Effectiveness of using high-fidelity simulation to teach the management of general anesthesia for Cesarean delivery

Efficacité de l'utilisation de la simulation haute fidélité pour l'enseignement de la gestion de l'anesthésie générale au cours d'une césarienne

Mrinalini Balki, MD · Subrata Chakravarty, MD · Aliya Salman, MD · Randy S. Wax, MD

Abstract

Purpose *The objective of this study was to assess the influence of a teaching plan consisting of didactic teaching and repeated simulations on the performance of anesthesia residents in the management of general anesthesia (GA) for emergency Cesarean delivery (CD).*

Methods *Twenty-one postgraduate year 2 (PGY2) and 3 (PGY3) anesthesia residents from the University of Toronto were recruited in this prospective cohort study. All participants received didactic teaching in the management of GA for emergency CD, which was followed one week later by assessment of performance in the same scenario using a high-fidelity simulator. Another simulation assessment was repeated two months later in the same scenario. All*

simulation video recordings were assessed by two blinded experts using a validated checklist and an Anaesthetists' Non-Technical Skills (ANTS) scale in order to rate their technical and non-technical skills, respectively. The participants' performance (based on the above scales) in the two simulation sessions were then compared.

Results *Nineteen residents completed both simulation sessions. There was an improvement in the mean (SD) weighted checklist score from 64.5% (7.1%) in session 1 to 76.7% (6.7%) in session 2 (P < 0.001). The mean (SD) ANTS scores also increased from 2.8 (0.5) in session 1 to 3.3 (0.4) in session 2 (P = 0.001). No difference in the checklist or ANTS scores was seen between PGY2 and PGY3 residents in any of the simulation sessions. Several common performance errors were identified, but these improved in the second session. The correlation between checklist and ANTS scores was moderately high (correlation coefficient [r] = 0.7; P < 0.001). The inter-rater reliability among the experts was also high (intraclass correlation coefficient [ICC] for the checklist = 0.72; 95% confidence interval [CI] 0.62 to 0.81; ICC for the ANTS = 0.74; 95% CI 0.49 to 0.89).*

Conclusion *Didactic teaching followed by simulation sessions enhances not only the technical skills but also the non-technical skills of residents, most likely due to the feedback received after the first simulation session.*

M. Balki, MD (✉) · S. Chakravarty, MD · A. Salman, MD
Department of Anesthesia and Pain Management, Mount Sinai Hospital, University of Toronto, 600 University Avenue, Room 19-104, Toronto, ON M5G 1X5, Canada
e-mail: mrinalini.balki@uhn.ca

M. Balki, MD
Department of Obstetrics and Gynaecology, Mount Sinai Hospital, University of Toronto, Toronto, ON, Canada

R. S. Wax, MD
Departments of Medicine, Queen's University and University of Toronto, Toronto, ON, Canada

R. S. Wax, MD
Department of Emergency Medicine and Critical Care, Lakeridge Health, Oshawa, ON, Canada

Repeated simulation sessions may help prepare residents to deal more effectively with similar critical situations in clinical practice with minimum errors.

Résumé

Objectif *L'objectif de cette étude était d'évaluer l'influence d'un programme d'enseignement associant un enseignement didactique et des simulations répétées sur la performance des résidents en anesthésiologie pour la gestion d'une anesthésie générale (AG) au cours d'une césarienne d'urgence.*

Méthodes *Vingt et un résidents en anesthésie de 2ᵉ année (PGY2) et de 3ᵉ année (PGY3) de l'université de Toronto ont été recrutés dans cette étude de cohorte prospective. Tous les participants ont reçu un enseignement didactique sur la gestion de l'AG pour une césarienne d'urgence, suivi une semaine plus tard par l'évaluation de la performance dans un scénario identique au moyen d'un simulateur de haute fidélité. Une autre évaluation par simulation a été répétée deux mois plus tard avec le même scénario. Tous les enregistrements vidéo de la simulation ont été évalués par deux experts tenus dans l'insu, utilisant une liste de contrôle validée et une échelle ANTS des compétences non techniques des anesthésiologistes afin de coter, respectivement, leurs habiletés techniques et non techniques. La performance des participants (basée sur les échelles ci-dessus) au cours de deux séances de simulation a alors été comparée.*

Résultats *Dix-neuf résidents ont complété les deux séances de simulation. Le score moyen (ET) pondéré de la liste de contrôle a été amélioré de 64,5 % (7,1 %) — pour la 1ʳᵉ séance — à 76,7 % (6,7 %) pour la 2ᵉ séance (P < 0,001). Le score ANTS moyen (ET) a également augmenté, passant de 2,8 (0,5) — pour la 1ʳᵉ séance — à 3,3 (0,4) pour la 2ᵉ séance (P = 0,001). Aucune différence dans les scores de la liste de contrôle et ANTS n'a été observée entre les résidents PGY2 et PGY3 pour chacune des séances de simulation. Quelques erreurs courantes d'exécution ont été identifiées, mais elles furent améliorées au cours de la seconde séance. La corrélation entre les scores de la liste de contrôle et ANTS a été modérément forte (coefficient de corrélation [r] = 0,7; P < 0,001). La fiabilité inter-évaluateur entre les experts a été également élevée (coefficient de corrélation intraclasse [ICC] pour la liste de contrôle = 0,72; intervalle de confiance [IC] à 95 % : 0,62 à 0,81; ICC pour le score ANTS = 0,74; IC à 95 % : 0,49 à 0,89).*

Conclusion *L'enseignement didactique suivi de séances de simulation n'a pas seulement amélioré les habiletés techniques, elle a aussi amélioré les habiletés non techniques des résidents, le plus probablement grâce au retour d'information reçu après la première séance de simulation. Des séances répétées de simulation pourraient aider à préparer les résidents à gérer plus efficacement des situations critiques similaires en pratique clinique avec un minimum d'erreurs.*

General anesthesia (GA) remains a choice for Cesarean delivery (CD) if there is an absolute or relative contraindication to neuraxial anesthesia or when expedited delivery is required for the safety of the mother or the neonate. Emergency CD requiring GA is a unique and challenging situation for the anesthesiologist as it involves two patients at the same time. Even the healthy mother undergoes anatomical and physiological changes of pregnancy, and the fetus may be stressed by innumerable issues. Some of the challenges while managing GA in a parturient include inadequate time for pre-oxygenation, difficult ventilation/intubation and airway management, rapid desaturation, aspiration risk, risk of intraoperative awareness, and uterine atony.[1]

According to the American Society of Anesthesiologists' closed claims analysis (1990-2003), the medicolegal liability claims in obstetric anesthesia for maternal death or permanent brain damage remain high, with GA for CD accounting for 28% of total claims. The most common causes for such claims were found to be difficult intubation (25%), inadequate oxygenation and ventilation (4%), aspiration of gastric contents (4%), and airway obstruction (4%).[2]

