The development of a scoring tool for the measurement of performance in managing hypotension and intra-operative cardiac arrest during spinal anaesthesia for caesarean section

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Background: At level one hospitals in South Africa a high annual number of maternal deaths occur due to the unrecognised/untreated complications of spinal anaesthesia. The authors developed a clinical scenario and scoring system to measure intern performance in managing hypotension and cardiac arrest during spinal anaesthesia for caesarean section on a human patient simulator. This system was then subjected to tests of validity and reliability.

Methods: The simulator-based clinical scenario was developed by two specialist anaesthesiologists. A modified Delphi technique was used to achieve consensus among 10 anaesthetic specialists regarding a standardised scoring system. A total of 20 medical officers with a Diploma in Anaesthesiology and 20 interns completed the scenario and were scored by two senior anaesthesiologists.

Results: Medical officers scored an average of 252 and 246 points, whereas interns scored an average of 216 and 215 points ($p = 0.005$ and $p = 0.013$, respectively). The scoring instrument demonstrated high inter-assessor reliability with an intra-class correlation coefficient of 0.983.

Conclusions: The scoring tool was shown to be valid and reliable. It offers a standardised assessment process and may be used to refine institutional intern training programmes, with a view to improving anaesthesia skills in community service medical officers.

Keywords: anaesthesia spinal, caesarean section, internship, residency, simulation, simulator

Background

South Africa has a high annual number of anaesthetic maternal deaths. The majority of these occur at level one hospitals due to the unrecognised/untreated complications of spinal anaesthesia.[1] These hospitals provide generalist services to inpatients and outpatients, who have ideally been referred from a community health centre or clinic.[2] Research has shown a lack of training, experience and supervision in anaesthesia at these hospitals,[3] and that community service doctors (CSMOs), in their first year of practice after internship training, are required to provide obstetric anaesthesia without supervision.[4] Research has previously indicated that internship training (a two-year training period of doctors who have completed their undergraduate medical degree but do not yet have a licence to practise medicine unsupervised) inadequately prepares CSMOs to fulfil this role.[5] Assessment of internship training programmes and intern performance at the end of their training is therefore critical.

Simulation assessments offer a means of assessing performance without the risk of direct patient harm.[6,7] However, for any assessment tool to have wider applicability it needs to be validated and reproducible. Previous studies have developed valid and reliable simulator-based assessment tools for the measurement of trainee doctor performance in providing anaesthesia in simulated environments.[8,9] Such tools have not been developed within South Africa. The objectives of this study were to develop a standardised simulator-based scenario and scoring tool for measuring intern performance, and then to assess the validity and reliability of the scoring tool in the simulated context. It was hypothesised that the scoring tool would yield higher scores for doctors who had qualified with a Diploma in Anaesthesiology (DA) (a South African postgraduate qualification requiring six months of supervised anaesthetic training in an approved training hospital or three months' supervised training with a case logbook meeting minimum requirements, and the successful completion of a national examination) (http://www.collegemedsa.ac.za/view_exam.aspx?examid=2) versus medical interns at the end of their anaesthetic training (validity), and that minimal variability in scores would exist among those performing the scoring (reliability).

Materials and methods

Ethical approval for the study was granted by the University of KwaZulu-Natal Biomedical Research Ethics Committee (BE288/13).

The modified Delphi process

A modified Delphi technique was used to obtain consensus anonymously among several experts (specialist anaesthesiologists who provide and teach obstetric anaesthesia) regarding a standardised scoring tool to evaluate intern performance of a simulated spinal anaesthetic complicated by hypotension and cardiac arrest. This technique has been used previously to develop simulation-based assessment tools.[8,9,10] A draft list of tasks deemed necessary to successfully perform spinal anaesthesia for caesarean delivery and manage the complication of hypotension progressing to cardiac arrest was developed by two anaesthetic specialists. The list of tasks was distributed to 10 anaesthetic specialists working at the study site — all involved in intern, medical officer and registrar training for obstetric anaesthesia. In the first round the specialists were asked to: (i) rank each task according to importance on a five-point scale (one = lowest importance to five = highest importance), (ii) suggest the addition or removal of any tasks, and (iii) provide reasoning for their proposed changes. After the mean score for each task was calculated, relevant comments were redistributed in the second round and the specialists were asked to change their scores based on the group mean, or to provide reasoning for not changing their scores (round two). New group means were calculated for each task, and the process was repeated again for a third round.

The result was a standardised list of tasks for the successful completion of the simulated scenario, each weighted according to level of importance as determined by the Delphi process.

