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CURRENT OPINION

Simulation in cardiology: state of the art

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Introduction

Simulation is the technique of imitating a process or situation for education, training, modelling of an uncommon or risky scenario, or testing systems when new elements are introduced (such as a new protocol).[1]

Simulation training is not new to medicine. Anatomical models were created in ancient times, and in the 1960s the Norwegian toy manufacturer Laerdal pioneered simulation to practise cardiopulmonary resuscitation and critical event drills.[2] Early models were crude, but they were widely adopted. The HARVEY cardiovascular simulator was one of the first manikins developed which was computer driven and provided replication of anatomy with palpable pulses and auscultatable areas. This allowed medical students to experience some of the findings from clinical examination for the first time in a standardized setting.[3]

More recently, with advances in technology, there has been a rapid expansion in simulating other aspects of healthcare, with increasing sophistication. Modern computing power allows the recreation of complex anatomical and physiological systems programmed to respond to inputs from the user. There have also been advances in manikins and devices to physically replicate the steps of performing complex procedures.

Fidelity is the degree of accuracy with which a simulation replicates a clinical scenario. This is defined in terms of the realism of the environment in which the simulation takes place, the equipment used and the psychological engagement of the learner. It is not necessarily synonymous with the technology of the simulator.[4–6]. Indeed, evidence suggests that the indiscriminate use of high-technology simulators alone is unlikely to be more effective than other methods.[7,8] The ability to use realistic clinical environments (or practice *in situ*), using equipment which closely replicates the look, feel and feedback of clinical situations will facilitate the *immersion* of the learner into the simulation, but it is important to consider their emotional response and behaviour. There is little to be gained if the learner reacts in an artificial manner, or is encouraged to perform risky actions as a result of a lack of engagement. This may result in the learning of poor practice, or a failure to achieve the intended learning. This lack of psychological engagement may be as a result of a scepticism towards the use of simulation or unfamiliarity with the process, including anxiety related to audio–video recordings. Thorough briefing prior to simulations, with an introduction to the equipment and environment used, what to expect, and what capabilities the simulators do not have will help to alleviate some of these issues.

Current drivers

Technology has not been the sole driver for simulation. Recently, quality and safety in healthcare, and reduction in error has been the subject of intense focus, with the recognition that staff training has an important role to play in improving standards. In the European Union, working hours have been moderated for staff, resulting in a significant reduction in training hours and loss of continuity of care.[9] Yet we are now able to offer our patients a wide range of complex and often minimally invasive procedures which require operator skill and practice to master. A report published by the UK Academy of Medical Royal Colleges in 2012 promoted a move towards consultant delivered care, with studies demonstrating that care delivered by less experienced trainees may be inferior.[10] Yet increased direct Consultant care will result in reduced time available for training. Using live procedures for training carries a cost burden due to reduced productivity, potential patient safety concerns, and patient preference is generally towards treatment by senior rather than junior doctors.[11,12] With these pressures, simulation may provide multiple benefits. The Technology Enhanced Learning Framework published in 2011 by the UK Department of Health makes strong recommendations for simulation adoption in routine practice, including the recommendation that skills should be learned in a simulation setting prior to undertaking them on patients.[13]

Importance

Parallels are frequently drawn between healthcare and the commercial aviation industry, in particular when the use of simulation training is discussed; the first recognizable flight simulators were produced before the onset of world war one, only a few years after the first powered flight. Today, simulation is an essential component of flight crew training at all stages, from initial training through to continuing practice. Simulation training has also been adopted widely in

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other 'high-risk' industries. Whilst the parallels drawn between medicine and aviation are frequent, it is important to recognize that the work doctors perform differs markedly from that of pilots, and hence the nature of the simulation should too. There is considerable focus on medical emergencies and practical procedural skills, but with scope to expand to other areas of care. The contribution of human cognitive performance to patient outcomes is well recognized; possession of the required knowledge and technical skills remains essential, but in addition, non-technical skills such as situational awareness and the ability to synthesize information, make decisions and communicate effectively with team members during times of stress and distraction.[14–16]

How does simulation work?