In current obstetric practice, however, GA has been largely replaced by regional anesthesia, which has led to a significant decrease in the practical exposure of trainee anesthesiologists to this important procedure and threatens their ability to achieve and maintain optimum skill level and clinical competency.[3-5] The factors specific to the obstetric arena, such as extreme time pressure, lack of availability of skilled assistance, anxiety about outcome, and poor team communication, further add to the common stressors of an emergency situation.[6,7] Complications during such events are often multicausal, and human errors and organizational factors contribute in 50-70% of the cases.[8]

Trainees are required to learn how to provide optimal treatment while ensuring patient safety, and balancing these two needs is an important part of residency training. Simulation-based learning can help mitigate this tension by developing trainees' knowledge, skills, and attitudes while protecting patients from unnecessary risk. Recent studies in medicine have suggested simulation as one of the most effective methods for formative and summative assessment of participants.[6,9,10] Furthermore, the use of simulation training in obstetric anesthesia has been endorsed in the triennial reports of the *Confidential Enquiry into Maternal and Child Health* (CEMCH) 2003-2005[11] and 2006-2008[12]

as a method of improving performance in the management of life-threatening emergencies, especially for junior staff. The reports also suggested that it should be incorporated as part of a nationally accredited scheme.

The objective of this study was to assess the influence of a teaching plan consisting of didactic teaching and repeated simulations on the performance of anesthesia residents in the management of GA for emergency CD. Further, we also aimed to identify areas of consistently poor performance so that more emphasis can be placed on these areas during teaching in our curriculum. We hypothesized that structured teaching and at least one high-fidelity simulation session after two months would be required to see improvement in the skills of the residents in the management of GA for emergent CD.

Methods

Design and recruitment of participants

Institutional Research Ethics Board approval (09-0108E) was obtained for this quasi-experimental study, which was conducted at Mount Sinai Hospital, Toronto from October 2009 to January 2011. Recruitment criteria included anesthesia residents in postgraduate years 2 (PGY2) and 3 (PGY3) at the University of Toronto who had already completed their dedicated three months of obstetric anesthesia training. All residents signed a written informed consent for participation in the study and for the videotaping and assessment of their performance. They also signed a confidentiality agreement not to disclose study details to anyone outside of the study personnel. The study structure consisted of a didactic teaching session followed by a simulation session after one week and a repeat simulation session two months later.

Didactic teaching

An interactive didactic PowerPoint©-based teaching session was held for all participants by the principal investigator. The presentation included information from standard anesthesia textbooks,[13] literature review,[14-16] and current guidelines (Electronic Supplementary Material).[17,18] The teaching included a comprehensive review of the physiology of pregnancy and management of GA for emergency CD with focus on the following points: preoperative assessment, including airway examination; checking equipment; preparation before induction; seeking assistance; aspiration prophylaxis; appropriate medications for induction and maintenance of anesthesia; monitoring standards; and postoperative recovery. The two-hour session generated extensive discussions on practical aspects of case management.

Simulation sessions

The simulation sessions were conducted at the SimSinai Centre at Mount Sinai Hospital. The simulation centre was set up as a virtual obstetric operating room equipped with a Laerdal SimMan® simulator mannequin (Laerdal Medical Canada Ltd, Toronto, ON, Canada) with programmable monitors (Laerdal Medical Canada Ltd., Toronto, ON, Canada), anesthesia machine (Datex Corporation, St. Laurent, QC, Canada), anesthesia drug cart and airway equipment, along with the instruments needed to perform a CD. An abdominal flap was fitted over the mannequin's abdomen to mimic pregnancy. The simulation programmer, with a view into the room, was seated outside the simulation room to input commands and manage the mechanical interfaces. The mannequin's voice was a speaker located inside the mannequin with a microphone in the programmer's console. There was capability for communication between the simulated operating room and the programmer's console speakers. A video camera in the simulated operating room recorded the events, which were displayed with superimposed vital signs on the image, and these recordings were used for subsequent evaluation by the raters. The participants were unaware of the nature of simulation, the details of the scenario, or the assessment criteria.

The simulations were performed with a common team of actors in the roles of obstetrician, nurse, and respiratory therapist. The programmer and actors were given guidelines on specific verbal responses to provide during the simulations, either voluntarily or in response to a participant's question. Participants were specifically instructed to perform all actions using the appropriate equipment as in a real-life case and to verbalize their thoughts to enable appropriate assessment. Before the simulation sessions, each resident underwent an orientation to the mock labour and delivery operating room, mannequin and monitors, as well as the method of debriefing and evaluation.

Two identical simulation sessions requiring GA for emergency CD were conducted two months apart. The first simulation session was held one week after the teaching session.

The simulation scenario involved a 38-wk pregnant woman presenting into the operating room with a prolapsed umbilical cord. The obstetrician was unable to elevate the presenting part on her vaginal exam. There was an associated sustained fetal bradycardia (50 beats·min^{-1}) and a stat CD was required.

Five minutes prior to case presentation, the anesthesia resident was asked to set up the operating room, similar to the practice at the change of shift at our hospital. During simulation, the programmer was instructed to alter the vital signs according to a flow sheet that indicated the suggested changes based on the type and doses of drugs administered.

After the first simulation session, the study investigator gave participants a focused feedback highlighting the critical errors. The participants were requested not to participate in any other simulation sessions during this time frame. The debriefing after the second session involved interactive oral feedback and a constructive critique and the opportunity for participants to provide the study investigators with feedback on their experience.

Development of technical skills checklist

To facilitate the evaluation process, the study investigators developed a checklist that was based on the literature review, previous guidelines, and common practice at our institution (Appendix)[1,13-19] and designed to reflect the specific tasks necessary for the appropriate performance of GA for emergency CD. The proposed checklist was delivered electronically to eight members of the Canadian Anesthesiologists' Society who are experts in obstetric anesthesia and represent several geographical areas of Canada. The experts were asked to validate the checklist using the modified *Delphi* technique.[20] The experts, six of whom participated in the entire process, were blinded to each other's identities. They weighed each checklist item on a scale of 0-4 based on the order of importance (where $0 =$ not important and $4 =$ extremely important). The items with "0" rating were removed from the checklist. After each round, each expert was given the opportunity to change their rating (based on the median score for that item), to suggest the elimination or addition of items on the list, and to make pertinent comments. Uniform consensus for the list of items was obtained in the second round, and the median weights of the items were finalized for scoring (Appendix).

