teaching tool. Responses were received from about half of the programs in the US ($n = 59$; 45%) and this survey highlighted a number of key issues and challenges facing simulation today. Of the respondents, only 24% of programs ($n = 14$; 24%) reported that they were currently employing simulation as a teaching modality in their interventional cardiology fellowship curricula. Of those who reported using simulators, the majority of them use the computer-enhanced mannequins that provide automated feedback to the trainees. These programs reported a very short duration of simulation training, i.e., between 2 and 10 days per year. Most programs agreed that the simulator allows trainees to identify areas of improvement, visual elements are simulated well, simulation allows faculty to define teaching objectives, and the simulation companies provide good technical support. Programs noted that simulators are good for rare or low volume procedures, could provide objective assessment of technical competence, and can help trainees with the initial understanding of a procedure, but do not replace the real patient experience. Few programs agreed that the auditory elements, tactile forces, and advancement of the catheter are all simulated well. Few agreed that the simulator experience is similar to a real catheterization lab experience, and that it actually results in improved catheterization lab skills. Programs expressed concerns about the financial burden of using simulation, indicated the need for a central simulation center, and the lack of pre- and post-training testing for fellows with substandard skills. These data suggest that even in programs currently utilizing simulation, the scope and effectiveness of the utilization of simulation is limited, and not entirely satisfactory in its current state for use as a consistent teaching or assessment tool.

## CURRENTLY AVAILABLE SIMULATION PLATFORMS

### Endovascular Simulators

There are four commercially available simulators that provide endovascular simulation in North America. These include Procedicus VIST (Mentice, Gothenburg, Sweden) [13–21], Simsuite (Medical Simulation Corporation, Denver, CO), Angiomentor (Simbionix, Cleveland, OH) [22–25], and CathLabVR [26–28] (CAE Healthcare, Montreal, Quebec, Canada) (Table I T1
and Fig. 1). All of these simulators use mechanical F1
*haptic* feedback, which refers to tactile feedback provided by active or passive resistance generated by the

simulator itself in response to user movement of tools or instruments placed in the simulator. This tactile feedback is created by a series of motorized carts which lock onto the inserted instrument allowing the subject to manipulate the simulated instrument in real-time with force-feedback, which provides a mechanical simulation of the sense of touch and or resistance [24]. There are subtle differences between the different simulators with some emphasizing physiological responses to drug administration and/or balloon dilatation more than others. All of the simulators provide quantitative metrics regarding the use of contrast, fluoroscopy time as well as recording how well operators respond to simulated adverse events. Table I compares some of the key features offered by each major manufacturer's main simulator platform. All angiography simulators currently available allow for a full range of angiographic procedures, including the insertion and manipulation of devices (guidewires, catheters, balloons, stents, and endografts) into the vascular system. They allow simulated control of a C-Arm and patient table with various fluoroscopic projections as well as the manipulation of fluoroscopic images with techniques such as "roadmaping." In addition, all systems offer vital sign monitoring, hemodynamic management, and drug administration with pharmacologic models to simulate appropriate responses to medications.

**TABLE I. Listing of Procedures Available per Simulator Company**

| | Procedure | CAE | MSC | Mentice | Symbionix |
|---|---|---|---|---|---|
| Coronary | | | | | |
| | LHC | X | X | X | X |
| PCI | Coronary | X | X | X | X |
| | SVG | | X | | |
| | FFR | | | X | |
| | IABP | X | X | X | |
| | Rotational Atherectomy | | X | | |
| | RHC | | X | | |
| | Radial | | | X | X |
| Structural | | | | | |
| | Transeptal | | X | X | X |
| | PFO/ASD | | X | X | X |
| | PABV | | X | X | X |
| | PMBV | | | X | X |
| | Alcohol Septal Ablation | | | | |
| | Evalve | | | | |
| | LAA Closure | | | X | X |
| | TAVI | X | X | X | X |
| Peripheral | | | | | |
| | Carotid | X | X | X | X |
| | Renal | X | X | X | X |
| | Iliac | X | X | X | X |
| | SFA/Popliteal | X | X | X | X |
| | Infrapopliteal | | | X | X |
| | Coiling | | | X | X |
| | Neuro-coiling | | X | X | X |
| | Thrombolytics | | | | |
| | Thrombectomy | | | | |
| | Atherectomy | | | | |
| | TEVAR | | | X | X |
| | EVAR | | | X | X |
| Adjunct Imaging | | | | | |
| | IVUS | | X | | |
| | OCT | | | | |
| | ICE | | X | X | X |
| | TEE | X | X | X | X |

An X delineates that the procedure listed is available through the simulator company. Each company is in development of additional simulators, please visit their websites for an updated list. CAE (www.caehealthcare.com); Medical Simulation Company (MSC) (www.medsimulation.com), Mentice (www.mentice.com), and Symbionix www.symbionix.com).