Simulation allows the deliberate practice of all or part of a skill to be undertaken. Complex situations can be broken down into constituent parts reproducibly, and each step rehearsed as many times as necessary to gain competence, with focus on areas which the individual learner or team finds most challenging. This can be equally applied to procedural skills such as the practise of specific parts of catheter-based procedures, and clinical scenarios such as communication during a telephone handover or task prioritization. This can be done under the supervision of a mentor, teacher, or peer who should provide feedback (debriefing) on performance and guidance, including points to focus on at the next repetition. This feedback is critical to performance improvement; there is consensus in education that delivering simulation alone has little or no effect on learning,[17] and may in fact encourage the acquisition and propagation of poor practice. Feedback is the mechanism by which errors in performance are identified and addressed.

Kolb's experiential learning theory is often used as the model for how simulation should be delivered; after an (simulated) experience, the learner is debriefed to examine the events, their own reactions and decisions, and areas of suboptimal performance. These are then abstracted from that specific situation and the learner is encouraged to form new models. The cycle is then completed when the learner is exposed to a similar situation to reinforce changes in practice.[18] This model does depend upon the learner engaging with the simulation in the same way as they engage during clinical practice as discussed above in the section on fidelity.

Simulation debriefing itself is an area of intense study. A number of different approaches have been proposed, including immediate and delayed debrief, the use of video playback and self-debriefing with no approach shown to be superior so far.[17] Simulation should not be applied without context, but used to support existing training and curricula, especially where gaps in provision are identified. It may not be the most appropriate or effective technique to use for all situations, and judicious use is likely to result in more effective learning.[19] It is therefore recommended that simulation delivery is planned according to curriculum and learner needs. This will depend on training needs identified by both learners and their supervisors, to augment clinical training.

Another important theory relevant to the practice of simulation is that of transfer of training.[20] This is based on the theory that learning in one context will transfer to other similar situations.[21] The underlying cognitive theories are similar to those of Kolb; underlying mental models are formed which can be applied to a variety of situations. This has given rise to the term 'transfer effectiveness ratio' which aims to quantify the amount of time saved by a novice practitioner learning a procedure through simulation.[22,23]

The transfer of learning from simulation to clinical practice and consequent improvement in outcomes for patients is perhaps the key question required of research in the area. There have been a number of studies that have demonstrated that the acquisition of technical skills in simulation does lead to an improvement in real life clinical practice.[24] This is likely to be of most use when the skills learnt in simulation are directly relevant to the clinical practice of learners. One advantage of simulation is the ability to recreate uncommon scenarios which are likely to be encountered infrequently during clinical practice, but which require maintenance of skills and knowledge. Transfer to clinical practice is discussed further below.

The acquisition of expert level performance has been studied in professional sport, music, and medical practice. While a number of theories exist as to how and why some individuals are able to perform at a high level, there is consensus that quality and quantity of training exposure are important factors in addition to innate ability.[25,26] Those who perform a procedure at a high volume have better outcomes than those who do so infrequently, and deliberate practice can play an important role in skill acquisition and maintenance.[27] Review of performance is another factor which aids in the acquisition of expertise, most commonly by watching videoed performances back to identify errors and focussing practice on these areas.[28,29] For these reasons, again simulation has been postulated as having the potential to assist clinicians developing technical skills to expert level, providing a safe environment in which to make mistakes, review performance, and the ability to stop the procedure and re-run any parts of the task where necessary.

What can we simulate?

With continuing growth in the range of invasive procedures which require technical expertise, fast changing unstable clinical scenarios and complex therapeutic options, the demands on the cardiologist in training and in practice are intense. Procedural training in particular is an area which concerns many; reductions in training hours limit exposure and there is a continued requirement to stay up to date. A number of simulators for endovascular procedure practice are available; these offer the ability to practise skills such as coronary angioplasty, pacing, electrophysiological studies, transcatheter valve placement, and peripheral vascular interventions. Typically, these have a library of predetermined cases available for the learner to work through, and are able to output metrics such as total procedure time, radiation time, contrast volume used, and replay of images. They offer the advantage of radiation-free practice and in some cases have the facility to generate patient specific models to allow a procedure to be rehearsed.[30] Features such as haptic feedback can enhance the experience, and the ability for the learner to progress at an appropriate rate is important. Echocardiographic simulators are also available for transthoracic and transoesophageal imaging, aiding the acquisition of rare cases for accreditation purposes. For all of these devices, the learner will be able to create a profile and track their progress with support from the educator.[31] Once again it is important that these

