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Simulation-based training in cardiology: State-of-the-art review from the French Commission of Simulation Teaching (Commission d'enseignement par simulation – COMSI) of the French Society of Cardiology

Abbreviated title: Simulation-based training in cardiology

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Discover the latest State-Of-The-Art Review on Simulation-based Teaching in Cardiology just published in #ACVD!

Overview proposed by the French Commission of Simulation Teaching of the French Society of Cardiology!

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Summary

In our healthcare system, mindful of patient safety and the reduction of medical errors, simulation-based training has emerged as the cornerstone of medical education, allowing quality training in complete safety for patients. Initiated by anaesthesiologists, this teaching mode effectively allows a gradual transfer of learning, and has become an essential tool in cardiology teaching. Cardiologists are embracing simulation to master complex techniques in interventional cardiology, to manage crisis situations and unusual complications and to develop medical teamwork. Simulation methods in cardiology include high-fidelity simulators, clinical scenarios, serious games, hybrid simulation and virtual reality. Simulation involves all fields of cardiology: transoesophageal echocardiography, cardiac catheterization, coronary angioplasty and electrophysiology. Beyond purely technical issues, simulation can also enhance communication skills, by using standardized patients, and can improve the management of situations related to the announcement of serious diseases. In this review of recent literature, we present existing simulation modalities, their applications in different fields of cardiology and their advantages and limitations. Finally, we detail the growing role for simulation in the teaching of medical students following the recent legal obligation to use simulation to evaluate medical students in France.

KEYWORDS

Simulation-based training;

Education;

Interventional cardiology;

Echocardiography;

Communication skills

Abbreviations: OSCE, objective structured clinical examination; TEE, transoesophageal echocardiography; TTE, transthoracic echocardiography.

Background

Simulation teaching is defined as “a technique to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner” [1]. Whereas simulators were introduced in aviation in the 1920s, the first documented use of simulation in healthcare only occurred in 1960, when a group of anaesthesiologists collaborated with a toy manufacturer to develop a full-size simulator of a patient in cardiac arrest [2]. Subsequently, a computer-controlled simulator was developed to teach endotracheal intubation [3], and a high-fidelity simulator was created to train anaesthesiologists in how to respond to critical situations in the operating room [4]. Thanks to progressive technical and ethical advances, simulation is now considered the cornerstone of medical education [5], with practices in France regulated by the authorities and law [6].

Whereas the adage “see one, do one, teach one” reflects an old tradition where patients were used both as the primary source and the subject of medical education, the adage “never the first time on the patient” clearly emphasizes the importance of simulation teaching in medicine [7]. We can even hope that this adage will soon be replaced by “never the first time without simulation training” [8].

In cardiology, simulation is particularly well suited to safely learning and practicing technical and team skills [9]. Patient care requires invasive procedures with potential complications, and efficient professional team performance in vital emergency situations. However, in a recent international survey of 172 young cardiologists from 43 countries, only 48% of the participants had already participated in simulation training, whereas 91% considered this teaching method “necessary” in cardiology [10].

This review aims to give an overview of all the simulation modalities in the different fields of cardiology, and to discuss the advantages and limitations of simulation teaching.

Rationale for simulation training

Patient safety and prevention of medical errors are crucial in our healthcare systems. Since the publication of the Institute of Medicine’s report “To Err Is Human”, which highlighted preventable deaths related to medical errors [11], it has been necessary to improve medical training to reduce risks. A reduction in clinical duty hours for medical trainees and a mandatory rest day after a night shift have been implemented progressively to minimize fatigue-related risk of medical errors in Europe. However, these measures have resulted in less instruction and fewer procedural opportunities for

trainees. Therefore, simulation teaching is an appealing solution to provide education that fills the gap between theory and practice, while minimizing patient risk. Acquisition of technical skills and knowledge through simulation leads to an improvement in real-life clinical practice [12]. Furthermore, simulation allows the simultaneous assessment of the individual and the entire team working together. In this way, weaknesses in patient management can be highlighted and corrected.