Evaluation of technical skills

Two raters, experts in obstetric anesthesia and simulation assessment, independently evaluated the technical and non-technical skills of the participants using video recordings. The raters received videos in a random order and were blinded to the residents' training level, simulation session, and each other's scores. The technical skills were assessed using our checklist generated via the *Delphi* technique. The participants scored "1" if the task was completed as per expectations and "0" if not done at all, done after prompting, not done timely, or done with error. Each task score was multiplied by its weighting factor, and the weighted scores were summed to provide a total score. The final score used for the analysis was the percent of the maximum possible score.

Evaluation of non-technical skills

The non-technical skills were assessed using a previously validated Anaesthetists' Non-Technical Skills (ANTS) checklist[21] that included such items as task management, teamwork, situation awareness, and decision-making, which were each rated on an anchored ordinal scale ($0 =$ not observed; $1 =$ poor; $2 =$ marginal; $3 =$ acceptable; and $4 =$ good). The raters had received prior instruction in the use of ANTS and were provided with the ANTS background literature with the User Manual.[A] Before independently rating the study videos, the reviewers viewed videos that did not include the study participants and discussed their individual ratings to produce an agreed rating. This exercise provided the opportunity for developing a clearer definition of the scoring rubric for each task.

Our primary objective was to assess the influence of a teaching plan on residents' performance in managing GA for CD over time, as measured by the checklist and ANTS scores. The secondary objectives were to compare performance based on level of residency, to identify common critical errors, and to receive participants' feedback.

Statistical analysis

The checklist scores were reported as mean (SD) in percentages, while ANTS scores were presented on a four-point scale as described in the Methods. Paired Student's *t* tests were used to identify significant differences in scores over time. In order to check if the skills in particular changed over time for each outcome, the proportion of participants completing the tasks in session 1 *vs* session 2 was compared using McNemar's test. All reported *P* values are two-sided. For each simulation session, we calculated Spearman's rank correlation between the checklist and ANTS total scores. Inter-rater reliability was summarized with the intraclass correlation coefficient (ICC[1,2]) for consistency determined from a two-way random effects model. For the purposes of calculating inter-rater reliability, session 1 and 2 scores were averaged. All analyses were completed using SAS® version 9.2 (Cary, NC, USA).

Sample size for Student's *t* test for paired samples was calculated using the methods outlined by O'Brien and Muller[22] which incorporate the within-subject correlation. Assuming a two-sided type I error of 0.05, a type II error of 0.20, and a conservative estimate of within-subject correlation (i.e., correlation between pre and post measures) of 0.60, we determined that 20 participants with pre and post measurements would be required to identify a moderate effect size (i.e., Cohen's d = 0.60).

Results

Twenty-one of the 40 anesthesia residents invited to enrol agreed to participate in the study. All participating residents attended the didactic teaching and both simulation sessions, except for two who did not appear for the second simulation. Of the 19 residents who completed the entire study, 12 were PGY2 and 7 were PGY3 residents. The mean (SD) age of the participants was 29 (3) yr. They had completed 5 (1.5) months rotation in obstetric anesthesia prior to their participation in the study. At our university, all residents complete an anesthesia rotation in hospitals with an obstetric specialty, a two-month rotation in their first year and four to eight months during their second year. Their posting to obstetric anesthesia typically consists of 12-16 shifts (9-10 hr/shift) during their first year and an average of 40-58 shifts (9 hr/day and 15 hr/night) during their second year of residency. All residents had received some previous simulator training using the SimMan mannequin during the residency program. Sixteen participants had attended at least one case of GA for CD with the attending staff present throughout the case, and the median (range) exposure was 2 (0-5) cases.
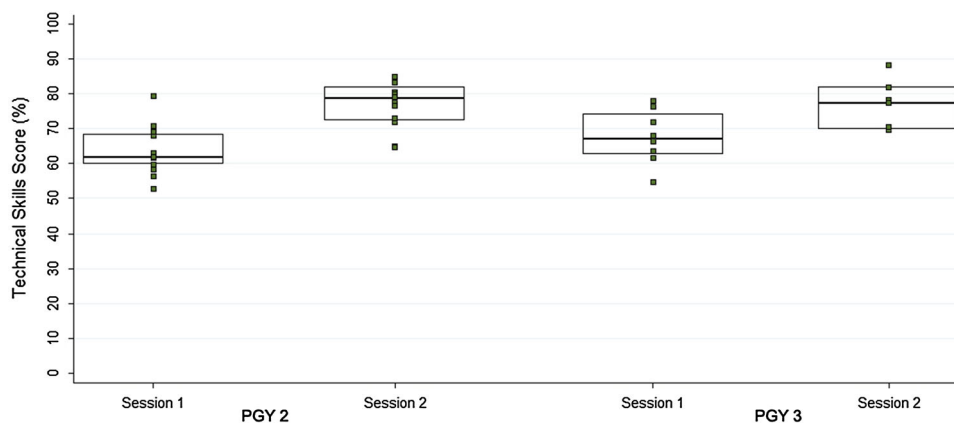
Checklist scores

The mean (SD) weighted checklist score of the participants was 64.5% (7.1%) in session 1 and an increase to 76.7% (6.7%) in session 2 (difference = 12.2%; 95% confidence interval [CI] 8.5 to 16.0; *P* < 0.001) (Table 1, Fig. 1). The differences in scores between PGY levels were small for both sessions and the improvement between sessions was similar (Table 2).

Anaesthetists' Non-Technical Skills scores

The overall mean (SD) ANTS score was 3.0 (0.4). The score improved significantly over time from 2.8 (0.5) in session 1 to 3.3 (0.4) in session 2 (*P* = 0.001), suggesting improvement from the acceptable to the good range (Table 3). There was no difference in the ANTS scores between PGY2 and PGY3 residents, with both groups demonstrating significant improvement in the second simulation session (Table 2, Fig. 2).

Table 1 Checklist scores in both simulation sessions

	Session 1 (n = 19)	Session 2 (n = 19)	Difference (95% CI)	P value
Preoperative assessment	54.7 (22.3)	60.1 (29.6)	5.4 (−8.4 to 19.2)	0.42
Equipment checking	33.8 (32.5)	66.8 (24.4)	33.1 (13.5 to 52.6)	0.002
Preparation before induction	50.7 (11.3)	64.1 (13.2)	13.4 (5.8 to 21.0)	0.002
Induction of anesthesia	81.8 (10.0)	91.5 (9.8)	9.7 (3.1 to 16.3)	0.006
Maintenance of anesthesia	73.7 (17.0)	80.8 (9.2)	7.0 (−1.3 to 15.3)	0.09
Recovery	28.3 (3.8)	29.7 (2.5)	1.4 (−0.4 to 3.2)	0.12
OVERALL	64.5 (7.1)	76.7 (6.7)	12.2 (8.5 to 16.0)	<0.001