Abbreviations: LHC, Left heart catheterization; SVG, Saphenous vein graft; PCI, Percutaneous coronary intervention; FFR, Fractional flow reserve; IABP, Intra-aortic balloon pump; RHC, Right heart catheterization; PFO, Patent foramen ovale; ASD, Atrial septal defect; PABV, Percutaneous aortic balloon valvuloplasty; PMBV, Percutaneous mitral balloon valvuloplasty; Evalve, Percutaneous repair of the mitral valve for mitral regurgitation; TAVI, Trans-catheter aortic valve implantation; SFA, Superficial femoral artery; TEVAR, Thoracic endovascular aneurysm repair; EVAR, Endovascular aneurysm repair; IVUS, Intravascular ultrasound; OCT, Optical coherence tomography; ICE, Intracardiac echocardiography; TEE, Transesophageal echocardiography.

## SIMULATION BASED COMPANIES AND PLATFORMS AVAILABLE IN NORTH AMERICA

### CAE

CAE, based in Quebec, provides a large-scale full function simulator, CathLabVR™. This simulator platform offers an assortment of procedures (Table I). All cases on the machine are divided into basic and advanced cases, which depending on the level of the case change the learning objectives and the degree of operator freedom, including the range of sophistication of decision making and drug availability. The simulator includes both basic and complex PCI cases. It also permits the simulation of 10 cases of challenging scenarios including acute myocardial infarctions, saphenous vein grafts and chronic total occlusions, ostial lesions, thrombus embolization, and the ability to prevent and treat complications with embolic protection devices. In addition, pharmacologic and cardiac rhythm management therapy and the ability to send a patient to "emergency cardiac surgery" can be simulated. The unit also includes a cardiac rhythm management simulation section, an extensive transcutaneous aortic valve simulation (both apical and endovascular approach), as well as "failed bioprosthetic valve" complications. CAE has also incorporated simulation of these complex procedures within a number of didactic modules that include pre- and post-questions and other teaching materials. As is common in many simulators, extensive

