

REVIEW ARTICLE

Use of simulation to improve management of perioperative anaphylaxis: a narrative review

Helen Kolawole^{1,2,*}, Anne Berit Guttormsen^{3,4}, David L. Hepner⁵, Mogens Kroigaard⁶ and Stuart Marshall^{1,2,7}

¹Department of Anaesthesia and Perioperative Medicine, Monash University, Melbourne, Australia, ²Department of Anaesthesia, Peninsula Health, Melbourne, Australia, ³Department of Anaesthesia and Intensive Care, Haukeland University Hospital, Bergen, Norway, ⁴Department of Clinical Medicine, University of Bergen, Bergen, Norway, ⁵Department of Anesthesiology, Perioperative and Pain Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA, ⁶Danish Anaesthesia Allergy Centre, Allergy Clinic, Department of Dermatology and Allergy, Copenhagen University Hospital, Gentofte, Denmark and ⁷Department of Medical Education, University of Melbourne, Melbourne, Australia

*Corresponding author. E-mail: hkolawole@phcn.vic.gov.au

Summary

Simulation-based education is often highlighted as a method to prepare health personnel to handle clinical emergencies through repeated training and the design of supports. As one of the most common clinical emergencies in anaesthesia, anaphylaxis is often included in simulation scenarios at both graduate and postgraduate levels. Case reviews of anaphylaxis management continue to identify deficiencies in clinical responses. We evaluated the evidence to support the use of simulation to address these deficiencies. We undertook a comprehensive review of the MEDLINE and Embase databases with MESH terms 'Anaphylaxis', 'Anaesthesia', 'Simulation training', and variations of these terms. Articles were also searched from reference lists in the identified papers. A total of 39 articles on perioperative anaphylaxis simulation were identified, with most focusing on the clinical skills of individuals. However, anaphylaxis scenarios are also being used in assessment of teams and in the evaluation of broader system performance. Many countries mandate simulation training and competency assessment at graduate and postgraduate levels: despite this, none of the articles linked simulation training or assessment with improved patient management or outcomes. We found evidence that *in situ* simulation and use of cognitive aids lead to improved teamwork and task performance. Quantitative and qualitative evidence for simulation-based perioperative training is limited. Future studies should investigate whether simulation training in perioperative anaphylaxis, particularly *in situ* simulation, translates into improved patient management and outcomes.

Keywords: anaesthesia; anaphylaxis; perioperative; perioperative outcomes; simulation training

Perioperative anaphylaxis is an unpredictable life-threatening condition with the potential of mortality and morbidity even in young healthy individuals.^{1,2} There is evidence that delays in diagnosis and treatment with epinephrine are common and lead to morbidity and mortality.^{1–3} Treatment has also been assessed as inadequate for the grade of anaphylaxis in some studies.^{2,3} At the same time, overdose with epinephrine is potentially life threatening, but much less common.^{1,4} Anaphylaxis also mimics other clinical scenarios and can develop in any patient group.^{5–7}

Simulation of anaphylaxis scenarios for training of individuals and teams has been used for many years with the aim of improving the diagnosis and management of the condition and, by extension, patient outcomes.^{2,5,8–10} This narrative review focuses on the published evidence of the use of simulation to address the deficiencies in management with the aim of improving outcomes from perioperative anaphylaxis. The review appraises the training and assessment of individuals and teams, and the potential to enhance clinical processes.

Methods

We used the population, intervention, comparators, and outcomes framework to formulate our literature search strategy as follows:

- (i) *Population/problem*: perioperative anaphylaxis management
- (ii) *Intervention*: application of simulation techniques, including immersive and electronic
- (iii) *Comparators*: other methods of education or process improvement
- (iv) *Outcomes*: evidence of strategies to address deficiency in anaphylaxis management

A comprehensive literature search of MEDLINE and Embase was undertaken using the terms 'Anaphylaxis', 'Anaesthesia', 'Simulation training', and variations of these terms from 1992 to 2018 (Supplementary Appendix S1). Further articles were identified from the reference lists of these papers. The evidence and quality of the papers were evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE).¹¹ Two authors independently rated the articles; where agreement was not reached, a third author also assessed the paper.

Results

A total of 41 relevant papers were identified describing the use of simulation to replicate features of perioperative anaphylaxis. The consensus of the authors was that the articles were broadly themed into three areas: (i) anaphylaxis simulation as a component of anaesthesia training,^{12–18} (ii) anaphylaxis simulation as a component of assessment and certification,^{7,8,19–31} and (iii) anaphylaxis simulation as a method of system evaluation and modification.^{31–50} The majority of the studies in the review were observational (Supplementary Table S1 describes and evaluates the quality for each of the studies), and according to GRADE, the majority of these articles were of low or very low evidence because of bias. In the GRADE terminology, evidence from randomised controlled trials starts at high quality of evidence, whilst observational studies start at low quality. Inherent elements in both categories might downgrade or upgrade the quality.

In addition to adult scenarios based in the operating room, paediatric,^{7,14,41} regional anaesthesia,^{15,29} and PACU^{16,29}

scenarios were described. Most studies focused on the training of individuals with only a few involving multidisciplinary teams.^{13,15,18,30} Some studies focused exclusively on anaphylaxis management training and assessment;^{7,14,16,19,44,46} in several anaphylaxis was one of two scenarios,^{12,15,23} and in the remainder, anaphylaxis was one of a number of potential scenarios utilised in crisis management training.

Overview of included articles

In a 2001 study of 42 anaesthetists, none made the correct diagnosis on a simulator during the first 10 min of anaphylaxis, and very few arrived at the correct diagnosis.¹⁹ Johnston and colleagues⁷ studied 17 anaesthesia residents on rotation to a children's hospital managing a paediatric anaphylaxis scenario. The average time to diagnosis was 7.6 min and time to administration of epinephrine was a further 6.5 min. They also noted that other important actions, such as starting chest compressions at a low heart rate, were often missed. A failure to diagnose anaphylaxis, omission or late administration of epinephrine, and inadequate fluid resuscitation have been observed by other researchers.^{20,22}

Nyssen and colleagues¹² compared the management of an immersive anaphylaxis scenario by 40 anaesthesia residents after either computer-screen-based simulation training or a mannequin-based simulation training. Both methods reduced time to diagnosis and increased the treatment scores significantly, but there was no significant difference between the two training methods.

Training in the actual clinical setting, or *in situ* simulation, was noted to have potential advantages over training in a purpose-built simulation centre. Several studies suggest cost savings, enhancement of the learning as a result of familiar surroundings, and identification of system safety issues when simulation training is undertaken *in situ*.^{13,29,50}

Minehart and colleagues¹⁷ discussed improving debriefing in order to focus the learners. They measured the quality of the debrief by evaluating what items were discussed. They showed that a 1 h intervention with the faculty improved the quality of debriefing an anaphylaxis scenario. In particular, the faculty was more likely to identify and explore performance gaps and address non-technical issues, such as calling for help.