CI = confidence interval; n = number of participants

Values are expressed as mean (SD) weighted percentage scores for all the participants in session 1 and session 2

Fig. 1 Box plots showing the distribution of technical skills scores of the residents. PGY = postgraduate year. Y axis represents average scores in percentages

Table 2 Checklist and Anaesthetists' Non-Technical Skills scores by residency level

	PGY2 (n = 12)	PGY3 (n = 7)	Difference (95% CI)	P value
Checklist scores				
Session 1	63.6% (7.2%)	66.1% (7.1%)	2.5 (−4.8 to 9.8)	0.47
Session 2	76.8% (6.8%)	76.6% (7.0%)	−0.2 (−7.1 to 6.7)	0.96
Improvement in scores	13.2% (7.9%)	10.5% (8.0%)	−2.7 (−10.9 to 5.5)	0.48
ANTS				
Session 1	2.72 (0.47)	2.83 (0.50)	0.11 (−0.36 to 0.59)	0.61
Session 2	3.32 (0.36)	3.16 (0.35)	−0.17 (−0.53 to 20.0)	0.34
Improvement in scores	0.58 (0.48)	0.40 (0.41)	−0.18 (−0.62 to 0.27)	0.42

Values are expressed as mean (SD)

ANTS = Anaesthetists' Non-Technical Skills scale 1-4 (1 = poor; 2 = marginal; 3 = acceptable; 4 = good). CI = confidence interval; n = number of participants; PGY = postgraduate year

**Table 3** Anaesthetists' Non-Technical Skills scores in all participants

ANTS score	Session 1 (n = 19)	Session 2 (n = 19)	Difference (95% CI)	P value
Task Management	2.8 (0.5)	3.3 (0.4)	0.5 (0.3 to 0.8)	0.001
Team Work	2.9 (0.5)	3.4 (0.3)	0.5 (0.3 to 0.7)	<0.001
Situation Awareness	2.8 (0.6)	3.3 (0.5)	0.6 (0.3 to 0.8)	0.001
Decision-making	2.6 (0.5)	3.0 (0.5)	0.4 (0.1 to 0.7)	0.007
OVERALL	2.8 (0.5)	3.3 (0.4)	0.5 (0.3 to 0.7)	0.001

Values are expressed as mean (SD)

ANTS = Anaesthetists' Non-Technical Skills scale 1-4 (1 = poor; 2 = marginal; 3 = acceptable; 4 = good); CI = confidence interval

Fig. 2 Box plots showing the distribution of Anaesthetists' Non-Technical Skills scores of the residents. PGY = postgraduate year. ANTS = Anaesthetists' Non-Technical Skills. Y axis represents Anaesthetists' Non-Technical Skills rating of 1-4, where 1 = poor; 2 = marginal; 3 = acceptable; 4 = good
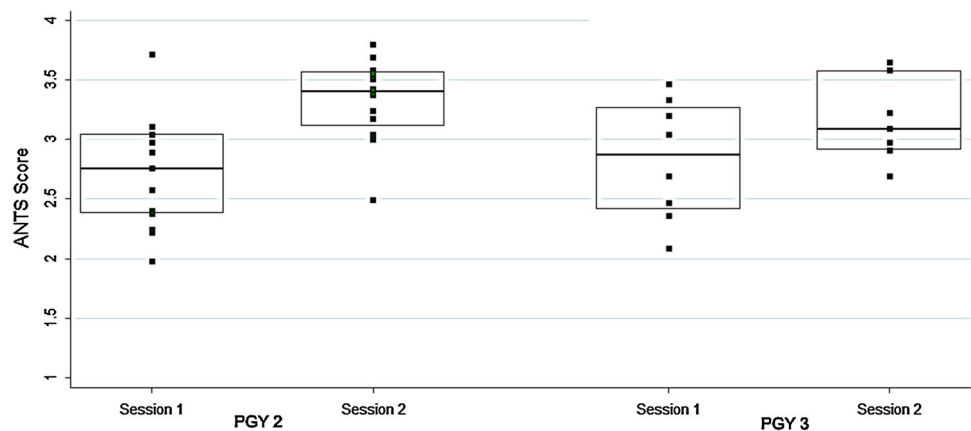
Common performance errors

Many of the tasks that the experts considered highly important (i.e., given a score of 4) were completed by fewer than 50% of the participants, especially in the first session. These tasks included: airway assessment, checking availability of airway equipment and emergency drugs, confirming left uterine displacement, positioning the patient's head properly for tracheal intubation, auscultation of the chest for bilateral breath sounds,

asking the assistant to release the cricoid pressure after intubation, and providing adequate preemptive analgesia to ablate intraoperative sympathetic responses and prepare the patient for postoperative pain (Table 4). More participants performed these tasks in the second simulation session.

Correlations and reliability

There was a moderately high correlation between the overall checklist and ANTS scores (correlation coefficient,