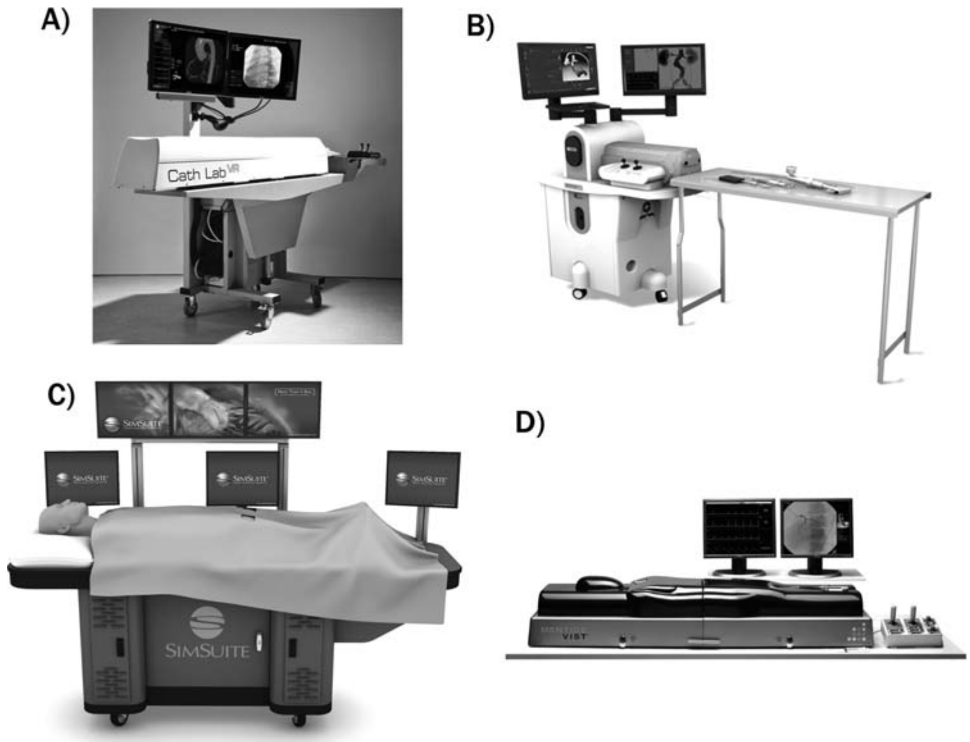


**Fig. 1. Currently available simulators. (A) CathLabVR (CAE Healthcare, Montreal, Quebec, Canada). (B) Angiomentor (Simbionix, Cleveland, OH). (C) Simsuite (Medical Simulation Corporation, Denver, CO). (D) Procedicus VIST (Mentice, Gothenburg, Sweden). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]**

metrics are compiled during each case and are available for feedback. CAE does not currently have an easily portable system for commercial sale. CAE is unique in offering a fully functional trans thoracic and trans esophageal echo simulator which can be used in conjunction with their cardiac catheterization simulator, though it is purchased as a separate unit.

## Medical Simulation Corporation (MSC)

Medical Simulation Corporation (MSC, Denver, CO) also provides a large-scale full function hospital based simulator called Simantha™ as well as a new more portable system called Compass™. Simantha™ with its numerous digital displays is designed to simulate both the procedure and the multimodality imaging which is often required in complex structural heart disease interventions. Multiple monitors display live fluoroscopy, captured images, EKG, static transesophageal echocardiography (TEE), live intravascular ultrasound (IVUS), and patient hemodynamics. Each case includes a complete case presentation including patient history, medications, allergies and physical exam. This simulator is unique in that it integrates simulation of IVUS and static TEE images in its case presentations. Numerous complications can occur for each module and are both pre-programmed and dynamic according to prespecified case parameters. The simulators record approximately 20 separate parameters during an individual's performance in a simulated case, which may be associated with a unique user, thus permitting performance tracking over time. MSC has also worked closely with the ABIM to develop specific interventional cardiology evaluative cases that currently receive credit in ABIM's MOC self-assessment program.

## Mentice

Mentice's main simulator platform is the Mentice Vist™, which is a full scale catheterization/endovascular simulator and provides full range of coronary, peripheral, neurovascular, and structural cases. The Vist™ system allows both single and dual access sites, and can simulate radial access as well. There are extensive metrics monitored during each simulation and a large number of didactic teaching modules that are included with each case done on the Vist™. A unique feature of this simulator is that an operator is permitted to freely navigate vessels and intervene irrespective of the goal of the case. Additionally, Mentice provides the ability to export the metrics obtained during each case to an Excel database (Microsoft Corporation, Redford, WA), and maintain unique profiles for various operators, allowing for tracking of learner performance, and progress. Mentice currently offers two easily portable simulators for easy travel, which provide nearly full function capacity of the more stationary Vist™.

### Simbionix

Simbionix provides three simulation platforms including AngioMentor™. The AngioMentor is a stationary system which provides complete simulation of a cardiac catheterization/endovascular suite similar to the other manufacturers. The AngioMini™ is the more portable version while the Dual Express™ is a laptop driven system for portability with dual units to simulate multiple access points to the patient. Simbionix currently provides well-developed simulations of EVAR and TEVAR on all its systems. A unique feature of the Simbionix platform is the procedural rehearsal studio. Using proprietary technology, patient specific data sets can be imported into simulated cases, so the procedure may be practiced on a model of the patient's actual anatomy. This feature is currently available for carotid angiography and intervention as well as endovascular treatment of abdominal aortic aneurysms (AAA). Complications for the simulators are both preprogrammed and dynamic and the simulators record 40 separate parameters about an individual's performance during a case, which may be associated with a unique user, allowing progress tracking.