Using a checklist and key action scoring for simulation scenarios, Murray and colleagues²¹ found a correlation between clinical performance and education and clinical experience. The creation of a set of grading checklists, including one for anaphylaxis by a group of anaesthetists, intensivists, and educators with simulation education, training, and research experience, was shown to reliably assess the simulated management of clinical crisis scenarios. A group of non-expert raters were trained to use these checklists and evaluate the role of a team leader in a simulated video. This study generated evidence of reliability and content validity of the assessment checklists. Furthermore, the non-expert raters agreed with the assessment of the experts the vast majority of time.²⁷

In Canada, a team of simulation educators representing all residency programmes developed a set of consensus-driven scenarios. The assessment was by specific checklists created via a modified Delphi technique, anaesthetic non-technical skills, and a validated global rating scale.²⁸ The American College of Surgeons/Association of Program Directors in

Surgery utilises a three-phase simulation-based curriculum: core skills, advanced procedures, and team-based skills. Rao and colleagues³⁰ assessed the implementation of the third phase, team-based skills, in an *in situ* setting of the operating theatre. A multidisciplinary team of junior surgeons and anaesthetists, anaesthesia technicians, and operating room nurses were evaluated utilising the NOTECHS II scale.⁵¹ The non-technical skills of all teams improved between two different scenarios after a systematic debriefing by surgery and anaesthesia faculty and an experienced simulation educator.

Several studies examined whether monitor interfaces or computer-aided decision support, such as 'smart monitors' that interpret physiological patterns, could help make the diagnosis earlier. Results from these studies were mixed. Two studies suggested either a different visual display or vibrotactile alarm improved the time to respond.^{33,34} Further small studies differed, showing a reduced time to act or no difference when smart monitors were used during simulated anaphylaxis events.^{43,49} Similarly, Berkenstadt and colleagues³⁵ found a reduction in epinephrine dosing errors during a simulation scenario when a point-of-care electronic cognitive aid was used. Several studies showed benefits when cognitive aids were used during anaphylaxis management by preventing omission of key steps and improving teamwork and safety culture.^{40,42,46,47} In a series of studies, Schulz and colleagues^{37–39,45} observed the visual scanning patterns, attention, and workload of experienced anaesthetists in crises, such as intraoperative anaphylaxis. They found a correlation between increased workload and clinician heart rate and pupil diameter, and that experienced clinicians paid more visual attention to patient signs than the monitor. These observations suggest that stress in the simulation environment is realistic compared with the actual clinical setting, and can be measured.^{37–39,45}

Discussion

Anaphylaxis simulation as a component of training

Simulation for training of junior anaesthetists and nurses in the management of perioperative emergencies is well established. A recent meta-analysis found evidence of moderate to large statistically significant effectiveness for knowledge, skills, and behaviours when comparing simulation-based training in anaesthesia to no intervention.⁵² This review concludes that non-technical team skills, and technical skills in anaphylaxis management, can be learned, but the optimal method of training is not yet clear. Multidisciplinary training recreates the social aspects of the work environment more faithfully and, as a result, the non-technical skills required to manage anaphylaxis are highlighted. Therefore, at least some of the simulation training in anaphylaxis should include a component that addresses team dynamics with all team members present, as it is a common cause of failure during anaesthesia crises.^{2,53}

The optimal level of physical realism of the simulation is not yet known, and may indeed be different for various aspects of training and experience levels. Recent educational literature suggests the characteristics, such as physical resemblance of a simulator, are of lesser importance than how the entire simulation presents important aspects of the scenario.⁵⁴ The latter is described as 'functional task

alignment', and it may make some aspects of the simulation 'hyper-real' and improve the signal-to-noise ratio for the learners, particularly junior clinicians. In contrast, a strong focus on accurate physical representations may introduce irrelevant distractors that divert attention from the primary goal of the simulation.⁵⁴ Simulation training is usually undertaken in simulation centres that have the advantage of special equipment, specialised staff, and a lack of clinical interruptions. However, there may be advantages by situating the learning in familiar surroundings when simulation training is undertaken *in situ*.^{13,29,50}

This review yielded small studies with limited quantitative evidence for the effectiveness of simulation training in addressing the deficiencies noted when reviewing perioperative anaphylaxis incidents. As similar deficiencies were observed during simulation training and assessment, it is not possible to recommend the type of equipment or educational approaches to utilise. The structural properties of the simulator and the location of the simulation should be determined by the learning objectives, in conjunction with logistic and cost constraints. We would encourage research comparing different anaphylaxis simulation strategies focusing on non-technical skills, and diagnosis, timely administration of epinephrine, and fluid resuscitation.

Anaphylaxis simulation in assessment and certification

Competency assessment in anaphylaxis simulation has evolved from non-validated checklists⁸ to validated broadly based assessment of technical and non-technical skills.^{28,30,55,56} This has led to the use of simulation for assessment and training, and several countries now mandate simulation training and assessment of medical students, anaesthesia trainees, and consultants. The Accreditation Council for Graduate Medical Education Residency Review Committee for Anesthesiology (Chicago, IL, USA) expects residents to participate in at least one yearly simulated intraoperative clinical experience, anaphylaxis being one of them.⁵⁷ A formal debriefing mechanism is expected so that residents can receive a competency-based outcomes assessment. The American Board of Anesthesiology includes a practice performance assessment and improvement in the Maintenance of Certification program.⁵⁸ In the drive towards a competency-based training system in Canada, the Canadian National Anesthesiology Simulation Curriculum has mandated a simulation-based competency assessment of trainee anaesthetists, which has been successfully implemented.²⁸

Since 2013, the Australian and New Zealand College of Anaesthetists (ANZCA) has required anaesthesia trainees to complete a 2.5 day simulation course, called Emergency Management of Anaesthesia Crises.⁵⁹ Anaphylaxis is also one of four emergency responses (along with major haemorrhage, cardiac arrest, and cannot intubate, cannot oxygenate emergencies) that ANZCA has mandated every fellow must study every 3 yrs.⁶⁰

In summary, given the results of the aforementioned studies and national programmes, performance in a simulated environment is being used for summative assessment during training and continuing professional development. Further research is needed to ensure that the testing and scoring systems used translate into an improved performance of

clinical teams, decreases in deficiencies identified when reviewing anaphylaxis incidents, and improved patient outcomes.

Anaphylaxis simulation as a method of system evaluation and modification

Simulation can be used not only to improve and assess the education of the practitioners, but also to understand how the environment and processes can be modified to support clinical staff faced with a severe allergic reaction. The first step in improving the processes that deliver care is to understand the system itself and identify common failures that can be addressed. This can be achieved by reviewing previous incidents or by observing *in situ* simulations.⁶¹ The advantage of the latter approach is that uncommon events, such as anaphylaxis, can be replicated and observed in a controlled setting without risks to patients. Furthermore, there may be actions being undertaken by experienced clinicians that proactively improve safety (or create resilience) that had not previously been imagined and could be incorporated into future guidelines.⁶²

A further potential benefit of *in situ* training may be that clinical staff learn where vital pieces of equipment are located. The training may also prompt the identification of system improvements, such as the contents and positioning of an anaphylaxis emergency box, as suggested by the 6th National Audit Project audit.² This has parallels with the *in situ* obstetric simulation training implemented by Draycott and colleagues⁶³ in Bristol, UK. *In situ* training of whole teams and process changes led to an improvement of perinatal outcome measures, such as Apgar scores and a halving of the rate of hypoxic ischaemic encephalopathy. A similar prospective study examining patient outcome measures would be difficult to implement for anaphylaxis because of the rare and unpredictable nature of the event. However, correlation of patient outcome measures after a reaction with access to simulation training would be possible.

