Simulator Training in Interventional Cardiology

Abhishek Joshi and Andrew Wragg

Barts and The London NHS Trust, Bart's Heart Centre, St Bartholomew's Hospital, London, UK

Abstract

Simulator training in interventional cardiology is becoming a central part of early career acquisition of technical and non-technical skills. Its use is now mandated by national training organisations. Haptic simulators, part-task trainers, immersive environments and simulated patients can provide benchmarked, reproducible and safe opportunities for trainees to develop without exposing patients to the learning curve. However, whilst enthusiasm persists and trainee-centred evidence has been encouraging, simulation does not yet have a clear link to improved clinical outcomes. In this article we describe the range of simulation options, review the evidence for their efficacy in training and discuss the delivery of training in technical skills as well as human factor training and crisis resource management. We also review the future direction and barriers to the progression of simulation training.

Keywords

Simulation, training, part-task, immersive, haptic, human factors

Disclosure: The authors have no conflicts of interest to declare.

Received: 12 September 2015 **Accepted:** 26 November 2015 **Citation:** *Interventional Cardiology Review*, 2016;**11**(1):70–3 DOI: 10.15420/icr.2016.11.1.70

Correspondence: Andrew Wragg, Department of Cardiology, Bart's Heart Centre, St Bartholomew's Hospital, West Smithfield, EC1A 7BE, UK.

E: andrew.wragg@bartshealth.nhs.uk

Simulator training provides the opportunity to acquire and practise technical skills in a safe, controlled and reproducible environment without the risk of harming patients. Although there is no evidence to prove that patient outcomes are worse if trainees undertake interventional procedures, there is an inevitable concern that procedures may not be as safe or successful if undertaken by doctors in training.^{1,2} Experiential training in the workplace exposes patients to the theoretical risks of the learning curve of trainees, especially in the radial era.³ Further, as catheter laboratory (cath lab) scheduling time is precious, having trainees undertaking procedures that inevitably take longer can be difficult to justify when the focus is on lab efficiency. Simulator training has the potential to offer focussed training opportunities that allow both the time and space to develop interventional skills.⁴ These skills can then be analysed and critiqued without any risk of patient harm or impact on the cath lab schedule. Enthusiasm for simulation training has increased dramatically over recent years because advances in technology have allowed the delivery of authentic simulated training opportunities.

Despite a broad body of evidence supporting the use of simulation in medicine, there are still some concerns when this evidence is extrapolated to less studied specialties.⁵ Simulation training enhances learning, especially when used alongside traditional, apprentice models of training, and it is now increasingly recognised in cardiology and interventional training programs.^{6,7} In interventional cardiology the evidence and experience of simulation continues to grow, although presently there are no studies that have documented a positive effect on patient outcomes.

As mentioned, many healthcare settings have restricted the weekly working hours for doctors in training due to an increasing demand on

cath lab schedules.^{8,9} Institutions are becoming risk averse and often limit training opportunities through fear that patient outcomes might be lowered when procedures are undertaken by doctors in training.¹ These two factors reduce exposure to practical procedures thus weakening the skills and experience of future specialists. Experience is an essential component of becoming an independent operator. Solutions are therefore required to enhance and increase training opportunities and simulation is one of the most useful practical options. Supervised simulated training experiences away from the bedside in a controlled, authentic environment will allow trainees to explore and develop techniques and consolidate their learning without exposing patients to risk, as has been seen in other medical specialties.

The Role of Simulation in Other Medical Specialties

Simulation is a long established form of medical training.¹⁰ The early cardio-pulmonary resuscitation dolls are a simple but effective way of delivering the core elements of resuscitation training by providing a safe environment to practise and rehearse tasks, algorithms and also create opportunities to receive feedback on performance.^{11–13} Simulation is a central part of resuscitation training and there is a large body of evidence to suggest that a number of metrics, from processes to patient outcomes, are positively affected through simulation of a simple, repeatable clinical scenario.¹² Simulated laparoscopic and endovascular surgery reproduce some of the technical skills in interventional cardiology, delivering the opportunity to simulate a complex, multi-step procedure, and using screen-based representations of the procedure rather than direct visualisation of the operative field. Virtual reality simulators have been shown to improve patient outcomes in real-life laparoscopic surgery¹⁴ and reduce procedural error.¹⁵ Part-task simulators have been used to focus on single steps in the process.