The evidence for simulation is classically described according to different levels of proof, following the Kirkpatrick model for evaluating the effectiveness of training programmes [13] (Fig. 1), the first step exploring learner satisfaction and the ultimate step being patient benefit. This last step is rarely achieved. A meta-analysis showed that simulation was more effective for learning invasive bedside procedures compared with other approaches [14]. Another meta-analysis specifically studied teaching of critical care skills to medical trainees, and found that simulation was more effective than other methods [15].

Beyond its value as an effective educational tool, simulation for procedural training helps to reduce complications. One study showed that the number of complications during the placement of a central venous catheter decreased significantly in the group of learners who followed a simulation programme compared with the group who received traditional education [16]. A meta-analysis demonstrated a clear benefit for simulation over traditional resuscitation training, with an increase in survival from cardiac arrests in centres running simulation-based programmes [17]. In a randomized study on thoracentesis training, pneumothorax and haemothorax decreased significantly in the group of learners who followed a simulation programme compared with the traditionally educated group [18]. A summary of the main randomized controlled trials investigating simulation-based training in cardiology is presented in Table 1.

Simulation methods

The transfer of learning [19] from simulation to clinical practice in cardiology is based on several complementary methods: task trainers, human patient simulators, serious games at an individual level, scenarios with debriefing at a team level, standardized patients and virtual and augmented reality [20]. The appropriate simulation modality is determined by the learning objectives specified by the teacher [12]. Table 2 lists the various modalities, their applications in cardiology and their advantages and disadvantages.

Task trainers are specialized models designed to help a learner practice a specific skill. Whereas high-fidelity simulators are important for practicing an entire patient examination, task trainers facilitate the refining of psychomotor skills in isolation. Regarding technical procedures in cardiology, task trainers allow learners to familiarize themselves with these procedures, which require repetitive practice in a safe environment.

Concerning scenario-based simulation, different combinations of simulators and staged scenarios with varying degrees of fidelity allow professionals to practice the principles of effective teamwork (e.g. in a crisis). Skills acquisition occurs not only during the simulation scenario, but also during the debriefing under the supervision of the teacher, who provides feedback, including points to focus on in the next session [21]. Feedback is the mechanism by which errors in performance are identified and addressed [7]. Simulation applied to emergency scenarios can provoke strong feelings in learners, such as failure or questioning. For that reason, it is important to carry out a constructive debriefing to analyse the simulation session's key points [22]. Different debriefing approaches have been described, using video playback, self debriefing or debriefing by other learners; however, no approach has been shown to be better than another [22]. The realization of these types of debriefing and the creation of simulation scenarios, both realistic and didactic, require a simulation teacher's expertise [23]. Therefore, specific diploma training to become a simulation teacher is mandatory.

“Serious games” is the term for computer software that replicates real-world environments to emphasize educational messages. Serious games have the advantage of being accessible on computers or smartphones, without requiring the purchase of additional equipment [24]. This flexibility is appreciated by learners [7], as they can perform the training whenever they want. In simulated clinical scenarios, each learner gains different knowledge based on their experience. Such simulations tend to propose scenarios that arise currently in routine clinical practice (such as a consultation for the management of the prescription of anticoagulants), but require the maintenance of skills and knowledge [7].

One of the most advanced stages of simulation teaching is in situ simulation, allowing learning in a real context, as simulated clinical scenarios are transported into a clinical environment; this specifically addresses high-stress environments, such as emergency rooms, critical care units or operating rooms. In situ simulation favours multiprofessional team learning; it is therefore very useful to improve communication and develop a sense of responsibility. By providing training where people

usually work, in situ simulation leads to a gain in organizational learning, and helps to develop local procedures; therefore, it is a good method to strengthen safety for patients as well as for professionals. A clear example is management of tamponade during a cardiac standard interventional procedure. This type of simulation presents logistical, technical and also human constraints. Experienced simulation teachers are required to organize and conduct these programmes [7, 25].