Simulation has also helped the development of new technologies to improve diagnosis and treatment, some of which show promise.^{33,34,43,49}

In addition, often overlooked aspects of the ability to manage complex emergencies are organisational factors, such as rostering and staffing. The effect of sleep deprivation on the management of simulated crises has also been evaluated using simulation. Acute sleep deprivation of anaesthetic trainees (one night without sleep) not surprisingly led to impairment in the medical management of anaphylaxis and another anaesthesia crisis.^{31,32} One method of counteracting some of this degradation in performance is the use of cognitive aids, such as anaphylaxis checklists, which have been demonstrated to improve medical care in a simulated clinical environment.⁴²

Anaphylaxis simulation to design decision support

There is now little doubt of the benefits of cognitive aids to supplement simulation training for improving teamwork and task performance.^{40,42,46,47,48} Simulation has played a key role in how these cognitive aids are presented and in their development. Many of the key research papers examining the use of cognitive aids in anaesthesia have included anaphylaxis in their testing. In particular, the design of cognitive aids has

recently undergone some examination using simulation, with more simple, linear designs being preferred over complex branched algorithms. Furthermore, computerised aids often appear more difficult to use during emergencies than paper.^{64,65} One of the main problems of cognitive aids is having them immediately available and remembering to use them. Simulation training may also play a key role in educating anaesthetists on when and how to use cognitive aids, thus improving the performance of teams more than just simulation alone.^{66–68}

Simulation of anaphylaxis emergencies cannot only provide training and ensure minimum standards, but can also be used to design a supportive environment and processes, facilitating improved clinician performance. We recommend that future simulation studies be undertaken, aimed at examining the effects of system changes on patient outcomes.⁶⁹

Limitations

Whilst this review has covered the published literature on simulation and anaphylaxis, there may be relevant literature published on simulation and other perioperative crises. This is partly addressed by the inclusion of a 2014 systematic review of simulation training in anaesthesiology.⁵²

Conclusions

Perioperative anaphylaxis is used widely as a scenario in simulation training and as part of competency assessment. Although we did not identify studies linking training, assessment, and system performance to improved management of anaphylaxis or patient outcome, this review found evidence that *in situ* simulation and the use of cognitive aids lead to improved teamwork and task performance. Simulation training, assessment, and research should focus on assessing solutions to management deficiencies. We recommend a shift in research priorities towards *in situ* simulation to improve team and system performance rather than focusing on the behaviour of individuals. This will not only address process and equipment issues in the clinical setting, but also support and enhance existing simulation education.

Authors' contributions

Study conception: all authors

Study design: all authors

Data collection, analysis, and interpretation: all authors

Drafting of manuscript: all authors

All authors reviewed drafts of the manuscript and approved the final version.

Declaration of interest

SM is in receipt of an Australian National Health and Medical Research Council Early Career Research Fellowship for the investigation of cognitive aids in emergencies. All other authors confirm that they have no interests to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bja.2019.01.035>.

References

- Reitter M, Petitpain N, Lata arche C, et al. Fatal anaphylaxis with neuromuscular blocking agents: a risk factor and management analysis. *Allergy* 2014; **69**: 954–9
- Harper NJN, Cook TM, Garcez T, et al. Anaesthesia, surgery, and life-threatening allergic reactions: management and outcomes in the 6th National Audit Project (NAP6). *Br J Anaesth* 2018; **121**: 172–88
- Garvey LH, Belhage B, Kroigaard M, Husum B, Malling HJ, Mosbech H. Treatment with epinephrine (adrenaline) in suspected anaphylaxis during anesthesia in Denmark. *Anesthesiology* 2011; **115**: 111–6
- Campbell RL, Bellolio MF, Knutson BD, et al. Epinephrine in anaphylaxis: higher risk of cardiovascular complications and overdose after administration of intravenous bolus epinephrine compared with intramuscular epinephrine. *J Allergy Clin Immunol Pract* 2015; **3**: 76–80
- Schwid HA, O'Donnell D. Anesthesiologists' management of simulated critical incidents. *Anesthesiology* 1992; **76**: 495–501
- O'Leary FM, Hokin B, Enright K, Campbell DE. Treatment of a simulated child with anaphylaxis: an in situ two-arm study. *J Paediatr Child Health* 2013; **49**: 541–7
- Johnston EB, King C, Sloane PA, et al. Pediatric anaphylaxis in the operating room for anesthesia residents: a simulation study. *Paediatr Anaesth* 2017; **27**: 205–10
- Chopra V, Gesink BJ, De Jong J, Bovill JG, Spierdijk J, Brand R. Does training on an anaesthesia simulator lead to improvement in performance? *Br J Anaesth* 1994; **73**: 293–7
- Kolawole H, Marshall SD, Crilly H, Kerridge R, Roessler P. Australian and New Zealand Anaesthetic Allergy Group/ Australian and New Zealand College of Anaesthetists Perioperative Anaphylaxis Management Guidelines. *Anaesth Intensive Care* 2017; **45**: 151–8
- Garvey LH, Mertes PM. Perioperative anaphylaxis—management and outcomes in NAP6. *Br J Anaesth* 2018; **121**: 120–3
- Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ* 2008; **336**: 924–6
- Nyssen AS, Larbuisson R, Janssens M, Penderville P, Mayne A. A comparison of the training value of two types of anesthesia simulators: computer screen-based and mannequin-based simulators. *Anesth Analg* 2002; **94**: 1560–5. table of contents
- McPherson K, Mir F. Simulation training in peri-operative emergencies. *Anaesthesia* 2013; **68**: 881
- Miller NB, Fehr J, White A, Bacharier LB, Ellis AG. Simulation-based education is an effective teaching tool for pediatric trainees, in the diagnosis and management of pediatric anaphylaxis. *J Allergy Clin Immunol* 2013; **1**: AB221
- Vedwan J, Vaughton A, Everett T, Jee R. Theatre simulation training for management of local anaesthetic toxicity. *Reg Anesth Pain Med* 2013; **1**: E149
- Mason VM, Lyons P. Use of simulation to practice multidisciplinary anaphylaxis management. *Dimens Crit Care Nurs* 2013; **32**: 280–5
- Minehart RD, Rudolph J, Pian-Smith MC, Raemer DB. Improving faculty feedback to resident trainees during a simulated case: a randomized, controlled trial of an educational intervention. *Anesthesiology* 2014; **120**: 160–71
- Kovatch KJ, Harvey RS, Schechtman SA, et al. Otolaryngology-anesthesiology simulation curriculum. *Otolaryngol Head Neck Surg* 2017; **157**. Supplement 215–216
- Jacobsen J, Lindekaer AL, Oostergaard HT, et al. Management of anaphylactic shock evaluated using a full-scale anaesthesia stimulator. *Acta Anaesthesiol Scand* 2001; **45**: 315–9
- Schwid HA, Rooke GA, Carline J, et al. Evaluation of anesthesia residents using mannequin-based simulation: a multiinstitutional study. *Anesthesiology* 2002; **97**: 1434–44
- Murray DJ, Boulet JR, Kras JF, Woodhouse JA, Cox T, McAllister JD. Acute care skills in anesthesia practice: a simulation-based resident performance assessment. *Anesthesiology* 2004; **101**: 1084–95
- Berkenstadt H, Kantor GS, Yusim Y, et al. The feasibility of sharing simulation-based evaluation scenarios in anesthesiology. *Anesth Analg* 2005; **101**: 1068–74. table of contents
- Cicarelli DD, Coelho RB, Bensenor FE, Vieira JE. [Importance of critical events training for anesthesiology residents: experience with computer simulator]. *Rev Bras Anestesiol* 2005; **55**: 151–7
- Murray DJ, Boulet JR, Kras JF, McAllister JD, Cox TE. A simulation-based acute skills performance assessment for anesthesia training. *Anesth Analg* 2005; **101**: 1127–34
- Ishiyama M, Nakamura K, Sato H, Kawakami H, Goto T. Simulation-based acute care performance assessment for the first year anesthesia residents. *Eur J Anaesthesiol* 2009; **45**: 199
- Everett TC, Ng E, Power D, et al. The Managing Emergencies in Paediatric Anaesthesia global rating scale is a reliable tool for simulation-based assessment in pediatric anesthesia crisis management. *Paediatr Anaesth* 2013; **23**: 1117–23
- McEvoy MD, Hand WR, Furse CM, et al. Validity and reliability assessment of detailed scoring checklists for use during perioperative emergency simulation training. *Simul Healthc* 2014; **9**: 295–303
- Chiu M, Tarshis J, Antoniou A, et al. Simulation-based assessment of anesthesiology residents' competence: development and implementation of the Canadian National Anesthesiology Simulation Curriculum (CanNASC). *Can J Anaesth* 2016; **63**: 1357–63
- Burgess H, Murphy J, Narang P, Barrett J, Paquet E. Scientific abstract: education perioperative disaster simulation team training program for complications following regional anesthesia administration. In: *Proceedings of the 41st annual regional anesthesiology and acute pain medicine meeting; abstract 1511*; 2016. https://www.asra.com/content/documents/_all_presented_abstracts_ra16.pdf
- Rao R, Caskey RC, Owei L, et al. Curriculum using the in-situ operating room setting. *J Surg Ed* 2017; **74**: e39–44
- Arzalier-Daret S, Buleon C, Bocca ML, Denise P, Gerard JL, Hanouz JL. Effect of sleep deprivation after a night shift duty on simulated crisis management by residents in anaesthesia. A randomised crossover study. *Anaesth Crit Care Pain Med* 2018; **37**: 161–6
- Neuschwander A, Job A, Younes A, et al. Impact of sleep deprivation on anaesthesia residents' non-technical skills: a pilot simulation-based prospective randomized trial. *Br J Anaesth* 2017; **119**: 125–31
- Blike GT, Surgenor SD, Whalen K. A graphical object display improves anesthesiologists' performance on a simulated diagnostic task. *J Clin Monit Comput* 1999; **15**: 37–44
- Ford S, Daniels J, Lim J, et al. A novel vibrotactile display to improve the performance of anesthesiologists in a simulated critical incident. *Anesth Analg* 2008; **106**: 1182–8