A multitude of simulated procedures are now available across multiple commercial platforms, ranging from basic diagnostic angiography through to complex coronary interventions. Specific packages also exist for more complex structural interventions, including atrial septal defect (ASD) closure and transcatheter aortic valve implantation (TAVI). Numerous simulators are also available for training in trans-thoracic and trans-oesophageal echocardiography, cardiac rhythm device implantation and testing.

Part-task Training Simulators

Although many cardiologists have seen or experienced the 'Immersive' cath lab simulators, there is still a role for simulators that allow the learning of specific single technical skills. Rather than simulate an entire procedure or clinical encounter, the constituent components of the task can be simulated and rehearsed, so-called part-task training (PTT). There is some evidence, primarily from psychological literature, that PTT improves the rate of skill acquisition when properly integrated into a learning framework,^{16–18} although there is less specific evidence for medical procedures. Arterial and venous access and closure lend themselves well to this format of training as they are discrete steps in interventional practice. A number of low and high fidelity simulators exist to aid these part-tasks, which can simulate pulsatile arterial blood flow for vascular access training. More sophisticated simulators allow practise of the Seldinger technique for vascular access^{19,20} and numerous simulators are available for training on vascular closure devices.

Cardiac Catheter Laboratory Simulators

Most cardiology interventions are highly complex, multi-step procedures and the technical skills that underpin them need to be learnt in an authentic environment. Sophisticated cath lab simulators are now available that combine hardware user interfaces with simulator software with the aim of providing high fidelity representations of real life practice, providing both visual and haptic (or tactile) feedback for the operator. As well as part-task simulations of individual parts of a procedure, modern simulators can provide immersive exposure and training in an entire clinical encounter. A library of simulated cases provides context and clinical background for trainees with the opportunity to administer medications or other therapies before undertaking a simulated procedure. Sensors detect the manipulation of real world tools (such as catheters and wires) in the simulator and translate these into movements of virtual objects on screens integrated into authentic fluoroscopic images. Tools can also return haptic or touch-based feedback to operators using either passive resistance to movement, or active motorised movement of the tool. These are felt by the operator as changes in the resistance to the movement of the tool. Simulators also allow control of the virtual fluoroscopy C-arm and display physiological data, which can be manipulated during the procedure through either by administration of drugs, or the success or otherwise of the procedure. Some systems allow other ways to view the simulated vascular system, particularly through the use of 3D rendered models, allowing better understanding in the anatomy. After the procedure is completed there are scoring systems that provide detailed technical feedback on the procedure, including unsafe catheter manoeuvres and inappropriate wire placement.

Does Simulation Improve Training in Medicine?

Despite the extensive selection of simulators available, what is the evidence that simulation is beneficial to trainees or indeed their future patients? Although there is widespread acceptance of simulation as a training modality across many medical and surgical specialties,^{21–24}

it is important that the evidence behind it is understood. There still remain empirical questions about the relevance and efficacy of simulation despite what is now a large body of evidence. In cardiology there are studies of efficacy although many cardiologists always want more. Studies on the effects of simulator training tend to be small and are extremely heterogeneous in the techniques simulated, the design of the educational intervention and the measured outcomes. However, a large meta-analysis pooled data from 609 studies of simulation in training for medical procedures in an attempt to gauge the potential impact of simulation training across medicine.⁵ This meta-analysis included studies of colonoscopy, laparoscopic surgery, suturing, emergency resuscitation, physical examination and team leadership amongst a vast range of topics. Studies of endovascular procedural training accounted for 10 studies. All included studies compared simulation training with no intervention; 66.5 % were pre-test/post-test studies and 22.5 % were a randomised, two-group design. Overall, 32,556 trainees were included and strong effects were seen for improvements in broad knowledge and skills categories in studies with objectively measured outcomes. More modest effects were seen in the small number of trials (n=32) reporting direct patient outcomes. A second meta-analysis looked specifically at patient outcomes after simulator training across a heterogeneous group of medical skills.²⁵ Fifty studies were included and the analysis found improvements in reported patient outcomes when compared to no intervention.

Whilst these data are encouraging for the general principle of improved outcomes with simulation, they are often drawn from small, single-centre studies with short follow-up periods. Further, whilst there is a general trend for simulation to improve outcomes compared with no intervention, no specific feature of simulation has been positively correlated with improvement in practice. It is therefore not clear how simulator training improves these measured outcomes, nor whether this robustly translates to improved patient outcomes. However, as cardiologists we can be over focused on seeking hard evidence for changes in important clinical end points before we embrace new technology. Most established training opportunities and structures were never submitted to the rigours of a randomised trial and we should accept that the face value and authenticity of modern simulators is strong and perhaps not be over preoccupied on wanting definitive evidence of clinical benefit.