## CURRENTLY AVAILABLE SIMULATED PROCEDURES

### Diagnostic Cardiac Catheterization and Percutaneous Coronary Intervention

Diagnostic cardiac catheterization, including both left and right heart catheterization has been in practice for over 50 years. In addition, the approach to these procedures is varied with both femoral and radial being the two most common, and each requiring a separate skill set. Simulation provides a safe arena wherein these skills may be developed and honed. All of the major companies have simulations including diagnostic cardiac catheterization and most provide simulated complications that permit the learner to see these potential complications and how they would treat them in a "safe" simulated environment as well as provide feedback if their treatment was not correct.

In the arena of coronary intervention, technology has advanced to permit the realistic portrayal of various clinical scenarios such as acute myocardial infarction, multivessel disease or chronic total occlusion. Operators are challenged to choose appropriate procedural pharmacologic agents, select diagnostic and guide catheters, wires, balloons, stents, and adjunct equipment. Measured metrics vary by program and intent, and these may include catheter selection, advancement and coronary cannulation, wire manipulation, appropriate device selection, lesion coverage, stent expansion, residual disease as well as "fluoroscopic," and procedural time.

While generic, non-branded programs exist, the major companies have also partnered to design and develop device specific simulations. Simulation programs for rotational atherectomy and distal protection devices for saphenous vein graft intervention serve as examples (Boston Scientific with MSC). Fundamentally, simulation not only increases exposure to these devices, but also provides the ability for one to gain or maintain proficiency using them in what are less common, but higher risk clinical situations.

Although the utility and benefits of simulation training are well established in endovascular procedures such as carotid stenting [29–32], surprisingly little data exist supporting simulation training in diagnostic left heart catheterization or percutaneous coronary intervention. A potential explanation lies in the relatively high volume of catheterizations that are performed each year which has led to the persistence of the apprenticeship model wherein fellows learn by "practicing on real patients." The high prevalence of CAD and the subsequent high volume of angiograms and coronary interventions relative to more novel procedures is a natural barrier to formally incorporate simulation into training programs. In addition, there is an inherent cost, both financial and educational (in time away from patients), to the use of simulators in training programs, with unclear "value added." Although no formal training guidelines or programs exist to date, simulators are now commonplace at most of the major meetings with considerable societal interest in incorporating them into fellowship training programs and eventually board certification. In fact, the ACGME has now mandated that simulation must be incorporated into each cardiology and interventional cardiology fellowship training program.

### Simulation in Transradial Catheterization and Intervention

Due to the increasing popularity and safety of the radial approach and the large number of practicing physicians not yet trained in transradial catheterization, there is much interest in the use of simulation for the transradial approach. Transradial procedures require a skill set distinct from trans-femoral procedures, training is currently available at only a few training programs and there is a "learning curve" associated with this technique [33] The learning curve is volume dependent and therefore, a certain number of procedures are needed to gain procedural competency. This provides an ideal procedure where simulation could be applied, i.e., a large group of operators who already have a basic skill set/knowledge base, e.g., left heart catheterization, but who must now learn how to approach it differently. There are two interrelated issues that arise from this: (1) the number of procedures required to gain proficiency is likely variable and dependent on the operator's current skill and overall procedural experience; and (2) defining "competence" in transradial procedures is even more challenging. Simulation could provide an opportunity to both train and assess operators who wish to perform transradial catheterization.

There are numerous simulators for training in diagnostic and interventional trans-radial cardiac catheterization currently available. These simulators provide several scenarios unique to forearm anatomy including radial and brachial loops, spasm, atherosclerotic radial arteries, and high takeoff radial arteries as well as variations in aortic arch anatomy and several possible coronary outcomes that could occur during intervention. The use of these simulators to familiarize new operators with the transradial approach initially was used for marketing purposes, but has been developed into a more formalized curriculum which is part of the SCAI sponsored Trans-radial Intervention Program (TRIP). The TRIP curriculum consists of two major components: (1) a cognitive module; and (2) a technique module. The cognitive module describes the procedural steps starting with patient selection, patient preparation, pre-procedural treatment, local anesthesia, radial artery access, forearm and aortic arch anatomy (normal and variations), radial artery spasm and its treatment, catheter selection, hemostasis, and complications (prevention and management). During training in the TRIP courses, topics are presented by experienced radial operators in a didactic fashion, with printed material given to the students. Following this classroom model of didactic teaching, the course attendees are divided into smaller groups, and technical aspects of the procedure are demonstrated in a simulated catheterization laboratory environment. This technique module uses a simulator (Mentice and Simbionix radial simulators) in conjunction with an access phantom in a mock catheterization laboratory suite. The simulators have the ability to present normal anatomic substrate as well as variations and complications, and the ability to choose from a large array of equipment in order to demonstrate procedural "tips and tricks" for specific anatomic variations. The course attendees learn about equipment choices and catheter manipulation in a "one-on-one" fashion with a faculty member, and develop catheter skills and learn tactile feedback. Case studies designed around different scenarios allow the attendee to learn how to address different situations and practice the skills needed to navigate through normal and abnormal or unusual anatomic variants. Complications specific to transradial procedures are also demonstrated.