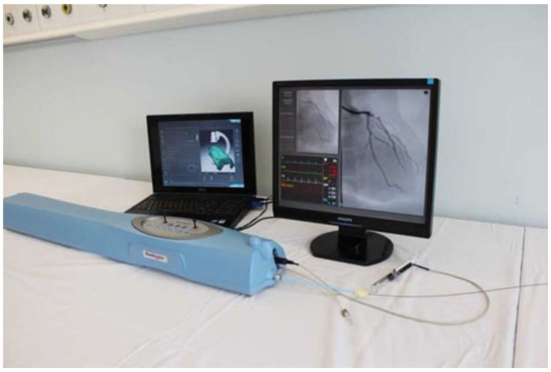

Figure 1 Example of coronary angiography simulator (picture courtesy Hull Institute of Learning and Simulation).

Figure 2 Simulated intra-operative emergency training (picture courtesy Hull Institute of Learning and Simulation).

are not simply used as stand-alone devices for free practice; successful completion of the modules may be achieved with an inappropriate technique (*Figure 1*).

More straightforward part-task trainers for simpler procedures are also available, including venous and arterial puncture, suturing, pericardiocentesis and intercostal drainage. In some cases, low-technology simple models are as effective as more complex devices.[32] There is also a movement towards self-built or customized devices which can be made on a low budget for specific purposes. These may include both prosthetic and animal tissue components. The low cost of such devices means that they can be made widely available in skills centres.[33]

High fidelity patient simulators are now widely available; these offer the ability to replicate complex physiological changes, often with sophisticated voice, movement and sound. Scenarios can be pre-programmed in advance, or as the simulation progresses in response to learner actions. These are typically used to generate simulated clinical scenarios such as emergencies either in purpose built skills centres or transported into clinical environments to be used *in situ*. This requires a higher degree of involvement and expertise on the part of the educator, but the reward is often rich experiences with learning outcomes applicable to everyday practice, which can be responsive in real time to the needs of individual learners. This approach also allows interdisciplinary training to be conducted with teams practising together in their usual working environment. The performance of not only an individual or single professional group but a whole team working together can be assessed and areas to be addressed can be identified which may not be apparent from other training methods.[34] Manikins have a wide variety of features, including portability, voice and urine output, pulse palpation, and auscultation of heart sounds but limitations do remain with regards to movement and battery life. Many operate wirelessly from a controller within a range of 10 m allowing facilitation from a control room or behind screens (*Figure 2*).

Another important role for *in situ* simulation is in the identification of latent errors within clinical systems. Areas for performance improvement among staff can be identified and rectified, but also system weaknesses such as equipment ergonomic problems, ineffective protocols and training needs may become apparent.[35–37]

Actors and standardized patients are often used to deliver simulation either alongside other techniques or alone. While it can be difficult to replicate physical pathology with actors, they can offer human interaction at a level which cannot be replicated by any available devices at present. The actor can then help to debrief the learner, offering an extra dimension and insight. Similarly, actors can be placed in scenarios in roles as staff members, relatives, or distractions.

Hybrid simulation is the term applied to mixing modalities to enhance the experience. An example of this is the situation of an angiographic procedure simulator under drapes alongside an actor playing the part of an anxious patient to allow both the practical skill of cardiac catheterization and the communication skills required when performing the procedure in real life to be simulated.[38,39]

Serious games is the term given to computer software in which real-world environments are replicated, with the goal of achieving specific learning outcomes. Some of these may take the form of simulations, where the learner is expected to play in their own role; however, others allow the learner to assume a different role or character.[40] One of the potential advantages of serious games is that they do not necessitate the purchase of specialist equipment and can often be completed at a time and pace suitable to the learner, allowing more flexible scheduling. Elements of assessment of learning both in terms of knowledge and skill may be incorporated within, and there is some evidence to suggest that motor skills gained using computer games improve motor performance in technical tasks. Assessment of underlying cognitive processes and deeper learning through serious games remains a challenge, however.[41] There is also some concern that in the absence of facilitation, engagement and motivation of learners may vary.[42]