Transferring to the Catheter Laboratory: Evidence in Interventional Cardiology?

What is the evidence for the impact of simulation training in interventional cardiology? There are three studies investigating simulation training and transfer of skills to cardiac angiography procedures.^{26–29} A single-centre trial based in Toronto enrolled 27 cardiology trainees over the course of one year (2011–12), and assessed their baseline technical proficiency in the 'real-life' catheter laboratory through two, observed and supervised femoral diagnostic angiograms.²⁹ Trainees were scored using technical and global performance scores. They were then block-randomised by year of clinical training to the control arm, who continued their usual, clinical training and the intervention arm. The intervention arm received between two and eight hours of mentored simulator training until a specific competence marker (being able to complete a full angiogram independently) was achieved. Trainees in the intervention arm also had full access to the simulator equipment for a week. At the end of the one-week intervention, trainees were again assessed on the performance of two femoral angiograms, with a second technical and global score calculated.

The authors report a clear improvement in technical performance score over the training period for those in the simulator arm and no such improvement for those in the control arm. Statistically significant improvement was seen for global performance scores in both simulator and control groups. There was a greater effect on technical scores for those trainees with little prior experience. Although the study design had limitations, such as problems with effective randomisation and study group imbalance (there were more experienced operators in the simulation arm of the trial), the results are encouraging and prove that simulation does improve clinical skills. It would be easy to suggest that the control trainees might have achieved the same results if given an additional eight hours of training time in the real cath lab, but this was not the reason for the study. As previously described, the benefit of simulation training is to re-create authentic training experiences in a risk averse training landscape that is often short of enough real opportunities.

More recently, a prospective, single-centre study from Chicago measured the performance of 14 early interventional trainees before and after a three-hour training session with one hour of didactic teaching and two hours of simulator training.²⁸ Trainees demonstrated significant improvements in their scores on an investigator-designed checklist for quality in diagnostic coronary angiography. This included appropriate consent, safety and sterile technique, description of placement of sheath (the simulator used does not include arterial puncture), correct exchange of catheter over wire and engagement and imaging of left and right coronary system. The trainees also demonstrated reduced fluoroscopy time and total procedure time but did not use significantly less contrast or better wire technique in the real world cath lab. Trainees themselves felt the exercise to be valuable.

The marked improvement in technical and non-technical skills from less than one day of training is encouraging, although the authors do not report which skills drive the significant improvement. This study also shows improvement in outcomes that could be directly related to patient outcomes. The authors may be criticised for using their own checklist to assess progression, rather than an externally validated measure, but no standardised measurement exists to date.

The two studies demonstrate some benefit to trainees, if not patients, from simulator training, however not all of the evidence in cardiology is positive. A retrospective cohort study from Stockholm provides another direct assessment of the transfer of skills from simulator to cardiac catheterisation.³⁰ The study identified 58 novices who began training during the study period, 20 % of whom attended an angiography simulator course. These trainees were enrolled in a two-day course comprising six hours of supervised simulator training and six hours of lectures. The simulator was also available out of course time for practice. Registry data for the outcomes of these operators as they progressed in their careers was collected and analysed. The study therefore collects patient-centred data per operator, including contrast dose received, fluoroscopy time and complication rates. Surprisingly, trainees who were enrolled in the simulator course appeared to perform less well than those who had only 'real-life' training. Fluoroscopy times were longer for simulator trained operators and learning curves for these participants showed a slower reduction in screening times. Course attendees had a higher rate of vascular complications. It is very tempting to draw conclusions about the potentially negative consequences of some simulation training. However, this data may relate to the course design and delivery and as a retrospective analysis the results are likely to be confounded by numerous other variables. Regardless, the

study does emphasise the point that simulation training needs to be authentic, delivered in a formal, structured manner and ensure that it does not allow the delegates to acquire potentially harmful approaches to procedures, one being over confidence. Without good guidance and high fidelity training, bad habits can easily translate into clinical practice.

Are Randomised Studies to Prove the Benefits of Simulation Training Needed?