Table 4 Number of individual tasks performed by the participants

Checklist items		Session 1 $n = 19$	Session 2 $n = 19$	P value
Preoperative assessment				
1	Allergies	15 (79.0)	14 (73.7)	0.65
2	Medications	10 (52.6)	13 (68.4)	0.26
3	Medical history	13 (68.4)	10 (52.6)	0.25
4	Relevant obstetric history	9 (47.4)	5 (26.3)	0.10
5	Anesthetic history (e.g., MH)	7 (36.8)	10 (52.6)	0.26
6	Last oral intake	8 (42.1)	9 (47.4)	0.65
7	Airway assessment	4 (21.1)	10 (52.6)	0.07
Check equipment				
8	Circuit	4 (21.1)	14 (73.7)	0.004
9	Suction functioning	7 (36.8)	11 (57.9)	0.21
10	Laryngoscope with functional light	6 (31.6)	14 (73.7)	0.01
11	Endotracheal tube (size 6-7)	8 (42.1)	15 (79.0)	0.02
12	Airway	2 (10.5)	6 (31.6)	0.10
13	LMAD/ difficult airway cart	3 (15.8)	3 (15.8)	0.99
Preparation before induction				
14	Alert staff or senior anesthesiologist	3 (15.8)	12 (63.2)	0.003
15	Call RT, assign roles	17 (89.5)	16 (84.2)	0.65
16	Prepare induction agents (thiopental/propofol and succinylcholine)	4 (21.1)	12 (63.2)	0.03
17	Prepare/ensure readiness of emergency drugs (atropine, ephedrine, phenylephrine, nitroglycerine)	2 (10.5)	11 (57.9)	0.01
18	Administer sodium citrate (30 mL *po*)	5 (26.3)	12 (63.2)	0.008
19	Confirm intravenous placement/function	12 (66.7)	8 (42.1)	0.06
20	Apply standard monitors (EKG, pulse oximeter, BP)	17 (89.5)	15 (79.0)	0.32
21	Obtain baseline readings	17 (89.5)	15 (79.0)	0.32
22	Administer ranitidine (50 mg *iv*)	1 (5.3)	4 (21.1)	0.08
23	Administer metoclopramide (10 mg *iv*)	2 (10.5)	3 (15.8)	0.65
24	Administer antibiotics (cefazolin 2 g *iv*)	2 (10.5)	2 (10.5)	0.99
25	Confirm left uterine displacement	3 (15.8)	4 (21.1)	0.65
26	Position patient's head properly for intubation	0 (0.0)	0 (0.0)	-
27	Ask the surgeon to prep and drape the patient	19 (100.0)	19 (100.0)	-
Induction of anesthesia				
28	Adequate preoxygenation (sealed mask, 3 min or 4-8 VC breaths)	19 (100.0)	18 (94.7)	0.32
29	Apply cricoid pressure	17 (89.5)	19 (100.0)	-
30	Administer induction agent and succinylcholine	15 (79.0)	19 (100.0)	-
31	Appropriate dose of induction agent (thiopental 5-7 $mg \cdot kg^{-1}$ OR propofol 2-3 $mg \cdot kg^{-1}$)	11 (57.9)	15 (79.0)	0.16
32	Appropriate dose of muscle relaxant (succinylcholine 1.5-2 $mg \cdot kg^{-1}$)	13 (68.4)	17 (89.5)	0.16
33	Intubate under direct laryngoscopy	18 (94.7)	19 (100.0)	-
34	Inflate cuff	18 (94.7)	18 (94.7)	0.99
35	Confirm the presence of $ETCO_2$	16 (84.2)	17 (89.5)	0.65
36	Release cricoid pressure	7 (36.8)	16 (84.2)	0.003
37	Check bilateral breath sounds	5 (26.3)	14 (73.7)	0.01
38	Secure endotracheal tube	16 (84.2)	18 (94.7)	0.16
39	Notify surgeons to proceed	10 (52.6)	18 (94.7)	0.005
40	Tape eyes	1 (5.3)	3 (15.8)	0.32
Maintenance of anesthesia				
41	Initiate mechanical ventilation (TV 500 mL, RR 10-12 $breaths \cdot min^{-1}$)	12 (63.2)	18 (94.7)	0.01
42	Adequate oxygenation (FiO_2 0.3-0.5)	17 (89.5)	19 (100.0)	-
43	Adequate ventilation ($ETCO_2$ 30-32 mmHg)	14 (82.4)	14 (82.4)	0.99

Table 4 continued

Checklist items		Session 1 $n = 19$	Session 2 $n = 19$	P value
44	Adequate hemodynamics	16 (84.2)	17 (89.7)	0.32
Before delivery				
45	Volatile agent (1 MAC) + N_2O (33-50% in O_2) OR intravenous propofol infusion	8 (42.1)	10 (52.6)	0.53
After delivery				
46	Volatile agent (0.7-1.0 MAC) + N_2O (66% in O_2) OR intravenous propofol infusion	10 (52.6)	11 (57.9)	0.76
47	Oxytocin infusion (20-40 $IU \cdot L^{-1}$ titrated to response, no boluses)	8 (42.1)	13 (68.4)	0.10
48	Confirm adequate uterine tone, estimate blood loss	8 (42.1)	7 (36.8)	0.71
49	Adequate preemptive analgesia (fentanyl 100-250 µg, morphine 10-15mg, ketorolac 30 mg)	6 (31.6)	8 (42.1)	0.41
50	Administer muscle relaxant as needed (small doses of succinylcholine or rocuronium)	2 (10.5)	2 (10.5)	-
Recovery				
51	Turn off vapour and N_2O timely	19 (100.0)	19 (100.0)	-
52	Give 100% oxygen	14 (73.7)	17 (89.5)	0.26
53	Assess neuromuscular function if NDMR has been given	1 (33.3)	2 (66.7)	0.32
54	Give reversal if NDMR has been given	2 (66.7)	1 (33.3)	0.32
55	Pharyngeal suction	8 (42.1)	15 (79.0)	0.02
56	Extubate when awake and responding to verbal commands	18 (94.7)	18 (94.7)	0.99
57	Give O_2 by mask after extubation	18 (94.7)	16 (84.2)	0.16
58	Confirm airway patency and O_2 saturation before transfer to recovery room	18 (94.7)	17 (89.5)	0.56

Values are expressed as *n* (%). BP = blood pressure; EKG = electrocardiogram; ETCO$_2$ = end-tidal carbon dioxide; FiO$_2$ = fraction of inspired oxygen; LMAD = laryngeal mask airway device; MH = malignant hyperthermia; NDMR = non-depolarizing muscle relaxant; N$_2$O = nitrous oxide; O$_2$ = oxygen; RT = respiratory therapist; RR = respiratory rate; TV = tidal volume; VC = vital capacity. The task was labelled as completed only if both reviewers identified it as completed

r = 0.7; 95% CI = 0.37 to 0.87; $P < 0.001$) and in the individual simulation sessions (session 1: r = 0.7; 95% CI = 0.38 to 0.87; $P < 0.001$) (session 2: r = 0.65; 95% CI = 0.26 to 0.85; $P = 0.003$). The correlations between the subscales of ANTS were also high and statistically significant in both sessions. For example, in session 1, those with high decision-making scores also had high scores in task management (r = 0.89), team work (r = 0.78), and situation awareness (r = 0.90); all differences were statistically significant ($P < 0.001$). The inter-rater reliability among the raters was high with an overall ICC for checklist scores of 0.72 (95% CI 0.62 to 0.81) and an overall ICC for ANTS of 0.74 (95% CI 0.49 to 0.89).

Participants' feedback

On average, the participants rated the setup and realism of the scenarios as 3.4 (0.6) and debriefing as 3.9 (0.2) on a four-point scale (1-4; 1 = poor and 4 = excellent). All participants mentioned that all components of the scenario were easy to understand and strongly indicated the need for simulation training. All stated that this experience would help them in clinical management. Prior to their first simulation session, the comfort level of performing the case in a clinical setting was rated as poor, marginal, satisfactory, and good by 33%, 25%, 42%, and 0% of participants, respectively; however, after the second session, the comfort level was rated good by 100% of participants.

Discussion

Our study shows that participants' technical and non-technical skills improved with successive simulation sessions, suggesting that didactic teaching alone may not be sufficient. The addition of hands-on practice with simulation and feedback during debriefing is beneficial in reinforcing the skills and enhancing performance. This also suggests a role for experiential learning with repetition of similar scenarios at short intervals.