35. Berkenstadt H, Yusim Y, Ziv A, Ezri T, Rubin O, Perel A. Assessment of a point-of-care information system in simulated pediatric anesthesia emergencies. *Rom J Anaesth Intensive Care* 2010; 17: 98–102
36. Allen W, Smith T, Kandasamy G. Using human factors simulation training to improve emergency response to anaesthetic crises. *Anaesthesia* 2012; 2: 38
37. Schulz CM, Schneider E, Fritz L, et al. Eye tracking for assessment of workload: a pilot study in an anaesthesia simulator environment. *Br J Anaesth* 2011; 106: 44–50
38. Schulz CM, Skrzypczak M, Schneider E, et al. Assessment of subjective workload in an anaesthesia simulator environment: reliability and validity. *Eur J Anaesth* 2011; 28: 502–5
39. Schulz CM, Schneider E, Fritz L, et al. Visual attention of anaesthetists during simulated critical incidents. *Br J Anaesth* 2011; 106: 807–13
40. Ziewacz JE, Arriaga AF, Bader AM, et al. Crisis checklists for the operating room: development and pilot testing. *J Am Coll Surg* 2011; 213: 212–217.e10
41. Ng CK, Stansfield D. Anaesthetic emergencies preparedness in a paediatric anaesthetic department. *Br J Anaesth* 2012; 2: ii349–50
42. Arriaga AF, Bader AM, Wong JM, et al. Simulation-based trial of surgical-crisis checklists. *N Engl J Med* 2013; 368: 246–53
43. Gorges M, Winton P, Koval V, et al. An evaluation of an expert system for detecting critical events during anesthesia in a human patient simulator: a prospective randomized controlled study. *Anesth Analg* 2013; 117: 380–91
44. Lonsdale S, Ferns J, Nazar A. Emergencies in the intra-operative period: a check and challenge audit for anaphylaxis and cardiac arrest. *Anaesthesia* 2014; s3: 129
45. Schulz CM, Schneider E, Kohlbecher S, et al. The influence of anaesthetists' experience on workload, performance and visual attention during simulated critical incidents. *J Clin Monit Comput* 2014; 28: 475–80
46. Marshall SD, Sanderson P, McIntosh CA, Kolawole H. The effect of two cognitive aid designs on team functioning during intra-operative anaphylaxis emergencies: a multi-centre simulation study. *Anaesthesia* 2016; 71: 389–404
47. Goldhaber-Fiebert SN, Pollock J, Howard SK, Bereiknyei Merrell S. Emergency manual uses during actual critical events and changes in safety culture from the perspective of anesthesia residents: a pilot study. *Anesth Analg* 2016; 123: 641–9
48. Lelaidier R, Balança B, Boet S, et al. Use of a hand-held digital cognitive aid in simulated crises: the MAX randomized controlled trial. *Br J Anaesth* 2017; 119: 1015–21
49. Marchant A. Investigation of dynamic decision support during simulated anaesthesia. *Anaesthesia* 2018; 73: 65
50. Alidina S, Goldhaber-Fiebert SN, Hannenberg AA, et al. Factors associated with the use of cognitive aids in operating room crises: a cross-sectional study of US hospitals and ambulatory surgical centers. *Implement Sci* 2018; 13: 50
51. Robertson ER, Hadi M, Morgan LJ, et al. Oxford NOTECHS II: a modified theatre team non-technical skills scoring system. *PLoS One* 2014; 9: e90320
52. Lorello GR, Cook DA, Johnson RL, Brydges R. Simulation-based training in anaesthesiology: a systematic review and meta-analysis. *Br J Anaesth* 2014; 112: 231–45
53. Cook TM, Woodall N, Frerk C, Fourth National Audit P. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. *Br J Anaesth* 2011; 106: 617–31
54. Hamstra SJ, Brydges R, Hatala R, Zendejas B, Cook DA. Reconsidering fidelity in simulation-based training. *Acad Med* 2014; 89: 387–92
55. Flin R, Patey R, Glavin R, Maran N. Anaesthetists' non-technical skills. *Br J Anaesth* 2010; 105: 38–44
56. Chin M, Lagasse RS. Assessment of competence: developing trends and ethical considerations. *Curr Opin Anaesthesiol* 2017; 30: 236–41
57. Accreditation Council for Graduate Medical Education. Review committee for anesthesiology. Available from, https://www.acgme.org/Portals/0/PDFs/FAQ/040_anesthesiology_FAQs_2017-07-01.pdf?ver=2017-06-19-105828-983. [Accessed 27 October 2018]. accessed
58. van Zanten M, Boulet JR, Simon FA. Flexner's global influence: medical education accreditation in countries that train physicians who pursue residency in the United States. *Acad Med* 2010; 85: 324–32
59. Australian and New Zealand College of Anesthetists. Training EMAC. Available from, <http://www.anzca.edu.au/training/emac>. [Accessed 27 October 2018]. accessed
60. Australian and New Zealand College of Anaesthetists. Continuing professional development. Emergency response activities. Available from, <http://www.anzca.edu.au/fellows/continuing-professional-development/emergency-response-activities>. [Accessed 27 October 2018]. accessed
61. Draycott T, Sibanda T, Owen L, et al. Does training in obstetric emergencies improve neonatal outcome? *BJOG* 2006; 113: 177–82
62. Brazil V. Translational simulation: not 'where?' but 'why?' A functional view of in situ simulation. *Adv Simul (Lond)* 2017; 2: 20
63. Schnittker R, Marshall SD. Safe anaesthetic care: further improvements require a focus on resilience. *Br J Anaesth* 2015; 115: 643–5
64. Marshall SD, Sanderson P, Kolawole H, McIntosh C. Perceptions and implications of cognitive aid design for medical emergencies. Proceedings of the 19th Triennial Congress of the International Ergonomics Association; 1102 https://www.iea.cc/congress/2015_presentation.html
65. Watkins SC, Anders S, Clebone A, et al. Paper or plastic? Simulation based evaluation of two versions of a cognitive aid for managing pediatric peri-operative critical events by anesthesia trainees: evaluation of the society for pediatric anesthesia emergency checklist. *J Clin Monit Comput* 2016; 30: 275–83
66. Goldhaber-Fiebert SN, Howard SK. Implementing emergency manuals: can cognitive aids help translate best practices for patient care during acute events? *Anesth Analg* 2013; 117: 1149–61
67. Marshall SD. Helping experts and expert teams perform under duress: an agenda for cognitive aid research. *Anaesthesia* 2017; 73: 289–95
68. Hepner DL, Arriaga AF, Cooper JB, et al. Operating room crisis checklists and emergency manuals. *Anesthesiology* 2017; 127: 384–92
69. Higham H, Baxendale B. To err is human: use of simulation to enhance training and patient safety in anaesthesia. *Br J Anaesth* 2017; 119: i106–14