An important question to consider when reviewing the data for educational interventions is whether the study design, adapted from medical trials of therapeutics and interventions, is the right way to measure educational impact and change in practice. Educationalists have multiple tools for assessing educational interventions that generally rely on the endpoint of a real clinical outcome.³¹ Whilst it is instinctively attractive to cardiologists to measure definable endpoints, the process of taking measurable outcomes and comparing them across groups may not capture the entire benefits of an educational intervention. Specifically, it is unlikely to be possible to accurately assess or measure trainees' use of reflection after training, or the effects of increased or reduced confidence on performance. On the other hand, the self-reported measures from trainees of their learning outcomes tend to be subject to reporting biases and may reflect intention but not necessarily action. Regardless, across medicine, and to a lesser degree cardiology, there is now strong evidence to show that simulation has an important role to play in training and it is arguable that further trials focused on clinical endpoints may not be appropriate or necessary.

Beyond Screening Time – Human Factors Training and Crisis Resource Management

The real clinical benefits of simulation may lie in human factors training. Despite the authentic nature of modern interventional simulators, the training is often delivered in a classroom environment which is completely different from a real cath lab. In addition to the focussed development of technical skills, the role of simulation in medical training has been used to train for rare events, and to train in non-technical or 'human' factors. This has been extensively used, an example being in cardiac arrest management where Advanced Life Support³² is used extensively in aviation. This type of training is best delivered in an immersive environment that brings together an authentic scenario with a real team grappling with difficult clinical problems supported by high fidelity simulation equipment. The study of crisis resource management (CRM) requires the development of communication, teamwork, leadership, situational judgement and decision-making skills.³³ Simulated situations again appear to provide a safe and controlled environment with the opportunity for structured feedback to improve performance. Human factors training often constitutes a team of trainees working in a simulated medical environment with a developing clinical scenario driven by trainers who either control the environment or directly interact with trainees as part of the clinical team or as patients.³⁴ Training sessions can be viewed live by other trainees or recorded as a video and replayed to trainees to allow reflection and analysis. Given the frequently acute nature of interventional cardiology, the need to be able to manage rare events and complications the benefits of improving CRM skills appear clear. This type of immersive cath lab training is being increasingly used to allow individuals and teams to work more effectively together in emergency situations and when unexpected, potentially life-threatening events or complications can occur.

Most research in this field is led by anaesthetic, emergency and critical care medical teams. A systematic review of the literature on

CRM training included over 80 studies. Most of the studies focused on either a change in the trainees' perspective or performance during the simulation. However, nine publications had study designs that reported either changes in real clinical practice or in actual patient outcomes after CRM training had been completed. These endpoints included mortality, resuscitation time or perinatal outcomes.³³ These studies documented beneficial changes in clinical practice as well as improvement in patient outcomes, including resuscitation time and length of hospital stay. Most studies reported a clear change in practice after simulated scenario training, and patient outcome measures, including one study which showed an improvement in mortality after perinatal cardiac arrest. Although many of these studies were small and single-centre with a risk of bias, the conclusions are encouraging and would support the more widespread use of this type of immersive simulation.

The use of actors or real patients in simulator situations is conceptually attractive and can access a complex web of conscious and unconscious professional responses. These include empathy, communication, clinical judgment and decision making.³⁵ It is clear that the use of actors as patients improves the transferability of simulator training to clinical practice, as the simulated situation carries the extra import of a patient-centred approach.

Accessibility and Cost

High fidelity simulators and immersive training environments are expensive. The investment required to acquire simulation hardware is significant and there has been a demand from training bodies to see demonstrable benefits from simulator training before purchasing the devices, some costing in excess of £90,000. Due to the increasing

positive evidence and the demand for simulation to fill the training gap, an increasing number of training centres have purchased the simulators. Perhaps not unexpectedly, access to simulation training is variable at present. In the UK for example, not all trainees have access to simulators locally although there are national programmes run by the British Cardiac Society that offer structured training programs to all trainees. Access to simulation is also variable in Europe.⁷

Conclusion

Simulator training has now been widely accepted as an important tool for procedural training and is seen as an important future development for interventional cardiology training programmes across the world. The BCS, ESC and AHA are all incorporating simulator training into their respective curricula and it is worth reflecting that other, more traditional, learning methods have been accepted in medicine without satisfying the rigorous demands of demonstrating a statistical benefit in a clinical outcome study. In addition to its clear face value, there actually is an increasing body of evidence across medicine, not just in cardiology, to support the use of simulation and its further roll out. Currently, access to simulators is variable and significant investment in equipment and trainer time will be required to improve access for all trainees in the future. Beyond the acquisition of technical and procedural skills, it is likely that the greatest benefit of simulator training will be to improve team-working and awareness of human factors in the often highly pressured cath lab environment. Training for rare events is another potential benefit. Simulator training provides a safe and flexible range of opportunities to practice technical and non-technical skills, and its use is likely to grow and be of great benefit to cardiologists of the future, and their patients. ■