Finally, technological progress is making it possible to orient the future of simulation towards high-performance tools, such as virtual and augmented reality, with the major advantage of avoiding acquisition of multiple items of expensive equipment [26]. Moreover, some simulators can record all the movements and forces of the simulated instruments, generating big data that can be analysed with artificial intelligence algorithms. These analyses could further enhance the psychomotor performance of our training courses [27]. There is no doubt that artificial intelligence will change some simulation methods in the coming years.

Simulation in interventional cardiology

Interventional cardiology appears ideal for simulation-based training because of its technical aspects and protocols that involve life-threatening complications. Several very sophisticated task trainers have been developed for interventional cardiology procedures, including coronary angioplasty with stent implantation, and more complex ones, such as the use of a Rotablator™ (Boston Scientific, Marlborough, MA, USA) simulator, pacing, electrophysiological studies, transcatheter valve placement and peripheral vascular interventions. Regarding the management of interventional complications, simulation allows training in how to react to some rare but severe complications (e.g. periprocedural coronary dissection). Some studies have shown an improvement in operator skills using these simulators compared with traditional mentor-based training [28-31]. The Education and Training European Association of Percutaneous Cardiovascular Interventions (EAPCI) recommends that training centres incorporate simulation sessions into interventional cardiology training [32].

Simulation training in procedures is particularly useful during the early phases of training [33], as it can be adapted to each trainee's learning speed, without exposing patients to potential harm. Examples include obtaining arterial access, engaging coronary arteries, injecting contrast, obtaining appropriate views and achieving haemostasis. In a study including 32 fellows, medical simulation training was associated with 2 minutes less fluoroscopy time per case [34]. The use of simulation early

in training has also been shown to improve the efficiency of catheter placement and the performance of transeptal catheterization by untrained electrophysiology fellows [35].

In interventional cardiology, it is well known that practitioners who carry out interventions at a high volume perform better than those who do so rarely. Simulation can allow frequent and supervised practice to acquire and maintain a certain level of skills. For that reason, it can be assumed that in the future, simulation-based mandatory certifications in interventional cardiology will be part of continuing education. Beyond technical skills, simulation in interventional cardiology tackles non-technical and human factors. Hybrid simulation is one way to mix modalities to enhance the training experience, such as performing radial puncture on an arm simulator with a standardized patient who mimics anxiety or aggression [36].

Simulation in cardiovascular imaging

Simulation is relevant for learning cardiovascular imaging with echocardiography, both transthoracic (TTE) and transoesophageal (TEE). Mannequin-based TTE and TEE simulators allow students to learn the required skills in a safe environment [37]. For that reason, there are already some educational programmes for residents in different regions of France. Although a complete training programme with theoretical and practical sections is necessary, a short self-study programme based on acquisition of basic knowledge in TTE through practice on a simulator could be proposed in a population of novices in echocardiography [38]. For example, Fredericksen et al. showed that novices in echocardiography obtained an 86% rate of interpretable images after only 2 hours of teaching and practice on two healthy volunteers [39]. Simulation-based echocardiography is also useful for teaching cardiac anatomy and physiology to undergraduate medical students [40]. Concerning TEE, several randomized studies have shown an improvement in psychomotor skills and knowledge of the anatomy after simulation-based TEE training [41-45]. However, a meta-analysis showed that there is little compelling evidence from published studies to support the widespread adoption of TEE simulation [46]. In addition, there are still some technical limitations, such as the sensation of the probe introduction in the oesophagus, which is not currently reproduced by the simulator. Specific data regarding the simulation-based teaching of vascular Doppler ultrasound remain scarce. Indeed, simulators for peripheral vascular ultrasound use flow detection, which presents a technical challenge, and are currently less advanced than those for echocardiography [47]. Interestingly, there are simple

methods that provide effective simulation teaching for pulmonary ultrasound, using simulated B-lines of hand ultrasound with a wet foam dressing material [48]. Regarding multimodal imaging, practical workshops on dedicated cardiac magnetic resonance imaging consoles were performed during the 2019 European Society of Cardiology congress, with a significant improvement in participants' confidence in cardiac magnetic resonance imaging analysis [10].