Supplementary Online Table 1. Summary and GRADE Rating of included studies in the same order as the Results Section of Manuscript

GRADE Certainty ¹			Quality of Evidence and Definitions				
High Quality			Further research is very unlikely to change our confidence in the estimate of effect.				
Moderate Quality			Further research is likely to have an important impact on our confidence in the estimate of effect & may change the estimate.				
Low Quality			Further research is very likely to have an important impact on our confidence in the estimate of effect & is likely to change the estimate.				
Very low Quality			Any estimate of effect is very uncertain.				
Anaphylaxis Simulation as a Component of Anaesthesia Training							
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings V low/Low/Moderate/ High
Nyssen 2002 ²	Nonrandomised study comparing mannequin with screen-based simulator training either same scenario or different scenario with 2 nd scenario 1 month later	40 anaesthesia trainees	Compared Score for initial and 2 nd scenario Time to diagnosis	Scoring significant increase on second scenario irrespective of method of simulation. Time to diagnosis reduced.	Subjects selected to have similar results in previous anaesthesia exam. Subjects rejected if clinical experience of anaphylaxis. Change in time to diagnosis only 1 min. Overlap of confidence interval for scored but reduced variability 2 nd	Non-random allocation subjects Blinded assessor. Non-validated scoring. Clinical significance of change in score and time to diagnosis uncertain.	Low
McPherson 2013 ³	Conference abstract Needs analysis followed by simulation training in situ	25 staff across range of OR staff	Subjective assessment of course by participants	Regular in situ programme continuing	Used as example of multidisciplinary simulation in situ	Conference abstract Limited information Descriptive only	Very low

Miller 2013 ⁴	Conference abstract RCT Effect of either simulation or lecture-based education on paediatric anaphylaxis on written assessment on immediately and at 2 weeks	25 trainees of mixed background including anaesthesia, critical care, immunology fellows,	Score immediately and at 2 weeks	Simulation group scored higher immediately and at 2 weeks	Limited information	Conference abstract Limited information Descriptive only	Very low
Vedwan 2013 ⁵	Conference abstract Observational study of multidisciplinary simulation in OR of LA toxicity and anaphylaxis	Multidisciplinary team	Satisfaction of participants	Limited precourse exposure to formal teaching High levels of satisfaction with the course Continued in situ education continued.	Limited information	Conference abstract Limited information Descriptive only	Very low
Mason 2013 ⁶	Observational study with description of development of anaphylaxis scenarios using multidisciplinary team.	169 nurse participants from variety of critical care backgrounds	Evaluation of course by participants. Description of course development.	Course highly rated		Descriptive study of course development.	Very low
Minehart 2014 ⁷	RCT Effect of 1 hour educational intervention on the quality of feedback in a standardised simulated case of anaphylaxis.	71 subjects from 5 academic hospitals	6 elements of Behaviourally Anchored Rating Scale	Intervention group significantly better maintaining a safe environment P= 0.001; Identifying and exploring performance gaps P=0.048; more frequently error of failing to call for help P=0.008	Anaphylaxis in patient with HOCM was the scenario used.	<u>Cochrane Risk of Bias tool</u> Random sequence L Allocation conceal U Blinding participants U Blinding outcome assess L Incomplete trial data L Overall rating L L=low U=Unclear H=High	Moderate

Kovatch 2017 ⁸	Conference abstract Description of integrated otolaryngology- head & neck intern training with head and neck anesthesiology training.	Otolaryngology head and neck interns and anaesthesiology	No outcome measures	Recommend further evaluation of simulation as part of training	Limited information Anaphylaxis one of the simulation components Primarily surgical program	Conference abstract Limited information Descriptive only	Very low

Anaphylaxis Simulation as a Component of Assessment and Certification	High correlation of	Not all scenarios equal in	Observational study	Low	GRADE certainty ratings		
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings
	Correlation of 4 scoring systems:			Correlation between scores and systems.	6 scenarios with only 1 postoperative	Correlation of 4 scoring systems	Very low/Low/Moderate/High
Johnston Ishiyama 2017 ¹⁷	Observational study of junior trainees' performance during simulation of a simulator	17 first-year residents at 4 months	Time to diagnosis of anaphylaxis, key actions and global score	CA2 residents experienced better global score. Small variance still more difficult to diagnose and good participant satisfaction.	Easy on time to diagnose and administer epinephrine with one being anaphylaxis. No resident commenced chest compression for	Observational study Conference abstract. Observational study only	Low High Very low
Berkenstadt 2005 ¹⁴	Observational study to determine if anaphylaxis	31 anaesthetic trainees	Validation of scoring system (same Global and checklist scales	Scores were higher in Israeli trainees compared with US trainees due to	Similar patterns of deficits in management 6 scenarios with one being anaphylaxis.	Observational study in simulation. Observation study No Randomisation	Low
Everett 2013 ¹⁸	Observational study to determine if anaphylaxis could be used for assessment of trainees MH cf. paediatric trainees	30 trainees	Global and checklist scales	High degree of reliability for both trainees due to	6 scenarios with one being anaphylaxis.		Low
Chopra 94 ¹⁰	Observational study describing the development of scoring systems and checklists for 5 simulation scenarios by experts followed by validity and study to reliability testing of these checklists by nonexpert raters who had received 4 hours of training in two scenarios	28 anaesthetists & trainees	Score for initial anaphylaxis scenario, undertaken prior to training compared with score for MH	More experienced in MH improved MH scores. At least 2 raters needed for anaphylaxis training	Anaphylaxis (50%) and initial code of scenario resuscitation (45%) Assessed as individual.	Method of allocation not described. Blinded assessors. Scoring system not validated only	Very Low
Cicarelli 2005 ¹⁵	Observational study of performance on computer based simulation of 2 of scoring systems and checklists for 5 simulation scenarios by experts followed by validity and study to reliability testing of these checklists by nonexpert raters who had received 4 hours of training in two scenarios	17 anaesthesiology residents 4 expert raters 4 nonexpert (medical student) instructors raters	Checking for inter-rater agreement	Graded checklists found to be valid and reliable in assessing perioperative crisis management, residents and instructors only	Included in review as description. 6 scenarios with one being anaphylaxis. Change in score and time to response uncertain.	Observational study	Very low
McEvoy 2014 ¹⁹	Observational study describing the development of scoring systems and checklists for 5 simulation scenarios by experts followed by validity and study to reliability testing of these checklists by nonexpert raters who had received 4 hours of training in two scenarios	4 expert raters 4 nonexpert (medical student) instructors raters	Checking for inter-rater agreement	Graded checklists found to be valid and reliable in assessing perioperative crisis management, residents and instructors only		Observational study	Moderate
Jacobsen 2001 ¹¹	Observational study	42 anaesthetists and nurse anaesthetists	Time to diagnosis ACRM score	More senior residents and instructors only	Correct management not instituted apart from IV fluids	Observational	Low
Murray 2005 ¹⁶	Observational study to reliability testing of these checklists by nonexpert raters who had received 4 hours of training in two scenarios	20 anaesthesiology residents and 15 participating institutions	2 checklist rating systems	6/21 at 15 minutes with prompt in	Not all scenarios equal in case difficulty	Observational study in simulation.	Low
Schwid 2002 ¹²	Validation of scoring system	20 residents and 15 participating institutions	Validation of scoring system	Scores increased with training junior and nurse anaesthetists. Small rater variance Largest variance due to nature of scenario.	Significant management deficits even at the end of training including failure to identify anaphylaxis (34%), give epinephrine (29%) and inadequate fluid resuscitation (64%)	Observational study in simulation. No Randomisation	Moderate
	scoring systems.						
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings
							V low/Low/Moderate/High

Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Vlow/Low/Moderate/High
Chiu 2016 ²⁰	Special Article describing the development, implementation and evaluation of Canadian National Anesthesiology Simulation Curriculum	114 residents	Global rating Scale use as primary assessment tool with scenario specific checklists	Program developed using Delphi consensus and high acceptance of program by residents	Consensus development of competency-based simulation assessment across Canadian Anaesthesia training program	Descriptive paper National simulation competency development	Moderate
Burgess 2016 ²¹	Description of Simulation course in situ in PACU and OR of local anaesthesia toxicity, tension pneumothorax and anaphylaxis.	Surgical, OR and PACU nursing and anaesthesia staff.	Pre and post simulation testing showed improvement in knowledge Satisfaction survey of staff involved	Improved scores and high level of satisfaction and modification to didactic teaching program.	Descriptive multidisciplinary and in situ.	Conference abstract Limited information	Very low
Rao 2017 ²²	Observational study of nontechnical skills of multidisciplinary teams as assessed by in situ simulation scenarios	8 surgical residents 16 anesthesiology residents 16 OR nurses 13 anesthesia technicians	NOTECHs II assessment of team and individuals comparing first and second scenario. Checking for inter-rater agreement Participant opinion survey	Increased NOTECHs score on second scenario. Inter-rater reliability only modestly significant for total team score and nursing subteam. Opinion survey of participants high level of preference for in situ over simulation centre based scenarios	Part 3 of American College of Surgeons simulation-based curriculum focussing on team-based skills. 4 different scenarios one being anaphylaxis In situ simulation	Observational study	Low

Anaphylaxis Simulation as a Method of System Evaluation and Modification							
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Very low/Low/Moderate/High
Neuschwander 2017 ²³	RCT examining the effect of sleep deprivation on non-technical skills during an intraoperative anaphylaxis scenario	20 trainee anaesthetists	Anaesthetists Non-Technical Skills (ANTS) score	Sleep deprived anaesthetists have lower teamworking scores and overall ANTS scores compared to rested group	No difference in technical skills observed	Randomised study with between group comparison.	Moderate
Arzalier-Daret 2018 ²⁴	RCT examining management of a cardiac and anaphylaxis scenario in rested and sleep deprived states.	48 trainee anaesthetists	Performance scores in each of two scenarios one being anaphylaxis	Sleep deprived anaesthetists committed more errors and scored lower than rested ones	Specific mention of incorrect epinephrine dose as an error being more likely (7/24 versus 1/24, p=0.01)	Randomised crossover trial between sleep deprived and rested and two scenarios.	High
Blike 99 ²⁵	RCT Effect of a novel monitor display in identifying five causes of shock including anaphylaxis	11 anaesthetists	Time and accuracy of identifying state and aetiology of shock from graphic or numeric display formats	A graphical display format led to more accurate and rapid diagnosis of anaphylaxis		Repeated measures, within subjects design. Objective measurement from computer recorded responses. Screen based simulation, not a realistic setting.	Low
Ford 2008 ²⁶	Simulation-based RCT to determine if a vibrotactile display could improve detection and management of intraoperative anaphylaxis	24 trainee and specialist anaesthetists	Time to epinephrine administration	Use of the vibrotactile display reduced the time to delivery epinephrine from 7.22 to 4.08 minutes	The display was introduced to the intervention participants only as a monitor of peak airway pressure. This may have biased them to expect a change in this variable.	Randomised. Explanation to the groups was not equivalent.	Moderate
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Very low/Low/Moderate/High
Berkenstadt 2010 ²⁷	Screen-based simulation with or	48 trainee and specialist	Knowledge score (derived from	A significantly higher number of	Screen presentation of the information does	Randomised. Blinded.	Low

	without an electronic help system to complete a series of questions on 12 clinical scenarios. One of which was anaphylaxis to latex	anaesthetists	Delphi process)	junior clinicians made “potentially life-threatening mistakes” when not using the aid (41% versus 9%)	not reflect how clinical decisions would normally be made. Authors suggest the system could be distracting during an actual event.	Within and between subject comparisons	
Allen 2012 ²⁸	Observational study to determine the number of accessible cognitive aids in an operating theatre suite	N/A	Number of cognitive aids available to 5 anaesthetic emergencies including anaphylaxis	Following simulation training the operating theatres and anaesthetic rooms had a higher number of cognitive aids present	The implementation of simulation training has a significant effect on the availability and use of cognitive aids in the clinical setting.	Conference abstract. Observational study only	Very low
Schulz 2011a ²⁹	Observational study examining eye tracking of junior and senior anaesthetic trainees or specialists during a simulated anaphylaxis	15 trainee or specialist anaesthetists	Eye tracking path patterns	Pupil size and heart rate are related to workload in a simulated anaphylaxis event	Visual attention patterns can aid training and monitor design. The study was limited by the limitations of the plastic mannequin in not being able to represent skin changes.	Observational. Cross-over with randomisation to no critical incident or anaphylaxis as first scenario 6 of 22 cases had no recorded data due to technology failures.	Low
Schulz 2011b ³⁰	Observational study examining eye tracking and workload of anaesthetists during a simulated anaphylaxis	15 trainee or specialist anaesthetists	Pupil diameter, heart rate	Increased workload can be reliably measured and is increased during simulated anaphylaxis	Same group as Schultz 2011a. Suggests stress in simulator is realistic compared to the actual clinical setting. Can be used to measure effects of interventions.	Randomised cross-over trial with same group as Schultz 2011a	Low
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Very low/Low/Moderate/High
Schulz 2011c ³¹	Observational study examining eye tracking and	15 trainee or specialist anaesthetists		Experienced clinicians pay more attention to patient	Same group as Schultz 2011a. Suggests stress in simulator is realistic	Randomised cross-over trial with same group as Schultz 2011a	Low