- Jones DA, Gallagher S, Rathod K, et al. Clinical outcomes after myocardial revascularization according to operator training status: cohort study of 22,697 patients undergoing percutaneous coronary intervention or coronary artery bypass graft surgery. *Eur Heart J* 2013;**34**:2887–95. DOI: 10.1093/eurheartj/ehs161. PMID: 23677845.
- Barbush IM, Minha S, Gallino R, et al. Operator learning curve for transradial percutaneous coronary interventions: implications for the initiation of a transradial access program in contemporary US practice. *Cardiovasc Revasc Med* 2014;**15**:195–9. DOI: 10.1016/j.carrev.2014.03.001. PMID: 24746598.
- Looi JL, Cave A, El-Jack S. Learning curve in transradial coronary angiography. *Am J Cardiol* 2011;**108**:1092–5. DOI: 10.1016/j.amjcard.2011.06.009. PMID: 21798498.
- Fox KF. Simulation-based learning in cardiovascular medicine: benefits for the trainee, the trained and the patient. *Heart* 2012;**98**:527–8. DOI: 10.1136/heartjnl-2011-301314. PMID: 22337950.
- Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA, American Medical Association* 2011;**306**:978–88. DOI: 10.1001/jama.2011.1234. PMID: 21900138.
- Harold JG, Bass TA, Bashore TM, et al. ACCF/AHA/SCAI 2013 update of the clinical competence statement on coronary artery interventional procedures: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence. *Circulation* 2013;**128**:436–72. DOI: 10.1161/CIR.0b013e318299cd8a. PMID: 23658439.
- Fox K, Bradbury K, Curran I, et al. Working Group Report on Simulation Based Learning August 2011. 2011;(August).
- Iglehart JK. Revisiting duty-hour limits—IOM recommendations for patient safety and resident education. *N Engl J Med* 2008;**359**:2633–5. DOI: 10.1056/NEJMp0808736. PMID: 19052119.
- Moonesinghe SR, Lowery J, Shahi N, et al. Impact of reduction in working hours for doctors in training on postgraduate medical education and patients' outcomes: systematic review. *BMJ* 2011;**342**(mar22_1):d1580. DOI: 10.1136/bmj.d1580. PMID: 21427046.
- Cooper JB, Taqueti VR. A brief history of the development of mannequin simulators for clinical education and training. *Qual Saf Health Care* 2004;**13** Suppl 1:11–8. PMID: 15465949.
- Perkins GD. Simulation in resuscitation training. *Resuscitation* 2007;**73**:202–11. PMID: 17379380.
- Mundell WC, Kennedy CC, Szostek JH, Cook DA. Simulation technology for resuscitation training: a systematic review and meta-analysis. *Resuscitation* 2013;**84**:1174–83. DOI: 10.1016/j.resuscitation.2013.04.016. PMID: 23624247.
- Perkins GD, Kimani PK, Bullock I, et al. Improving the efficiency of advanced life support training: a randomized, controlled trial. *Ann Intern Med* 2012;**157**:19–28. DOI: 10.7326/0003-4819-157-1-201207030-00005. PMID: 22751757.
- Seymour NE, Gallagher AG, Roman SA, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Ann Surg* 2002;**236**:458–63; discussion 463–4. PMID: 12368674. PMID: PMC1422600.
- Gallagher AG, Seymour NE, Jordan-Black J-A, et al. Prospective, randomized assessment of transfer of training (ToT) and transfer effectiveness ratio (TER) of virtual reality simulation training for laparoscopic skill acquisition. *Ann Surg* 2013;**257**:1025–31. DOI: 10.1097/SLA.0b013e318284f658. PMID: 23426342.
- Goettl BP, Shute VJ. Analysis of part-task training using the backward-transfer technique. PMID: 11541091.
- Sülzenbrück S, Heuer H. Effective part-task training as evidence of distinct adaptive processes with different time scales. *PLoS One Public Library of Science* 2013;**8**:e60196. Epub 2013 Mar 27. DOI: 10.1371/journal.pone.0060196. PMID: 23544133. PMID: PMC3609823.