In our study, despite prior intensive interactive teaching, the scores in the first simulation session were not remarkable. Although the participants were unaware of the assessment criteria, all the items on the checklist were extensively discussed during the teaching session. This implies that trainees may not be able to retain all the

knowledge gained during didactic teaching and/or may not be able to put that knowledge into practice. Poor scores could also be related to residents' limited clinical exposure to such cases and their awareness of being videotaped and evaluated in the simulation environment.

Significant improvement in the second session suggests that the skills in the management of this scenario do not deteriorate after an interval of two months. Practical experience gained through simulation and focused debriefing during the first session may have reinforced the management decisions of the residents and led to an improvement in performance in the second simulation session. There was a potential for the third-year trainees to outperform the second-year trainees; however, we found no difference in their technical or non-technical skills during any of the simulation sessions. This could be because the residents in their third year rotate through internal medicine with no exposure to anesthesia or obstetric specialties.

Many variables have been shown to affect retention of skills and could be difficult to isolate in real-life or simulated scenarios.[23] Factors, such as hands-on practice, simplicity of instruction, multimedia presentations, and feedback from instructors, have shown to have a positive effect on skills retention. We have observed that a structured teaching plan that includes more than one or all of these factors is required to realize the effective outcome.

It is necessary to define protocols for uniformity and standardization of practice, especially in critical scenarios that are not routinely encountered. Nevertheless, adherence to standard protocols or guidelines while managing crisis situations varies as per the type of emergency and the time interval after training.[24,25] It has been shown that about 50% of anesthesiologists deviate from in-house protocols when dealing with failed intubation in obstetrics.[24] Studies in both basic and advanced cardiac life support show short retention times and linear degradation of skills with time.[23,26] Similarly, any skill, including that learned in a simulation setting, is likely to follow a similar fate, and the optimal interval for reinforcement of such training remains to be determined.

In their simulation study on failed intubation in obstetrics, Goodwin et al.[27] demonstrated several deficits in the performance of anesthesia trainees. These, however, improved significantly after practice and formal teaching, with a greater adherence to the protocol on the second occasion. Scavone et al.[28] studied the performance of trainees in the simulated management of GA for emergency CD and found higher scores in those trained on a patient simulator with this scenario as compared with those trained on GA for a non-obstetric scenario. Our study further reinforces the importance of hands-on practice in enhancing not only the procedural skills but also the non-

technical skills, which the participants would possibly have learned in an implicit way during the first simulation session. There was a higher adherence to the institutional protocol for GA for CD in the second simulation session. This could be related to the shorter intervals between the teaching session and first simulation session, and the first and second simulation sessions, in addition to the feedback from the first simulation session. More simulation sessions at various intervals may be necessary until the participants demonstrate the best possible performance.

Several areas of weakness were identified in the first session. Lack of appropriate preoperative assessment was observed; this has been shown to be a contributory factor in anesthesia-related mortality.[29] Despite being given enough time to check the availability of equipment and emergency drugs, many residents failed to accomplish this task. A previous study published by our group on unanticipated difficult airway management in obstetrics revealed a concerning observation, i.e., study participants did not call for help or request a difficult airway cart, and they made infrequent use of a laryngeal mask airway device.[30] Although this was not a difficult intubation and/or ventilation scenario, the importance of availability of equipment for an unanticipated difficult intubation was highly emphasized in the teaching session. Very few residents ensured left uterine displacement of the patient. It is likely that residents assumed that the patient was positioned with left uterine displacement, considering that this task is performed most often by the nurses. Asking for timely release of cricoid pressure was often forgotten. After intubation, it is crucial to confirm endotracheal tube placement by auscultation of the chest for bilateral breath sounds. We noticed a threefold improvement in this task in the second session. Frequent findings in our study were inadequate anesthesia prior to delivery and inadequate preemptive analgesia after delivery. These were likely due to fear of neonatal depression and the short length of the procedure, respectively. Focusing on these commonly performed errors in classroom teaching could lead to further improvement in case management.

The American Joint Commission root cause information (2004-2012) recently revealed that communication errors were responsible for greater than 50% of overall maternal sentinel events.[31] To avoid such major adverse events, it is important to train the residents in their non-technical skills, such as communication, cooperation, leadership, etc., which are promising tools to foster teamwork. Although we did not provide any explicit training on non-technical skills during the teaching session, we noticed a significant improvement in their ANTS scores in the second simulation. A good correlation between our objective checklist and the ANTS scale indicates that both explicit and implicit processes play a complementary role for better

overall performance. Furthermore, a strong correlation between the individual subscales of the non-technical skills indicates a high interdependency of these items for overall improvement.

Our procedural checklist was predominantly tailored to the practice at our hospital and was validated by experts from Canada. Compared with the checklist by Scavone et al.,[19] our list has some additional items, including a section on recovery, and the experts have given different weight to the items. Bould et al.[32] suggested that a different group of experts may not agree on each point on the checklist, thus necessitating the development and validation of additional checklists for assessing skills for similar procedures. An additional advantage of this process is that the checklist will have an intrinsic validity of content if it is well constructed, ensuring that it incorporates and examines what is taught in that institution.[32] Our checklist does show good validity and reliability of content, and the scores of our participants are comparable with those in the study by Scavone et al.

All participants strongly indicated the need for high-fidelity simulation training on GA for CD and agreed that it is a useful method of testing and enhancing their knowledge. Given our results, we look forward to incorporating formal teaching followed by a simulation session into our own residents' program of study in the future.

There are some limitations to our study, including a small sample size, as only half the number of invited residents agreed to participate in the study. However, in our view, they represent the typical cohort of our residents. In the absence of previous research on the effect of successive simulations and with our observation of improvement in performance, especially of non-technical skills, we think this study could form a foundation for further investigations in this area. A further limitation was that our raters were recruited from faculty at the institutions attended by the residents; hence, it is possible that the raters could identify some of the subjects. Nevertheless, they were blinded to the residents' training level and simulation session (first or second) and all videos were allocated in a random order. Since the participants performed similar scenarios in both sessions with the same actors, it is unlikely that the reviewers had any potential bias in the assessment.

Another limitation of our study is the lack of a control group without didactic teaching or a group with didactic teaching but without a first simulation session. Since our study included junior residents with limited exposure to such cases, it was decided to provide them with uniform baseline information to ensure a better learning experience. Furthermore, teaching is a standard practice in most institutions and not teaching some residents would have deprived them of the unique learning experience. Skipping

the first simulation session would perhaps have led to even worse scores in the simulation at two months due to a longer interval between teaching and simulation. Nevertheless, the residents served as their own controls for tracking their performance over time through repeated simulations. The findings of our study may have clinical significance since our specific teaching plan improved scoring as measured by our checklist.