During the simulator-based assessment the candidates' actions were marked on the assessment sheet by the assessor. At the end of the simulation the completed tasks were multiplied by their weighting factor, the sum of which provided a total score.

The simulator

The study was conducted at the Grey's Hospital Simulation Centre. The simulator was a high-fidelity, life-sized human patient computerised mannequin manufactured by Medical Education Technologies, Inc (sarasota, USA) with Müse graphical interface software. The mannequin is operated wirelessly from a computer, with technology that mimics human physiology (cardiovascular, respiratory and neurological). This includes voice simulation and the ability to do procedures on the mannequin. The computer interface allows for instant visual control of both the mannequin and the vital signs monitors, represented on a separate computer screen. The simulator software was programmed by the investigators to follow a set timed clinical course as outlined in Table 1. Additional equipment available during the simulation included a Dräger Fabius anaesthetic machine (Draeger Medical Inc, Telford, PA, USA), airway management equipment, appropriately labelled drugs, intravenous fluids, needles and syringes, and surgical drapes.

The scenario

The candidate was orientated to the simulator by the investigator at the start of each assessment. The candidate was then told that it was his/her first day working at a rural hospital as a CSMO (for intern candidates), or on outreach (for medical officer candidates), and had been called to theatre to provide anaesthesia for an emergency

Table 1: Outline of simulator sequence of events and expected management

Progress*	Vital signs†	Patient condition	Expected management	Theatre activity
Baseline	BP 125/80 HR 85 RR 18 Sats 95%	No complaints	Wedge Facemask oxygen preparation for spinal Set non-invasive blood pressure cycling to 1 minute	Surgeon scrubbed Anaesthetic nurse to assist anaesthetist
Vitals post spinal insertion	BP 130/80 HR 90 RR 18 Sats 94%	No complaints	Insert wedge Monitor vitals and IVI fluid Communicate with patient	Candidate informed spinal completed
0–240 seconds	BP 115/70 HR 85 RR 18 Sats 96%	Reports T8 sensory level	Communicate with patient Test level of sensation Perform WHO checklist	Surgeon to clean and drape abdomen
240–300 seconds	BP 70/30 HR 135 RR 25 Sats 92%	Nausea and dizziness	IVI fluid bolus Vasoactive drug boluses Check uterine displacement	Surgeon: "cutting skin" Anaesthetic nurse: "patient is restless"
300–360 seconds	BP 45/20 HR 155 No Sats trace	Drowsy Poorly responsive	Assess ABC Free running IVI fluid Vasoactive drug boluses Manual displacement of uterus	Surgeon: "Is there a problem? What must I do to help?" Anaesthetic nurse: follow instructions
> 360 seconds	Apnoea Pulseless electrical activity	Un-responsive	Initiate CPR Call for defibrillator Instruct surgeon to deliver foetus	All to follow instructions Can ask: "what must I do?"

*Times given are approximate values for transition during the scenario. The assessors had the ability to adjust the transition times manually during the simulation.
†During the simulation the vital signs fluctuated around these approximate values.
Note: only non-invasive blood pressure recordings were displayed on the monitor.

caesarean section. In the room the surgeon (investigator) informed the candidate that the patient was an 18-year-old primigravida with obstructed labour, but no foetal distress, requiring a caesarean section. He advised the candidate to take time to prepare the theatre. The anaesthetic assistant (actor) informed the candidate that he could assist in preparing the theatre by providing any equipment requested — only the operating table and anaesthetic machine were visible at this stage. The candidate was expected to thoroughly prepare theatre including the emergency trolley, airway trolley, function of the operating table, and any drugs needed. The candidate was provided only with the equipment as requested. The candidate was required to state that a machine check is necessary but was informed that it was not part of the assessment.

When the candidate indicated that preparation was complete, the surgeon announced that the patient was now in theatre and unveiled the previously covered mannequin. The surgeon asked to be told when he could start operating. The candidate was expected to perform a thorough preoperative assessment on the patient and was given information only if he/she asked for it or if he/she performed the examination. Information provided included the following: the patient had no medical problems, took no regular medication, had no allergies and had been fasted for 12 hours. The candidate was required to perform a systemic and airway examination and at each step was informed that the findings were normal. The candidate was required to counsel the patient on the method of anaesthesia; should the candidate choose a general anaesthetic he/she was instructed to perform a spinal anaesthetic, prescribe pre-medication, initiate monitoring, and establish intravenous access.