In the United States, where individual operator PCI volumes are likely lower than in some other countries [34], simulation may become vital component of developing the skills necessary to become proficient in trans-radial procedures. Curriculum development for simulation based training has helped to standardize the TRIP simulation training sessions, and given structure to the use of simulators in training operators interested in learning transradial procedures in this context. The next phase of the TRIP simulation based training is to "grade" the course attendee by using a standardized evaluation tool that assesses procedural decision-making in response to presented scenarios, and technical proficiency by having the learner complete a trans-radial case on the simulator. The development of a standardized curriculum for transradial catheterization is an excellent example of how simulation may be used to advance procedural education. High fidelity simulators develop and refine psychomotor skills in a safe environment. Each operator must first have a solid knowledge base foundation upon which these skills can be added. TRIP is unique in its composite approach and likely should serve as a model for future educational efforts involving simulation.

## Structural Heart Intervention

Potentially the greatest potential for simulation based training is in the realm of structural heart intervention. As an entity, structural heart disease interventions include a assortment of interventional procedures including closure of atrial septal defects (ASD) and patent foramen ovale (PFO), occlusion of the left atrial appendage (LAA), and transcatheter mitral and aortic valve therapies. In contrast to coronary and peripheral vascular procedures, structural heart disease interventions often involve diverse pathophysiologic processes that demand a understanding of three-dimensional anatomic relationships. This often requires integration of adjunctive imaging (transesophageal echocardiography (TEE) and intracardiac echocardiography (ICE) techniques into a single procedural approach. Formalized training programs in structural heart disease interventions are very limited in the United States, with very few programs offering dedicated exposure from either a clinical or a procedural perspective with volumes often being quite low. For all of these reasons, simulation may be an ideal means to provide such training.

As with the other facets of interventional cardiology, the major simulator companies have teamed with industry to develop device simulations with appropriate metrics. Trans-septal catheterization training programs are available on a number of simulator platforms and the newer programs incorporate adjunctive imaging with both TEE and ICE. Additionally, there are data that simulation of trans-septal puncture can actually enhance operator's skill level with this procedure. In an albeit small but randomized trial, De Ponti et al.[35] evaluated conventional versus simulator training in trans-septal technique and showed that simulator training resulted in shorter training time and greater procedural ability and efficiency. Recently with the commercialization of trans-catheter aortic valve replacement (TAVI), simulator training is a mandatory component of site training for the operators. For left atrial appendage occlusion, simulations do exist, and with eventual commercialization, simulator training will most likely have a prominent role.

Structural heart intervention is an innovative field with rapidly expanding procedural applications. Simulation of these complex procedures is also evolving with the incorporation of simulated multi-modality imaging along with the actual procedure. The role of simulation in the training, certification and maintenance of skills required for these procedures remains unexplored.

## Peripheral Vascular Intervention

In contrast to the other arenas, simulation has been used quite extensively in the endovascular arena. With the high prevalence of peripheral vascular disease (8–12 million people in the United States [36]), there has been a steady rise in the use of catheter-based therapy to treat patients with symptomatic PAD [37]. This has been driven by the decreased morbidity, cost, length of stay, and the lower mortality associated with endovascular intervention [38]. Complicating the rapid expansion of endovascular procedures is the number of treating sub-specialties who perform these procedures. Each specialty possesses diverse training backgrounds which complicates standardization of training and care.