Quality assurance and faculty

Simulation facilities and equipment in isolation cannot provide a complete educational experience. Faculty recruitment and development is critical to the success of simulation activity and can prove challenging.[43] Inexperienced faculty will require training in equipment use and techniques, with particular focus on debriefing, which requires skills not required for other forms of teaching.[44] Support from experienced and committed educators will ease this process and improve commitment. It is recognized that a substantial time requirement from faculty is often required to run successful simulation programmes, and this can be difficult to schedule.

The use of standardized, prepared scenarios, and learning objectives which align with curriculum objectives will assist in ensuring quality, alongside response to learner feedback and regular review of activity.[19] Faculty observation and debriefing of teaching performance will also develop. In North America, the Society for Simulation in healthcare runs an accreditation programme for simulation centres and individual educators, setting minimum standards required.[45] In Europe, moves are afoot for similar measures, although there is concern that formalizing the process may put some off volunteering time to education.

The evidence for simulation

One of the challenges of simulation has been the lack of evidence for patient benefit and quality of care. One important model used in educational research is the Kirkpatrick hierarchy.[46] Evidence for an educational intervention resulting in a change to patient outcome is considered to be the highest level available. Below this lies a change in behaviour or performance, knowledge below this and reaction at the lowest level. Studies assessing simulation against other educational techniques or no intervention are generally small in scale, and frequently do not recruit the entire healthcare team who will be responsible for the care of a specific group of patients, focusing instead on doctors or other health professional groups. Meta-analyses have demonstrated an improvement in outcomes, when compared with no educational intervention, but we lack evidence for superiority over other forms of learning.

Many studies demonstrate a positive reaction to simulation or improved confidence. However these advantages correlate poorly with external assessment. The utility of such measures is therefore questionable.[47–49]

Further studies have demonstrated transfer of knowledge from simulation to the clinical environment, although retention studies yield conflicting results, with some demonstrating decay within 6 months, and others showing good retention at beyond 12 months. For resuscitation, studies have demonstrated a benefit from the use of high fidelity simulation over traditional resuscitation training. Increased survival from cardiac arrests in centres with these programmes running has been demonstrated in one meta-analysis.[50–53]

Some studies examining the acquisition of expert performance in catheter-based techniques and laparoscopic surgery have used performance in simulation as the measure of outcome, demonstrating that practice on a simulator improves performance on a simulator.[29,54,55] Metrics studied include time taken for procedure completion, complication rates and expert assessment of skills performance. There is shortening of the learning curve, with a time to plateau after about 10 repetitions to acquire basic competence, but no evidence of transfer to clinical practice.[56] Another study has demonstrated an improvement in total fluoroscopic time during electrophysiology procedures after simulation training.[57] Use of an echocardiographic simulator has been shown to aid image acquisition skills in novices with a similar efficacy to live patient practice.[58,59] Use of a laparoscopic simulator as a warm-up prior to performing an operative list shortens procedure time and reduces error and complications.[60,61] Simulation has also been used to demonstrate an increase in the performance of other technical skills such as airway manipulation when assessed by expert or gold standard criteria.[62,63] A few landmark trials have shown improvement in patient outcomes following intensive, targeted simulation training, notably in neonatal outcomes and blood stream infections, and consequent cost savings from the improved outcomes.[64–66]

Disadvantages of simulation

Simulation, by definition, attempts to recreate real situations, scenarios and procedures without the presence of a patient. Inevitably, therefore, there will be an element of unreality (e.g. catheter procedures lack fluid or blood). Procedural skills are often broken down into component parts, and unless using a hybrid approach, a procedure simulator will offer no human interaction. In addition, any equipment malfunction during the simulation can break the immersion, and disrupt any learning that has occurred. Equipment purchase can be costly, and with rapid improvements can quickly become outdated. Software updates and additional scenarios are often available, but often at extra cost. The risk of broken immersion here is probably the most serious, if learner perceives that what is happening is an artificial feature of the simulation, their responses will be different to those in clinical practice, potentially breaking the opportunity for transfer of training. Ingraining of poor practice may occur in the absence of adequate supervision where simulator design is poor, and this will not necessarily be reflected in the output metrics from the simulator such as total procedure time, radiation time or contrast volume.[67,68] Unlearning these undesirable behaviours can be difficult.[69] Additionally, skills learned on a single occasion will decay if regular practice is not maintained.[70]