Simulation teaching for crisis management in cardiology

Management of crisis situations was one of the first applications of simulation in healthcare, specifically in anaesthesia and intensive care [4]. In cardiology, simulated crisis management can improve technical and behavioural performance, using scenarios such as myocardial infarction, life-threatening arrhythmias or cardiac arrest [49]. Using human patient simulators, advanced cardiac life-support training can improve organizational aspects of medical emergency team performance, such as independently assuming designated roles, completing tasks assigned to each role and communicating accurately and directly [50]. Constructive debriefing with oral or video-assisted feedback is mandatory in all simulated crises, to benefit trainees [22].

Communication skills training with simulation

Simulation with standardized patients supports the teaching of communication skills to clinicians for a variety of patient interactions. In a study using standardized patients, oncology residents significantly improved their communication efficiency after a dedicated 4-day training course [51]. Similarly, McCallister et al. demonstrated that the communication skills of critical care fellows in meetings with patients and families improved after a 12-month communication curriculum [52].

In cardiology, it is crucial to develop communication skills for breaking bad news, such as a serious disease or a poor prognosis, but also to announce a chronic disease (heart failure) or for planning cardiac transplantation. Whereas most attention paid to simulation is directed towards the learning of technical skills, educational programmes dedicated to communication skills for these daily situations in cardiology are potentially useful to improve residents' self confidence and thus patient care.

Simulation to teach medical students

The “Health Law 2022” mandates simulation in the evaluation of graduate medical students in France. This major change in medical studies is based on the objective structured clinical examination (OSCE). Already in use for over 20 years in Canada and Switzerland, the OSCE is a standardized tool to assess clinical skills in addition to traditional knowledge skills. The idea is to expose students to simple or more complex problems (based on clinical situations encountered as a future general practitioner) early in their training. The objective is to assess different aspects of medical practice, such as the doctor-patient relationship, medical knowledge, clinical skills, clinical reasoning skills, physical examination, ethical and professional behaviour and communication skills. However, compared with traditional oral exams, the OSCE requires a greater investment in time, manpower (teacher-evaluators and simulated patients) and budgets. In cardiology, such programmes can be used to practice cardiac auscultation using a cardiac simulator, allowing an evaluation that will verify that the learner has positioned the stethoscope on the correct auscultation sites with, for example, the ability to diagnose a murmur of aortic stenosis.

Although some studies suggest a role for simulation-based echocardiography in the teaching of cardiac anatomy and physiology to undergraduate medical students [40], Labbe et al. have shown that simulation may be insufficient to perform a complete extended basic critical care transthoracic echocardiogram, including Doppler capabilities [53]. However, a recent study showed that a teaching programme combining standardized patients and cardiac simulators may be ideal for transferability to patients [54]. Beyond these traditional methods of teaching at the bedside, the recent technical development of simulation tools makes it possible to imagine an even greater impact on the future training of medical students.

Simulation limitations

Simulation-based training has some limitations. The first is the perception of the learner, who is aware of simulation’s artificial aspect; there is a risk of not being able to transfer skills to real life. Immersion in simulation can be disrupted in case of a technical problem with the simulator, and then limit the transfer of knowledge [7]. Second, the recruitment and training of a team of teachers is crucial to the success of the simulation activity, but can be challenging. This teaching method is very time consuming, requiring a significant amount of time to devote to the task of offering successful simulation programmes. Some pedagogical experts recommend that when learners complete

simulation-based training programmes on procedures, they should achieve a minimum pass score on a post-test or complete further simulation training until they pass [5]. However, this rigorous process is a real challenge, because it requires flexibility of both the teacher's time and the access to simulation tools [12]. Third, the financial investment is huge and constant to maintain the programme and purchase software updates and additional scenarios. For this reason, simulation centres are most often based on multiple funding (university, national, regional and international grants, sponsorships, etc.). Finally, as with any teaching method, there is a substantial learning curve for both learners and teachers. Moreover, the knowledge and skills acquired by learners during the simulation and by teachers during the debriefing may be gradually lost in the absence of regular practice.