**Carotid Artery Stenting.** The endovascular procedure that has received the most intense scrutiny regarding operator training is carotid artery stenting (CAS). CAS, like any complex procedure, has a definite learning curve that includes diagnostic cerebral angiography skills [39]. This procedure is unique however in that the risks conferred to the patient as a result of the physicians' learning curve are unacceptably high and immediately apparent [40]. In 2004, an FDA panel voted to accept a proposal that virtual reality (VR) simulation would be an important component of a training package for carotid stenting [41]. Subsequently, the Society for Cardiovascular Angiography and Intervention (SCAI), the Society for Vascular Medicine and Biology (SVMB), and the Society for Vascular Surgery (SVS) publicly supported the use of VR simulation for CAS [42].

CAS, given its inherent challenges and risks coupled with the support it has received for VR simulation, is also the most well-studied simulated endovascular procedure. VR simulation for CAS has been shown to shorten learning curves [40], allow assessment of the impact of CAS training [25], as well as distinguish between levels of endovascular experience [43]. Furthermore, simulation-based CAS training has been successfully shown to be so effective in teaching CAS that when used in training with inexperienced CAS operators they gain a procedural skill set matching their more experienced colleagues in a direct comparison study [13].

The most interesting and unique use of simulation for CAS has been the simulation of a patient about to undergo CAS, so-called "mission rehearsal" [44]. In this study, by Cates et al., an operator was able to perform CAS using patient-specific anatomic data on the "patient" using a simulator before entering the catheterization suite to perform the real procedure. This approach permits operators to work through the challenges one might face during CAS, in order to try to minimize errors which could result in procedural complications or procedural failure. It is well known that tortuous anatomy, complex lesion morphology and difficult device access leads to increased procedural time, fluoroscopy exposure, contrast use, and complications during CAS [25,45]. By practicing the procedure, using patient-specific DICOM data, operators can select the best working angulations for minimization of vessel overlap and foreshortening as well as select stent diameter and length before the real case. The operator can then "practice" on the simulated patient and determine the best of several possible approaches and address potential complications before performing the real procedure on the real patient [46]. In one study, performance of CAS a priori in a simulated environment influenced the real case in terms of optimal fluoroscopy C-arm position, choice of selective catheter, choice of sheath or guiding catheter and balloon dilatation strategy [47]. Hence, simulators are useful at all levels of experience for CAS, for both the novice and the expert who is about to place a real carotid stent.

There is such interest in the use of simulation for CAS, that there have emerged several training programs(Carotid Artery Stenting Program (EduCAS) and Emory NeuroAnatomy Carotid Training (ENACT) program) for interventionalists who wish to learn the procedure that use VR simulation as a main component [25,40,48]. There is also a dedicated research team whose focus is not just CAS but the simulation of all endovascular procedures in Europe called the European Virtual Reality Endovascular Research Team (EVER-esT). The value of educational programs using simulators appears to be tangible and likely the path of all future endovascular training courses [49].

**Other Endovascular Simulations.** Though CAS is by far the most commonly simulated endovascular procedure, all of the commercially available simulators do have modules involving renal, iliac and SFA/popliteal endovascular intervention. Most of the literature investigating the use of simulators for non-CAS intervention comes from the training of vascular surgery residents wherein simulators have been used to assess the impact of didactic and cognitive training for residents, highlighting the need to incorporate the development of both psychomotor as well as cognitive skills [29]. Simulation has also demonstrated that operators accustomed to 0.035″ wire based interventions are not as adept as those used to training on 0.014″ wires by comparison of renal versus iliac interventions in a simulated environment [50].

There has been only one randomized trial evaluating simulation based education to date involving surgical trainees using catheter-based therapy for lower extremity occlusive disease [51]. This study is also the only study to show "VR to OR" translation of simulator based skills. Twenty general surgery residents were randomized to either simulation based training or none. All residents then participated in two consecutive mentored catheter-based interventions for lower extremity occlusive arterial disease in an OR/angiography suite. Residents were graded by an attending surgeon who was blinded to the residents simulator training status. Residents exposed to simulation scored higher than controls on the first OR/angiography intervention and even better on the second intervention when compared to controls. This albeit small study is the only one to date to critically assess whether simulation training can actually have an impact in the angiography suite in a small group of trainees. Whether this effect is long lasting is unknown and has not been studied.