There were no time limits for the theatre preparation or the assessment of the patient and no prompting was given to complete any task. To create a sense of urgency the surgeon was scripted to regularly ask the candidate if he/she was ready to start the case. When the candidate was ready to administer the spinal anaesthetic he/she was instructed to explain the procedure to the examiners verbally. The candidate was then informed by the examiners that the spinal anaesthetic had been successfully administered, the patient had been lowered from a sitting position into a supine position and that the candidate should continue to manage the anaesthetic. The surgeon then proceeded to clean and drape the abdomen. The pre-set sequence of events that followed is shown in Table 1.

Candidate selection and testing
It was estimated with 95% confidence and 5% tolerance error that a sample size of 40 subjects (20 in each group) with two observations per subject would achieve the required efficiency of the experiment. The sample size was calculated using Sample XS software (http://www.brixtonhealth.com/).

Twenty-seven medical officers from the study's institution with a DA were randomly selected, using an Internet-based random-number generator (http://www.randomizer.org), and invited to participate in the study. Of these two were on annual leave, two did not reply, and three did not want to participate. The remaining 20 medical officers were all assessed over four consecutive days.

Medical interns in the last two weeks of their anaesthetic rotation at the time when the study was conducted were invited to participate in the study. The intern group consisted of 18 interns so all were invited to participate. Two interns opted not to participate. Thus 16 interns were assessed over the same four-day period as the medical officers. The remaining four interns required for assessment were

randomly selected from the subsequent intern group at the end of their anaesthetic rotation, and were assessed on one day, approximately two months after the first group.

All participants gave written informed consent to participate in the study.

Reliability and validity
The 20 medical officers and 20 medical interns were assessed by two examiners while performing the scenario. The examiners scored the candidates separately on standardised mark sheets and were blinded to each other's score. Candidates were identified by the order (number) in which they participated in the study and were instructed not to discuss the details of the study with anyone. At the end of the scenario each candidate completed a questionnaire indicating how many hours he or she had previously spent training on a high-fidelity simulator and to rate the realism of the simulator environment, the simulator mannequin and the case scenario on a numeric rating scale from 1 to 10. The candidates were also asked to indicate whether they had prior knowledge of the study or simulation that may have affected their performance.

Statistics
Agreement among the panel of experts participating in the modified Delphi process was assessed using the Kendall W statistic. Score differences between each of the three Delphi rounds were assessed using the Wilcoxon signed-rank test. Internal constancy was evaluated using Cronbach's alpha and the intra-class correlation was examined. The realism scores given by the medical officer and intern group for the simulation environment, simulation mannequin and the simulation scenario, as well as the number of hours of prior simulation experience, were compared using an independent sample t-test. All normality testing was done using the Kolmogorov–Smirnov test. For all analysis a two-sided p-value of < 0.05 was used to define statistical significance.

Results

The Modified Delphi process
The final list of tasks agreed on by the panel of experts, with the mean scores for the first, second and third rounds are indicated in Appendix 1. The mean score in round three was the final weighted score for each task (mean scores were rounded up to a whole number). Tasks with mean scores of zero in round one were added after suggestions by the experts, and included: (i) expanding the task of checking the airway trolley to checking each item individually, (ii) expanding the task of preparing emergency drugs to preparing each drug individually, as well as (iii) other additions evident in the appendix. Two additional tasks were suggested in round one that were rejected by the majority of experts and were excluded from the final assessment tool, namely the manual elevation of the patient's legs when profoundly hypotensive, and the administration of 50 ml of 50% dextrose when profoundly hypotensive. Therefore, the final weighted scoring system consisted of 85 tasks, each weighted by importance, for a total possible score of 367 points.

There was a significant difference in scores across all three Delphi rounds ($p < 0.0001$) with the final overall concordance being 0.668. Internal consistency between the 10 specialists was high with a Cronbach's alpha of 0.738.

Medical officers performed significantly better than the interns during the assessment. The mean medical officer score was 252

(95% CI 237–268) versus a mean intern score 216 (95% CI 196–237) for assessor 1 ($p = 0.005$), and 246 (95% CI 231–261) versus 215 (95% CI 195–235) for assessor 2 ($p = 0.013$). The intra-class correlation coefficient for the two examiners was 0.983 ($p = 0.0001$), indicating strong inter-observer consistency.

The medical officer scores showed no evidence of improvement as the simulation testing progressed from candidates 1 to 20. However, there was a gradual improvement in the performance (as scored by both raters) of the medical interns from candidates 1 to 16 (the first assessment group), and candidates 17 to 20 (the second assessment group) achieved a higher mean score than the first assessment group (mean of 218 versus 212). The significance of this difference cannot be assessed due to the low sample numbers.