Despite the presence of high technology, there is a substantial learning curve for both learners and facilitators. The technology itself and acquisition of debriefing skill can be daunting to educators, and if not used frequently, these skills themselves may decay.[43] Increased use of pre-prepared learning packages and simulation scenarios may remove some freedom from the teachers and learners to tailor their own learning. Mentorship and peer tutoring programmes may help with this somewhat, and the use of virtual reality simulation can allow asynchronous learning to occur. The logistics of arranging staff time to train, especially if entire team training is desired can be challenging. In acute care areas where there is little 'downtime'. There needs to be high level management 'buy-in' to support such activities to ensure success.

Future directions

The technology of simulation continues to advance, offering devices capable of improved fidelity in virtual reality simulation, more sophisticated procedural practice and advanced patient simulators. In addition, there is a growing and enthusiastic simulation faculty, with national and international societies and conferences with peer reviewed publications available. The evidence base continues to grow as studies progress and many hospitals and clinics adopt simulation, and there is an active research community. Documents such as the UK Technology Enhanced Learning framework demonstrate a centrally driven agenda for increased adoption of simulation, with the goal of improving patient safety. One major recommendation is that before any healthcare professional performs a skill on a patient, they should have the opportunity to perform that skill in simulation.[13] This is especially relevant as training hours and exposure to patients by trainees is reduced. Simulation will play an important part in ensuring adequate exposure as a result of this reduction in training hours. Ensuring equitable access for all, and the time to train will be a major challenge for health services.

Simulation is being adopted in training curricula, particularly in undergraduate medicine and early years postgraduate training.[71] Specific simulation curricula are also emerging.[72] Those taking up cardiology training posts with limited procedural experience will be required to achieve minimum standards of competence using simulation prior to performing procedures on patients, and experienced operators will be able to develop competence in newly developed technologies.[73,74] Serious and uncommon emergency drills in simulation will be routinely practised by teams, either *in situ* or at skills labs and team debriefing will allow for a more open and reflective culture.[75] Several simulation specific assessment tools have been developed and validated for these purposes, and may be used in a formative fashion to track progress or highlight areas of focus.[76] There is also a role for experienced practitioners to use simulation, both in maintaining existing skills and practising uncommon scenarios, and potentially in continued demonstration of competence.[77,78]

Summative assessment by simulation remains controversial, although some studies have demonstrated validity.[79] Without compelling evidence that clinical practice is actually improved, and with few reliable assessment tools, it is hard to make a case for high stakes assessments with simulation.[80] If a doctor's performance falls short in simulation, there may be other factors not at play in clinical practice which account for this.[81] Some areas, notably in North America, incorporate simulation assessment in certification.[82] There is a stronger case for the use of simulation to provide remedial training for those in difficulty, allowing them to develop individualized learning plans focusing on specific procedure skills, communication or human factors.[83]

Threats to greater adoption include the resource cost of equipment and facility acquisition and the time required of both faculty and learners. It is difficult to envisage mandated simulation training until access to simulation is universal, and staff are granted sufficient time within their scheduled job plans to make use of this. When new equipment, protocols or staff are introduced, *in situ* simulation can be used to ensure familiarization and to identify safety threats prior to 'going live'.

Conclusions

After a slow start, simulation in Cardiology is expanding rapidly, due to advances in technology, shortened training hours and increased healthcare complexity. Simulation aims to enhance patient safety through improved procedural competency and human factors training in a risk free environment. It is particularly applicable to a practical, procedure-orientated, 'craft' specialty such as Cardiology. Simulation can be useful for novice trainees, experienced clinicians (e.g. for revalidation) and team working. New procedures can be tested prior to implementation, rarely used skills can be maintained, and underperforming doctors can be supported. It is unknown whether patient outcomes are improved, and issues of access and providing training time are challenges to be surmounted.