Conclusions

Beyond representing the cornerstone of education for medical students, simulation provides crucial help for clinicians to develop technical and communication skills in a safe environment, and to achieve and maintain a high level of expertise. Cardiology is ideal for simulation in terms of technical procedures, communication skills and team management. Therefore, it is essential to continue to promote and develop simulation in cardiology through the establishment of a national training curriculum supported by an active simulation research field, as well as by technological innovation, such as virtual and augmented reality.

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Figure legend

Figure 1 and Central illustration. Kirkpatrick levels of training evaluation applied to simulation-based training in cardiology. To illustrate the four Kirkpatrick levels in cardiology, we present the example of the different validation steps for a simulation-based transoesophageal echocardiography (TEE) course (on the right side of the figure).

Table 1 Summary of the main randomized controlled trials investigating simulation-based training in cardiology.

Study reference	Year	Number of students	Study design	Rhythm of the sessions	Blind assessment	Improvement in practical skills	Study in simulated or real procedures	Main findings
TTE								
Neelankavil et al. [55]	2012	61	Simulation versus lecture-based education	Fixed-time simulation sessions	Yes	Yes	Simulated	Improved skills in image acquisition and anatomy identification on volunteer subjects
Edrich et al. [56]	2013	46	Simulation versus live volunteer	Fixed-time simulation sessions	Yes	Yes	Simulated	Simulation-based training on simulator was not inferior to teaching on live volunteers
TEE								
Damp et al. [42]	2013	27	Apprenticeship training and simulation versus apprenticeship training alone	Fixed-time simulation sessions	No	Yes	Real	At 1 month, fellows in the simulation group significantly outperformed those in the non-simulation group
Ferrero et al. [43]	2014	42	Simulation versus	Fixed-time	Yes	Yes	Real	Students with the lowest

			lecture-based education	simulation sessions				baseline experience had the best learning curve
Ogilvie et al. [44]	2015	52	Simulation versus theatre-based training	Fixed-time simulation sessions	No	Not investigated	Real	Improved knowledge
Bloch et al. [41]	2017	44	Simulation versus lecture-based education	Fixed-time simulation sessions	Yes	Yes	Real	Improved ability of novice operators; substantial skill level in correct quantification and interpretation of the images
Weber et al. [45]	2019	51	Simulation versus e-learning education	Fixed-time simulation sessions	No	Yes	Real and simulated (two groups)	Improved psychomotor skills and knowledge of the anatomy
Coronary angiography								
Bagai et al. [33]	2012	27	Apprenticeship training and simulation versus apprenticeship	Mastery learning	Yes	Yes	Real	Reduction in procedure time

training alone for
coronary
angiography

Voelker et al. [31]	2015	18	Simulation versus lecture-based training for coronary angioplasty	Fixed-time simulation sessions	Yes	Yes	Simulated	Improved angioplasty skills after simulation
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Fischer et al. [28]	2018	118	Traditional face-to- face teaching versus simulation for coronary angiography interpretation	Fixed-time simulation sessions	Yes	No	Simulated	Improved angioplasty interpretation skills after simulation
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Electrophysiology

De Ponti et al. [35]	2011	14	Simulation versus apprenticeship training for transseptal	Mastery learning	Yes	Yes	Real	Simulation reduced the training time (27-day reduction compared with conventional training)
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catheterization

TEE: transoesophageal echocardiography; TTE: transthoracic echocardiography.

Table 2 Summary of the main simulation modalities used in cardiology.