For any form of simulation, realism or authenticity of the experience is important for participants. Although the mannequin used in our study was human-like and had physiologic responses consistent with the clinical situation, it cannot be mistaken for a live person. One of the common concerns is that simulation is obviously an "artificial environment", and therefore, the amount of stress created in this setting could be far less than that in the real situation, as the performer knows well that life is not at risk. This may have been the reason for some of the common failures and errors seen in our study. It may be argued, however, that this provides learners with an opportunity to learn from their own mistakes.

As with any study using high-fidelity simulation as an evaluative tool, any findings should ideally be confirmed by evaluating performance in real situations. Unfortunately, the infrequent and unpredictable nature of emergency CD makes it challenging to perform an evaluation of such events in anesthesiology. Periodic reinforcement of skills in a simulation environment may be beneficial to help with their translation in a real-life scenario.

We suggest that use of simulation for obstetric anesthesia has the potential to decrease the number and effects of medical errors, facilitate open discussions in training situations, and enhance patient safety. By accepting simulation as a standard of training and certification, health systems will be viewed as more accountable and ethical by the populations they serve. Such simulations can facilitate the objective assessment of the residents, identify gaps in teaching, and ultimately lead to improved clinical practice.

Appendix: Weighted scores of checklist items in round 1 and 2 (final) of Delphi process

Checklist: DVD#_____VIDEO #____ (weight 0-4: 0 = not important, 4 = highly important)

Done as per expectations (✔) = done timely and correctly
Not done as per expectations (X) = not done at all, done after prompting, not done timely or done with errors

Checklist items	Final Weighted score Median (Range)	Round 1 Weighted score Median (Range)
Preoperative assessment		
1 Allergies	4 (3-4)	4 (2-4)
2 Medications	2 (2-4)	2 (2-4)
3 Past medical history	2.5 (2-4)	2 (2-4)
4 Relevant obstetric history	3 (2-4)	-
5 Past anesthetic history (e.g. MH)	3 (1-4)	3 (2-4)
6 Last oral intake	3 (1-4)	2.5 (1-4)
7 Airway assessment	4 (4-4)	4 (4-4)
Check equipment		
8 Circuit	4 (3-4)	4 (3-4)
9 Suction functioning	4 (3-4)	4 (3-4)
10 Laryngoscope with functional light	4 (1-4)	3 (1-4)
11 Endotracheal tube (size 6-7)	4 (1-4)	4 (1-4)
12 Airway	4 (2-4)	-
13 LMA/ difficult airway cart	4 (3-4)	-
Preparation before induction		
14 Alert staff or senior anesthetist		
15 Call RT, assign roles	3 (2-4)	3 (1-4)
16 Prepare induction agents (Thiopental/Propofol and Succinylcholine)	4 (3-4)	4 (3-4)
17 Prepare/ensure readiness of emergency drugs (Atropine, Ephedrine, Phenylephrine, Nitroglycerine)	4 (4-4)	4 (4-4)
18 Administer sodium citrate (30 ml PO)	2.25 (1-3)	2.5 (1-3)
19 Confirm IV placement/function	4 (4-4)	4 (4-4)
20 Apply standard monitors (EKG, pulse oximeter, BP)	3.5 (3-4)	4 (2-3)
21 Obtain baseline readings	3 (2-4)	3 (1-3)
22 Administer ranitidine (50 mg IV)	2 (1-2)	2 (1-3)
23 Administer metoclopramide (10 mg IV)	2 (1-2)	2 (1-2)
24 Administer antibiotics (Cefazolin 2 g IV)	2.5 (1-3)	2.5 (1-3)
25 Confirm left uterine displacement	4 (4-4)	4 (4-4)
26 Position patient's head properly for intubation	4 (4-4)	4 (2-2)
27 Ask the surgeon to prep and drape the patient	3 (2-3)	3 (2-3)
Induction of anesthesia		
28 Adequate preoxygenation (sealed mask, 3 min or 4-8 VC breaths)	4 (4-4)	4 (2-4)
29 Apply cricoid pressure	3 (3-3)	3 (2-3)
30 Administer induction agent and succinylcholine	4 (4-4)	4 (4-4)
31 Appropriate dose of induction agent (Thiopental 5-7 mg/kg OR Propofol 2-3 mg/kg)	3 (3-4)	3 (2-3)
32 Appropriate dose of muscle relaxant (succinylcholine 1.5-2 mg/kg)	3 (3-4)	3 (2-3)
33 Intubate under direct laryngoscopy	4 (4-4)	4 (4-4)

Checklist items		*FinalWeighted scoreMedian (Range)*	*Round 1Weighted score Median (Range)*
34	Inflate cuff	4 (4-4)	4 (4-4)
35	Confirm the presence of $ETCO_2$	4 (4-4)	4 (4-4)
36	Release cricoid pressure	4 (4-4)	4 (4-4)
37	Check bilateral breath sounds	4 (4-4)	4 (4-4)
38	Secure endotracheal tube	4 (3-4)	4 (2-4)
39	Notify surgeons to proceed	3 (3-3)	-
40	Tape eyes	2 (2-2)	-
Maintenance of anesthesia			
41	Initiate mechanical ventilation (TV 500 mL, RR 10-12/min)	4 (4-4)	4 (4-4)
42	Adequate oxygenation (FiO_2 0.3-0.5)	4 (4-4)	4 (4-4)
43	Adequate ventilation ($EtCO_2$ 30-32 mmHg)	4 (4-4)	4 (4-4)
44	Adequate hemodynamics	4 (3-4)	4 (3-4)
Before delivery			
45	Volatile agent (1 MAC) + N_2O (33-50% in O_2) OR IV propofol infusion	2.5 (2-3)	2 (2-3)
After delivery			
46	Volatile agent (0.7-1.0 MAC) + N_2O (66% in O_2) OR IV propofol infusion	3 (2-3)	2 (1-3)
47	Oxytocin infusion (20-40 IU/L titrated to response, no boluses)	2 (1-3)	2 (1-2)
48	Confirm adequate uterine tone, estimate blood loss	2 (1-3)	1 (1-3)
49	Adequate preemptive analgesia (fentanyl 100-250 µg, morphine 10-15 mg, ketorolac 30 mg)	1 (1-2)	1 (1-2)
50	Administer muscle relaxant as needed (small doses of succinylcholine or rocuronium)	4 (4-4)	4 (4-4)
Recovery			
51	Turn off vapour and N_2O timely	2 (1-4)	2 (1-2)
52	Give 100% oxygen	4 (4-4)	3 (1-4)
53	Assess neuromuscular function if NDMR has been given	2 (1-4)	3 (1-3)
54	Give reversal if NDMR has been given	3 (1-4)	3 (2-3)
55	Pharyngeal suction	2.5 (1-3)	3 (2-4)
56	Extubate when awake and responding to verbal commands	3 (2-4)	3 (2-4)
57	Give O_2 by mask after extubation	3 (2-4)	3 (1-4)
58	Confirm airway patency and O_2 saturation before transfer to recovery room	3 (2-3)	4 (4-4)