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CARDIOVASCULAR FLASHLIGHT

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Intracardiac cement embolization in a 65-year-old man four months after multilevel spine fusion

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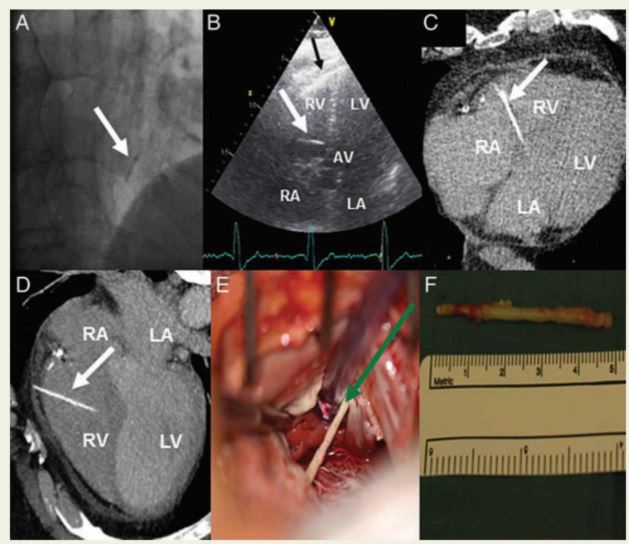

A 65-year-old man was transferred to our cardiac intensive care unit under suspicion for NSTEMI. His medical history included beside hypertension, diabetes mellitus, and adipositas (BMI 33 kg/m^2), multilevel spine fusion L3–S1 4 months ago due to chronic back pain caused by a lumbar radicular syndrome. After rising from an armchair, the patient described a sudden onset of right thoracic, stabbing pain with radiation in the dorsal neck which was breath and position dependent.

ECG documented sinus rhythm (HR: 68 b.p.m.), left anterior bundle branch block, and right bundle branch block. However, a paroxysmal atrial fibrillation with spontaneous conversion into sinus rhythm was seen during monitoring. Blood tests revealed an elevated hs-troponin 80 ng/L (<14 ng/L) and an elevated D-dimer of 1.68 mg/L (<0.5 mg/L).

Coronary angiography showed only coronary sclerosis without significant stenosis. However, in the AP view there was a mobile, toothpick-like, foreign body in projection on the right ventricle (*Panel A* and Supplementary material online, *Videos S1 and S2*). Echocardiography showed a near normal LV-EF with normal valve function. In concordance with the fluoroscopy, however, a floating object in the right ventricle (*Panel B*, withe arrow) and a pericardial separation filled with echo dense material was detected (*Panel B*, black arrow).

A computerized tomography showed a pericardial effusion in front of the right ventricle and the presence of a foreign body (50×2 mm) in the right ventricle, almost parallel to the tricuspid valve, fixed between the anterior wall and the interventricular septum. The object perforated the lateral wall up to the epicardial fat (*Panels C* and *D*).

In the synopsis of the findings, a bone-cement embolism after the multilevel spine fusion was suspected. The patient was sent to the operating theatre due to the threat of a cardiac tamponade. After median sternotomy and opening of the pericardium, a bloody pericardial effusion originating from the perforated tip of the foreign body in the anterior right ventricle area became visible. After establishment of the extracorporeal circulation and opening of the right atrium, the foreign body was seen in the right ventricle through the tricuspid valve (*Panel E* and Supplementary material online, *Video S3*). The object was completely removed (*Panel F*) and the right-ventricular perforation was overstitched. The pathological examination of the object confirmed bone cement. The following clinical course was uneventful.

In summary, the patient experienced a bone-cement embolism 4 months following multilevel spine fusion. Perivertebral cement leakage after augmented screw fixation is a frequent complication. However, cement leakage into the venous system rarely occurs after pedicle screw fixation. This case reminds of the potential risk for cement embolization as a cause of chest pain even long after spine surgery.

Supplementary material is available at *European Heart Journal* online.