- Wickens CD, Hutchins S, Carolan T, Cumming J. Effectiveness of part-task training and increasing-difficulty training strategies: a meta-analysis approach. *Hum Factors* 2013;**55**:461–70. PMID: 23691838.
- Luboz V, Zhang Y, Johnson S, et al. ImaGiNe Seldinger: first simulator for Seldinger technique and angiography training. *Comput Methods Programs Biomed* 2013;**111**:419–34. DOI: 10.1016/j.cmpb.2013.05.014. PMID: 23787028.
- Luboz V, Hughes C, Gould D, et al. Real-time Seldinger technique simulation in complex vascular models. *Int J Comput Assist Radiol Surg* 2009;**4**:589–96. DOI: 10.1007/s11548-009-0376-0. PMID: 20033335.
- Fairhurst K, Strickland A, Maddern G. The LapSim virtual reality simulator: promising but not yet proven. *Surg Endosc* 2011;**25**:343–55. DOI: 10.1007/s00464-010-1181-0. PMID: 20614142.
- Hishikawa S, Kawano M, Tanaka H, et al. Mannequin simulation improves the confidence of medical students performing tube thoracostomy: a prospective, controlled trial. *Am Surg* 2010;**76**:73–8. PMID: 20135944.
- Snyder CW, Vandromme MJ, Tyra SL, Hawn MT. Retention of colonoscopy skills after virtual reality simulator training by independent and proctored methods. *Am Surg* 2010;**76**:743–6. PMID: 20698383.
- Kneebone R. Simulation in surgical training: educational issues and practical implications. *Med Educ* 2003;**37**:267–77. PMID: 12603766.
- Zendejas B, Brydges R, Wang AT, Cook DA. Patient outcomes in simulation-based medical education: a systematic review. *J Gen Intern Med* 2013;**28**:1078–89. DOI: 10.1007/s11606-012-2264-5. PMID: 23595919. PMID: PMC3710391.
- De Ponti R, Marazzi R, Ghiringhelli S, et al. Superiority of simulator-based training compared with conventional training methodologies in the performance of transseptal catheterization. *J Am Coll Cardiol* 2011;**58**:359–63. DOI: 10.1016/j.jacc.2011.02.063. PMID: 21757112.
- De Ponti R, Marazzi R, Doni LA, et al. Simulator training reduces radiation exposure and improves trainees' performance in placing electrophysiologic catheters during patient-based procedures. *Heart Rhythm* 2012;**9**:128–5. DOI: 10.1016/j.hrthm.2012.04.015. PMID: 22516184.
- Schimmel DR, Sweis R, Cohen ER, et al. Targeting clinical outcomes: Endovascular simulation improves diagnostic coronary angiography skills. *Catheter Cardiovasc Interv* 2015 Jul 21 [Epub ahead of print]. DOI: 10.1002/ccd.26089. PMID: 26198625.
- Bagai A, O'Brien S, Al Lawati H, et al. Mentored simulation training improves procedural skills in cardiac catheterization: a randomized, controlled pilot study. *Circ Cardiovasc Interv* 2012;**5**:672–9. DOI: 10.1161/CIRCINTERVENTIONS.112.970772. PMID: 23048053.
- Jensen UJ, Jensen J, Olivecrona G, et al. The role of a simulator-based course in coronary angiography on performance in real life cath lab. *BMC Med Educ* 2014;**14**:49. DOI: 10.1186/1472-6920-14-49. PMID: 24621310. PMID: PMC3995776.
- McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. Effect of practice on standardised learning outcomes in simulation-based medical education. *Med Educ* 2006;**40**:792–7. PMID: 16869926.
- Isenberg DL, Bissell R. Does advanced life support provide benefits to patients?: A literature review. *Prehosp Disaster Med* 2005;**20**:265–70. PMID: 16128477.
- Boet S, Boul MD, Fung L, et al. Transfer of learning and patient outcome in simulated crisis resource management: A systematic review. *Can J Anesth* 2014;**61**:571–82. DOI: 10.1007/s12630-014-0143-8. PMID: 24664414. PMID: PMC4028539.
- Scrivener R. Human factors – what are they? 2014. Available at: <http://bit.ly/1Q1M3el> (accessed 4 December 2014)
- Kneebone R, Nestel D, Wetzel C, et al. The human face of simulation: patient-focused simulation training. *Acad Med* 2006;**81**:919–24. PMID: 16985358.