## CONCLUSIONS

Simulators have been used in the medical field for over a decade with their initial application being in laparoscopic surgery where it showed promising results in randomized controlled studies involving trainees [4]. The traditional approach of "see one, do one, teach one" is slowly being replaced with the more progressive concept of "learn the operation before the operating room" [51]. One of the major issues with integrating simulation is the cost which can range from $90,000 to $250,000 per simulator. Clearly, most training programs would not be able to afford to have their own simulator. However, with surgeons, cardiologists, interventional radiologists and even neurosurgeons now often using simulation for training, perhaps institutions might be able to pool resources so that simulators could be made available at a shared simulation center for their residents. It is known from the surgical literature that approximately $50,000 per surgical resident is spent over a training period of 4 years due to increased operative time and decreased efficiency that occurs when operating with a trainee [15]. There are no similar data for fellows training in the cardiac catheterization or peripheral angiography suite, but likely the cost is not insignificant. Perhaps sending trainees to regional simulation centers, which has been shown to be cost effective in one study, is the most cost effective approach [52]. Simulators for catheter-based training are incredibly complex and are evolving each year with advancements in computer technology. Unfortunately, with these advancements comes an increase in costs. It is imperative that our professional societies lead the future direction for the best possible education of interventional cardiology and its trainees.

To date, although most major societies recognize the efficacy of simulation based training, none have proposed a standardized format. Society of Interventional Radiology(SIR)/ Radiological Society of North America(RSNA)/Cardiovascular and Interventional Radiological Society of Europe (CIRSE) have their own Joint Medical Simulation Task Force [53] which recommends the validation and defined standards for the use of simulation in education, but provides no guidance on how to approach this challenging goal. Part of the reason behind this is that despite being available for nearly a decade, the validation of many simulators is not yet finished [18]. In addition, though simulators can aid in the development of psychomotor skills, they must be coupled with didactic curricula to be most effective. For endovascular intervention, since each procedure can be accomplished in a variety of ways, the development of a set curriculum is particularly challenging. This coupled with the high cost of simulation and the lack of large studies showing improved patient outcomes has led to the relatively slow adoption of simulation nationwide.

Simulation has rapidly evolved as a learning tool and technology over the past 15 years, and has been shown to be an effective method for teaching both novice and experienced learners. Despite this, the field of cardiovascular medicine is still in the primitive stages of adopting simulation. The reasons cited for this include: the high cost of simulators, a dearth of didactic curricula to accompany the psychomotor skill learned on a simulation, the wide variability and/or lack of consistency that exists among the simulation platforms, and a complete absence of large scale trials showing that this expensive technology actually improves operators' skill in the angiography suite and presumably enhances patient outcomes. Despite all this, the ACGME now mandates that cardiovascular fellowship training programs must have some component of simulation as part of fellow training. This is just one example of how regulatory bodies are adopting simulation as a valid method for training and certification. Indeed, the FDA recently adopted simulation training as part of its new procedure device training. Hence, as a professional society, we should accelerate our adoption of this novel technology and actively participate in the development and implementation of simulation in cardiovascular medicine. We must work with the vendors as a Society to make this technology more affordable and available.

With this in mind SCAI's Simulation Committee offers the following recommendations for simulation moving forward:

1. We anticipate the eventual requirement that fellows in invasive specialties will be expected to demonstrate competency in the procedures they are being trained to perform in practice. To prepare for this, we recommend that SCAI as a society, in conjunction with the ACC and ABIM develop a set of standardized cases that embodies the essential psychomotor and knowledge base skill sets required to be an interventional cardiologist.
2. These standardized cases should be developed and integrated with a standardized didactic curriculum that meets current evidenced based learning standards as dictated by the Accreditation Council for Graduate Medical Education (ACGME) and Core Cardiovascular Training Symposium (COCATs). This curriculum and the simulations should be available on all simulation platforms to maximize fellow training and testing at all SCAI events including the Fall Fellows Course.
3. We advocate for the initiation of large scale studies to evaluate the impact of simulation in a number of key areas including: (a) feasibility and efficacy of a simulation-based training curricula as a training modality for both fellows and more experienced operators learning new procedures and (b) reliability and validation of simulation as a tool for the maintenance of competency.
4. Finally, we recommend that formal simulation training programs be included in the annual scientific sessions and integrated into the program for fellows and practicing physicians.

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