Type	Description	Advantages	Disadvantages	Cardiology applications
Task trainers [20]	Simulators representing a part of the body (e.g. thorax) for training in basic or specific skills	Lower cost than full-body simulators; easy to set up, move and maintain; efficient for repeatedly practising specific skills	Replacement parts needed in cases of high usage; training limited to the region of interest of the simulator	Simulation of cardiac arrest with objective assessment of quality of chest compressions during cardiac massage; pericardial drainage; intubation with high-fidelity option can integrate difficult airway training by making the tongue swell
Human patient simulators: low-fidelity	Full-body static simulators for a clinical situation or to practise a specific skill	Lower cost than high-fidelity simulators	Risk of lack of realism; unsuitable for group interpersonal skills	Appropriate reactions to emergency situations
Human patient simulators: high-fidelity [7]	Full-body simulator with ability to control the mannequin's various functions, vital signs and haemodynamic variables	Replicate complex physiological changes, (sophisticated voice, movement and sound) in a realistic clinical environment; vital variables (blood pressure, heart	Expensive to buy and maintain; require a high degree of teacher involvement and expertise	High-fidelity model and perfusion simulator can be used to demonstrate extracorporeal membrane oxygenation cannulation, initiation and

		rate) can be adjusted in response to learners' interventions; provide time for medication administration and patient management by learners; allow interdisciplinary training		stabilization; analysis of simulated multiple life-threatening electrocardiograms
Standardized patient [7]	Live person (volunteer patient or actor) who has received specific training to realistically play a role in a specific situation; standardized patients can be placed in scenarios as staff members or family members	Personalized training to adapt to each learner; standardized patients most often participate in the debriefing to provide personalized comments (extra dimension and insight); offers human interaction; teaches how to deal with intense emotional situations; crucial tool for communication skills	Difficult to recruit and train standardized patients; cost of standardized patients; challenging to schedule coordination of standardized patients and clinicians; risk of loss of control and emotional reaction by the standardized patient during the debriefing	Communication skills development (e.g. managing a situation with an aggressive patient who asks to be discharged from hospital against medical advice); development of communication skills related to the announcement of a serious disease or a poor prognosis (e.g. heart failure or cardiac transplantation)
Hybrid simulation [36]	Modelling approach that combines two or more of the	Combines learning a technical act on the simulator with a realistic	Similar to those of standardized patients; difficult to organize	Perform a radial puncture on an arm simulator with a standardized

	<p>following methods: discrete-event simulation, system dynamics and agent-based simulation;</p> <p>traditionally, a standardized patient is combined with a task trainer simulator</p>	<p>patient situation to be managed during this procedure</p>	<p>availability of the standardized patient and the simulator</p>	<p>patient who mimics anxiety or aggression</p>
In situ simulation [7, 25]	<p>Simulation-based teaching physically integrated into the clinical environment in a real intensive care room or cardiac catheterization room</p>	<p>Realistic; important tool to identify latent errors within clinical systems that can compromise patient safety</p>	<p>Issues related to culture, performance anxiety, time pressures and patient perceptions can interfere; significant logistical and human constraints because dedicated staff and a real treatment room are used for the simulation</p>	<p>Assess team management during cardiac arrest occurring in intensive cardiology care; identify system weaknesses, such as equipment ergonomic problems, ineffective protocols and training needs</p>
Serious games [7, 24]	<p>Computer software in which real-world environments are replicated to emphasize educational messages</p>	<p>Great flexibility for learners, who can access the training when they want without constraint</p>	<p>Lack of realism</p>	<p>Teach proper conduct during a medical consultation</p>
VR [26]	<p>Computer-generated three-</p>	<p>Does not require any simulation</p>	<p>Cost; variable quality of graphics</p>	<p>Simulate a patient with acute</p>

	dimensional interactive environment that immerses the learner; necessary equipment includes VR headsets and student devices with charging stations and tablets for the teacher to control the session	space	and realism; technical knowledge required to use software and equipment	heart failure and pulmonary oedema
AR [26]	Overlays digital computer-generated information on real-world objects or places	Possibility of being in a realistic environment	Similar to those of VR	Simulate vessel images combined with a low-fidelity simulator for arterial or central venous catheter insertion training

AR: augmented reality; VR: virtual reality.

Figure 1 and Central illustration.