	workload of anaesthetists during a simulated anaphylaxis			signs than the monitor	compared to the actual clinical setting. Can be used to measure effects of interventions.		
Ziewacz 2011 ³²	Randomised study to determine if a cognitive aid improved care in 8 emergencies including anaphylaxis	2 teams (11 participants)	Number of critical processes omitted	Reduction of critical processes omitted from 11/46 to 2/46	Pilot study with only two teams	Method of randomisation to cognitive aid or no cognitive aid not clear. Same order of scenarios may have led to a learning effect.	Moderate
Ng 2012 ³³	Observational study to determine preparedness for 5 paediatric anaesthetic emergencies	Interviews with 25 staff members including 13 anaesthetic trainees and specialists	Equipment, cognitive aids and knowledge about 5 emergencies including anaphylaxis	Suggested multidisciplinary simulation to improve preparedness	No data are given to support the assertion that multidisciplinary team training could be valuable.	Observational	Very low
Arriaga 2013 ³⁴	RCT examining the effect of emergency cognitive aids	17 clinical teams (n=67 participants) undertaking a total of 103 scenarios	Failure to perform critical steps during simulated perioperative emergencies including anaphylaxis. Acceptance of cognitive aids	Reduction in critical steps omitted when a cognitive aid was used. Nearly all participants (97%) stated they would use cognitive aid	Teams did not include surgeon.	Groups of scenarios undertaken together which may have introduced bias from a learning effect. Team stayed the same through all scenarios	Moderate

Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Very low/Low/Moderate/High
Gorges 2013 ³⁵	RCT comparing smart monitor with routine monitor	20 trainee and 15 specialist anaesthetists. Undertaking three scenarios each with respiratory abnormalities including anaphylaxis	Time to identify the event and initiate treatment. Workload during the event	Reduction in time to diagnose and treat event.	Five scenarios excluded due to technical problems.	Scenarios randomised and crossover with some scenarios with and some without the smart monitor. No external validation of the scenarios outside of the researchers' group.	Moderate
Lonsdale 2014 ³⁶	Observational study based on a case of anaphylaxis being presented to staff in their place of work	Total of 45 participants including 10 anaesthetists, 6 surgeons, 1 junior doctor and 25 nurses and others	Awareness of emergency protocols and cognitive aids in the operating theatre environment	All staff were aware of the protocols. Nurses and doctors have complementary skills during clinical emergencies	Despite strong results of good awareness the authors suggested improved signage and the use of regular emergency drills.	Conference abstract Observational only in a single institution.	Very low
Schulz 2014 ³⁷	Observational study looking at visual attention during a simulated anaphylaxis	4 inexperienced and 8 experienced anaesthetists	Relationships between pupil size, heart rate and workload	Under-reporting of workload by experienced clinicians but good correlation with heart rate and pupil size	Workload can be assessed from multiple sources to help improve design	Observational. Limited sample	Very low
Marshall 2016 ³⁸	RCT examining the effect of two designs of cognitive aid on team performance during a simulated anaphylaxis case	24 anaesthetic teams from 3 institutions (72 participants)	Team scoring system. Performance score	When teams used the linear design of cognitive aid the team work score was higher than a branched design, or no cognitive aid.	No technical performance difference were identified.	Randomised, crossover study. Used team of senior and junior anaesthetist and anaesthetic nurse as would be normal in the clinical setting. Several Australian hospitals included.	High
Reference	Study design	Number of participants	Outcome measure	Conclusions	Comments	Quality	GRADE certainty ratings Very low/Low/Moderate/High

Goldhaber-Fiebert 2016 ³⁹	Survey of trainee anaesthetists to determine barriers to cognitive aid use	76 anaesthetic trainees	Survey of use in clinical emergencies including anaphylaxis	More likely to use cognitive aids if previously used in a simulation setting		Survey of a single institution.	Low
Lelaidier 2017 ⁴⁰	Randomised controlled trial. Each participant allocated to two scenarios of five, one with and without a cognitive aid.	46 anaesthetic trainees	Completion of management items and Non-Technical Skills using a global rating scale	Improved technical and non-technical performance with a cognitive aid.	Of the 92 testing scenarios, 17 were intraoperative anaphylaxis	Single institution. Randomised, crossover study with another clinical emergency	Moderate
Marchant 2018 ⁴¹	Investigation of the use of a smart monitor to prompt diagnosis in anaphylaxis and malignant hyperthermia	10 anaesthetists	Time to diagnose and need for prompting during scenario.	No difference between groups with smart monitor and normal monitor	8 of the 10 participants believed the system would be advantageous	Conference abstract Single centre, randomisation and experience of participants not stated	Very low
Alidina 2018 ⁴²	Survey to determine the uptake by health services of emergency cognitive aids including for anaphylaxis	368 respondents (including 311 anaesthetists)	Associations between health service characteristics and cognitive aid implementation.	Structured roll-out of cognitive aids that includes leadership engagement and time for training		Only institutions downloading the anaesthesia emergency cognitive aids from the website were included, potentially biasing the sample	Low

References

- 1 Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ* 2008; **336**: 924-6
- 2 Nyssen AS, Larbuisson R, Janssens M, Pendeville P, Mayne A. A comparison of the training value of two types of anesthesia simulators: computer screen-based and mannequin-based simulators. *Anesth Analg* 2002; **94**: 1560-5, table of contents
- 3 McPherson K, Mir F. Simulation training in PERI-operative emergencies. *Anaesthesia* 2013; **68 (8)**: 881
- 4 Miller NB, Fehr J, White A, Bacharier LB, Ellis AG. Simulation-based education is an effective teaching tool for pediatric trainees, in the diagnosis and management of pediatric anaphylaxis. *J Allergy Clin Immunol* 2013; **1**: AB221
- 5 Vedwan J, Vaughton A, Everett T, Jee R. Theatre simulation training for management of local anaesthetic toxicity. *Reg Anesth Pain Med* 2013; **1**: E149
- 6 Mason VM, Lyons P. Use of simulation to practice multidisciplinary anaphylaxis management. *Dimens Crit Care Nurs* 2013; **32**: 280-5
- 7 Minehart RD, Rudolph J, Pian-Smith MC, Raemer DB. Improving faculty feedback to resident trainees during a simulated case: a randomized, controlled trial of an educational intervention. *Anesthesiology* 2014; **120**: 160-71
- 8 Kovatch KJ, Harvey RS, Schechtman SA, et al. Otolaryngology-anesthesiology simulation curriculum. *Otolaryngology - Head and Neck Surgery (United States)* 2017; **157 (1 Supplement 1)**: P215-P6
- 9 Johnston EB, King C, Sloane PA, et al. Pediatric anaphylaxis in the operating room for anesthesia residents: a simulation study. *Paediatric Anaesthesia* 2017; **27**: 205-10
- 10 Chopra V, Gesink BJ, De Jong J, Bovill JG, Spierdijk J, Brand R. Does training on an anaesthesia simulator lead to improvement in performance? *British Journal of Anaesthesia* 1994; **73**: 293-7
- 11 Jacobsen J, Lindekaer AL, Oostergaard HT, et al. Management of anaphylactic shock evaluated using a full-scale anaesthesia stimulator. *Acta Anaesthesiologica Scandinavica* 2001; **45**: 315-9
- 12 Schwid HA, Rooke GA, Carline J, et al. Evaluation of anesthesia residents using mannequin-based simulation: A multiinstitutional study. *Anesthesiology* 2002; **97**: 1434-44
- 13 Murray DJ, Boulet JR, Kras JF, Woodhouse JA, Cox T, McAllister JD. Acute care skills in anesthesia practice: A simulation-based resident performance assessment. *Anesthesiology* 2004; **101**: 1084-95
- 14 Berkenstadt H, Kantor GS, Yusim Y, et al. The feasibility of sharing simulation-based evaluation scenarios in anesthesiology. *Anesthesia & Analgesia* 2005; **101**: 1068-74, table of contents
- 15 Cicarelli DD, Coelho RB, Bensenor FE, Vieira JE. [Importance of critical events training for anesthesiology residents: experience with computer simulator.]. *Rev Bras Anesthesiol* 2005; **55**: 151-7
- 16 Murray DJ, Boulet JR, Kras JF, McAllister JD, Cox TE. A simulation-based acute skills performance assessment for anesthesia training. *Anesth Analg* 2005; **101**: 1127-34, table of contents
- 17 Ishiyama M, Nakamura K, Sato H, Kawakami H, Goto T. Simulation-based acute care performance assessment for the first year anesthesia residents. *Eur J Anaesthesiol* 2009; **45**: 199
- 18 Everett TC, Ng E, Power D, et al. The Managing Emergencies in Paediatric Anaesthesia global rating scale is a reliable tool for simulation-based assessment in pediatric anesthesia crisis management. *Paediatric Anaesthesia* 2013; **23**: 1117-23
- 19 McEvoy MD, Hand WR, Furse CM, et al. Validity and reliability assessment of detailed scoring checklists for use during perioperative emergency simulation training. *Simul Healthc* 2014; **9**: 295-303