References

1. *Lyons G, Akerman N.* Problems with general anaesthesia for caesarean section. Minerva Anestesiol 2005; 71: 27-38.
2. *Davies JM, Posner KL, Lee LA, Cheney FW, Domino KB.* Liability associated with obstetric anesthesia: a closed claims analysis. Anesthesiology 2009; 110: 131-9.
3. *Bucklin BA, Hawkins JL, Anderson JR, Ullrich FA.* Obstetric anesthesia workforce survey: twenty-year update. Anesthesiology 2005; 103: 645-53.
4. *Palanisamy A, Mitani AA, Tsen LC.* General anesthesia for cesarean delivery at a tertiary care hospital from 2000 to 2005: a retrospective analysis and 10-year update. Int J Obstet Anesth 2011; 20: 10-6.
5. *Johnson RV, Lyons GR, Wilson RC, Robinson AP.* Training in obstetric general anaesthesia: a vanishing art? Anaesthesia 2000; 55: 179-83.
6. *Douglas MJ, Preston RL.* The obstetric airway: things are seldom as they seem. Can J Anesth 2011; 58: 494-8.

7. *Hawthorne L, Wilson R, Lyons G, Dresner M.* Failed intubation revisited: 17-yr experience in a teaching maternity unit. Br J Anaesth 1996; 76: 680-4.
8. *Haque MF, Sen S, Meftahuzzaman SM, Haque MM.* Anesthesia for emergency cesarean section. Mymensingh Med J 2008; 17: 221-6.
9. *Fox R, Walker JJ, Draycott TJ.* Medical simulation for professional development—science and practice. BJOG 2011; 118: 1-4.
10. *Boulet JR, Murray DJ.* Simulation-based assessment in anesthesiology: requirements for practical implementation. Anesthesiology 2010; 112: 1041-52.
11. *Lewis G* (Ed.). Confidential Enquiry into Maternal and Child Health (CEMACH). Saving Mothers' Lives: Reviewing Maternal Deaths to Make Motherhood Safe 2003-2005. The Seventh Report of the Confidential Enquiries into Maternal Deaths in the United Kingdom. London: RCOG Press; 2007.
12. *Cantwell R, Clutton-Brock T, Cooper G, et al.* Saving mothers' lives: Reviewing maternal deaths to make motherhood safer:

2006-08. The Eighth Report on Confidential Enquiries into Maternal Deaths in the United Kingdom. BJOG 2011; 118(Suppl 1): 1-203.

13. *Tsen L.* Anesthesia for cesarean delivery. In: Chestnut DH, Polley LS, Tsen LC, Wong CA, editors. Chestnut's Obstetric Anesthesia: Principles and Practice. 4th ed. Philadelphia PA: Mosby Elsevier; 2009. p. 521-73.

14. *Robins K*, *Lyons G.* Intraoperative awareness during general anesthesia for cesarean delivery. Anesth Analg 2009; 109: 886-90.

15. *Levy DM*, *Duggal K.* Traditional rapid sequence induction is an outmoded technique for caesarean section and should be modified. Int J Obstet Anesth 2006; 15: 227-9.

16. *Chin KJ*, *Yeo SW.* Bispectral index values at sevoflurane concentrations of 1% and 1.5% in lower segment cesarean delivery. Anesth Analg 2004; 98: 1140-4.

17. *Merchant R*, *Bosenberg C*, *Brown K*, *et al.* Guidelines to the practice of anesthesia: revised edition 2011. Can J Anesth 2011; 58: 74-107.

18. *American Society of Anesthesiologists Task Force on Obstetric Anesthesia.* Practice guidelines for obstetric anesthesia: an updated report by the American Society of Anesthesiologists Task Force on Obstetric Anesthesia. Anesthesiology 2007; 106: 843-63.

19. *Scavone BM*, *Sproviero MT*, *McCarthy RJ*, *et al.* Development of an objective scoring system for measurement of resident performance on the human patient simulator. Anesthesiology 2006; 105: 260-6.

20. *Clayton MJ.* Delphi: a technique to harness expert opinion for critical decision-making tasks in education. Educ Psychol 1997; 17: 373-86.

21. *Fletcher G*, *Flin R*, *McGeorge P*, *Glavin R*, *Maran N*, *Patey R.* Anaesthetists' Non-Technical Skills (ANTS): evaluation of a behavioural marker system. Br J Anaesth 2003; 90: 580-8.

22. *O'Brien RG*, *Muller KE.* Unified power analysis for t-tests through multivariate hypotheses. In: Edwards LK, editor. Applied Analysis of Variance in Behavioral Science. New York: Marcel Dekker, Inc.; 1993. p. 297-344.

23. *Smith KK*, *Gilcreast D*, *Pierce K.* Evaluation of staff's retention of ACLS and BLS skills. Resuscitation 2008; 78: 59-65.

24. *Rahman K*, *Jenkins J.* Failed tracheal intubation in obstetrics: no more frequent but still managed badly. Anaesthesia 2005; 60: 168-71.

25. *Schwid HA*, *O'Donnell D.* Anesthesiologists' management of simulated critical incidents. Anesthesiology 1992; 76: 495-501.

26. *Nyman J*, *Sihvonen M.* Cardiopulmonary resuscitation skills in nurses and nursing students. Resuscitation 2000; 47: 179-84.

27. *Goodwin MW*, *French GW.* Simulation as a training and assessment tool in the management of failed intubation in obstetrics. Int J Obstet Anesth 2001; 10: 273-7.

28. *Scavone BM*, *Toledo P*, *Higgins N*, *Wojciechowski K*, *McCarthy RJ.* A randomized controlled trial of the impact of simulation-based training on resident performance during a simulated obstetric anesthesia emergency. Simul Healthc 2010; 5: 320-4.

29. *Gannon K.* Mortality associated with anaesthesia. A case review study. Anaesthesia 1991; 46: 962-6.

30. *Balki M*, *Cooke ME*, *Dunington S*, *Salman A*, *Goldszmidt E.* Unanticipated difficult airway in obstetric patients: development of a new algorithm for formative assessment in high-fidelity simulation. Anesthesiology 2012; 117: 883-97.

31. *DeRosier J*, *Stalhandske E*, *Bagian JP*, *Nudell T.* Using health care Failure Mode and Effect Analysis The VA Center for Patient Safety's Prospective Risk Analysis system. Jt Comm J Qual Improv 2002; 27: 248-67.

32. *Bould MD*, *Crabtree NA*, *Naik VN.* Assessment of procedural skills in anaesthesia. Br J Anaesth 2009; 103: 472-83.