- 20 Chiu M, Tarshis J, Antoniou A, et al. Simulation-based assessment of anesthesiology residents' competence: development and implementation of the Canadian National Anesthesiology Simulation Curriculum (CanNASC). *Can J Anaesth* 2016; **63**: 1357-63
- 21 Burgess H, Murphy J, Narang P, Barrett J, Paquet E. Scientific abstract: Education perioperative disaster simulation team training program for complications following regional anesthesia administration. *Proceedings 41st Annual Regional Anesthesiology and Acute Pain Medicine Meeting of the American Society of Regional Anesthesia and Pain Medicine, ASRA 2016* https://www.asracom/content/documents/all_presented_abstracts_ra16pdf
- 22 Rao R, Caskey RC, Owei L, et al. Curriculum Using the In-Situ Operating Room Setting. *Journal of Surgical Education* 2017; **74**: e39-e44
- 23 Neuschwander A, Job A, Younes A, et al. Impact of sleep deprivation on anaesthesia residents' non-technical skills: a pilot simulation-based prospective randomized trial. *Br J Anaesth* 2017; **119**: 125-31
- 24 Arzalier-Daret S, Buleon C, Bocca ML, Denise P, Gerard JL, Hanouz JL. Effect of sleep deprivation after a night shift duty on simulated crisis management by residents in anaesthesia. A randomised crossover study. *Anaesth Crit Care Pain Med* 2018; **37**: 161-6
- 25 Blike GT, Surgenor SD, Whalen K. A graphical object display improves anesthesiologists' performance on a simulated diagnostic task. *Journal of Clinical Monitoring and Computing* 1999; **15**: 37-44
- 26 Ford S, Daniels J, Lim J, et al. A novel vibrotactile display to improve the performance of anesthesiologists in a simulated critical incident. *Anesthesia and Analgesia* 2008; **106**: 1182-8
- 27 Berkenstadt H, Yusim Y, Ziv A, Ezri T, Rubin O, Perel A. Assessment of a point-of-care information system in simulated pediatric anesthesia emergencies. *Jurnalul Roman de Anestezie Terapie Intensiva/Romanian Journal of Anaesthesia and Intensive Care* 2010; **17**: 98-102
- 28 Allen W, Smith T, Kandasamy G. Using human factors simulation training to improve emergency response to anaesthetic crises. *Anaesthesia* 2012; **2**: 38
- 29 Schulz CM, Schneider E, Fritz L, et al. Eye tracking for assessment of workload: a pilot study in an anaesthesia simulator environment. *British Journal of Anaesthesia* 2011; **106**: 44-50
- 30 Schulz CM, Skrzypczak M, Schneider E, et al. Assessment of subjective workload in an anaesthesia simulator environment: reliability and validity. *European Journal of Anaesthesiology* 2011; **28**: 502-5
- 31 Schulz CM, Schneider E, Fritz L, et al. Visual attention of anaesthetists during simulated critical incidents. *British Journal of Anaesthesia* 2011; **106**: 807-13
- 32 Ziewacz JE, Arriaga AF, Bader AM, et al. Crisis checklists for the operating room: development and pilot testing. *J Am Coll Surg* 2011; **213**: 212-7 e10
- 33 Ng CK, Stansfield D. Anaesthetic emergencies preparedness in a paediatric anaesthetic department. *Br J Anaesth* 2012; **2**: ii349-ii50
- 34 Arriaga AF, Bader AM, Wong JM, et al. Simulation-based trial of surgical-crisis checklists. *N Engl J Med* 2013; **368**: 246-53
- 35 Gorges M, Winton P, Koval V, et al. An evaluation of an expert system for detecting critical events during anesthesia in a human patient simulator: a prospective randomized controlled study. *Anesthesia & Analgesia* 2013; **117**: 380-91
- 36 Lonsdale S, Ferns J, Nazar A. Emergencies in the intra-operative period: A check and challenge audit for anaphylaxis and cardiac arrest. *Anaesthesia* 2014; **3**: 129
- 37 Schulz CM, Schneider E, Kohlbecher S, et al. The influence of anaesthetists' experience on workload, performance and visual attention during simulated critical incidents. *Journal of Clinical Monitoring & Computing* 2014; **28**: 475-80
- 38 Marshall SD, Sanderson P, McIntosh CA, Kolawole H. The effect of two cognitive aid designs on team functioning during intra-operative anaphylaxis emergencies: a multi-centre simulation study. *Anaesthesia* 2016; **71**: 389-404
- 39 Goldhaber-Fiebert SN, Pollock J, Howard SK, Bereiknyei Merrell S. Emergency Manual Uses During Actual Critical Events and Changes in Safety Culture From the Perspective of Anesthesia Residents: A Pilot Study. *Anesth Analg* 2016; **123**: 641-9

40 Lelaidier R, Balanca B, Boet S, et al. Use of a hand-held digital cognitive aid in simulated crises: the MAX randomized controlled trial. *Br J Anaesth* 2017; **119**: 1015-21

41 Marchant A. Investigation of dynamic decision support during simulated anaesthesia. *Anaesthesia* 2018; **73 (Supplement 2)**: 65

42 Alidina S, Goldhaber-Fiebert SN, Hannenberg AA, et al. Factors associated with the use of cognitive aids in operating room crises: a cross-sectional study of US hospitals and ambulatory surgical centers. *Implement Sci* 2018; **13**: 50

Supplementary online Appendix 1. Research Strategy

With the assistance of a reference librarian we searched Ovid MEDLINE(R) and Embase (Ovid) 1974 to October 08, 2018. The research strategy utilised the terms for intervention (e.g. simulation), topic (e.g. anaphyl*) and population (e.g. anaesth*)

PRISMA Flow Diagram