Both the simulator scenario and simulator mannequin realism were assessed significantly higher by the interns as compared with the medical officers, with mean scores of 8.5 versus 7.5 ($p = 0.015$), and 7.7 versus 6.9 ($p = 0.04$) respectively. The simulator environment realism was also rated higher by interns although this was not statistically significant with mean scores of 7.3 versus 6.3 ($p = 0.161$).

The interns reported significantly more hours of prior simulation experience than the medical officers with a mean of 3.6 hours (SD 3.4 hours) versus 1.4 hours (SD 2.4 hours) ($p = 0.02$).

Discussion

The 5th Saving Mothers Report by the National Committee for Confidential Enquiry into Maternal Deaths (NCCEMD) in South Africa has shown that 70% of anaesthetic-related maternal deaths occurred at level one hospitals, with spinal anaesthesia accounting for the majority. The commonest cause of death under spinal anaesthesia was severe uncorrected hypotension, followed by hypotension/high motor blockade, and high spinal block.[1]

In 2005 assessment of level one and two hospitals performing obstetric anaesthesia in South Africa found a lack of training, experience and supervision in anaesthesia, and that doctors were basing their anaesthetic practice on their internship training (consisting of two weeks of anaesthesia).[3] Subsequently, the medical internship training programme in South Africa was extended to two years, and this included a lengthening of the anaesthesia rotation to two months. In 2008 a questionnaire-based study of interns' anaesthetic knowledge showed that despite increased training their knowledge still appeared inadequate for the safe provision of unsupervised anaesthetics during community service.[5] A recent study in KwaZulu-Natal showed there was still a lack of training and experience in obstetric anaesthesia in level one hospitals and that CSMOs are required to provide obstetric anaesthesia without supervision.[4]

In the Pietermaritzburg Hospital Complex, following a structured two-month training programme, interns are assessed clinically in performing a general anaesthetic for a surgical case and a spinal anaesthetic for a caesarean section using a standardised mark sheet. This assessment is done by a medical officer with a DA,[11] but is limited as the assessor may intervene to ensure patient safety, and the case may progress without complication. It therefore remains unclear whether the intern can independently provide a safe anaesthetic and manage serious complications as they arise.
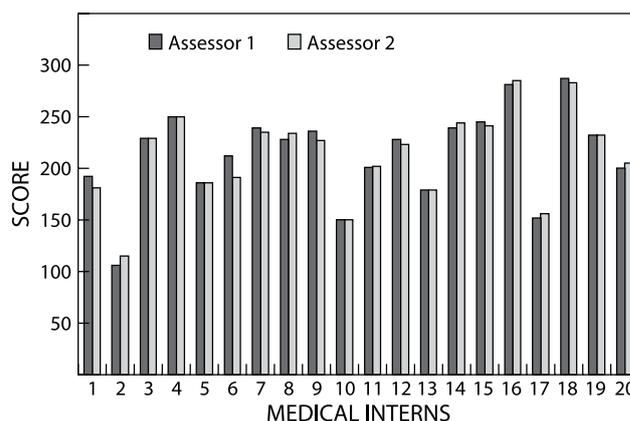

Figure 1: Intern total scores during the simulation assessment by the two assessors.

The first objective of this study was to develop a standardised assessment tool. Previous studies included between five and 28 experts in the Delphi process.[8,9,10] We achieved good internal consistency providing a high degree of confidence in our sample size of 10 experts.

To address the issue of content validity we aimed to achieve consensus amongst a group of experts using a Delphi process. The concordance achieved was 0.668. It is likely that a fourth Delphi round would have achieved higher concordance. A similar study achieved a concordance of 0.75 after two Delphi rounds.[8] The lower concordance observed may be due to varied inter-individual clinical practices and the absence of a gold standard management protocol for this particular scenario.

The construct validity of the assessment tool was assessed by comparing the scores of medical officers with a DA (the current South African gold standard in non-specialist assessment) against interns. The medical officers performed significantly better than the interns, indicating good construct validity. This method of assessing construct validity has also previously been successfully employed.[8,9] The face validity of the assessment was assessed in three parts (simulator, scenario and environment) using a numeric rating scale. The interns scored the realism significantly higher in two of the three categories, suggesting that their lower performance was not due to lower perceived realism. Despite their better performance, the medical officers gave low assessments of the realism of the simulator mannequin and environment but the reasons for this were not assessed.

A previous study found acceptable inter-assessor reliability between four assessors who assessed each candidate, reporting though that factor analysis indicated 96% of the variance from the mean score was explained by scores from two assessors.[8] We therefore used only two assessors and found acceptable inter-assessor reliability (Figures 1 and 2).

Limitations

There were a number of limitations in this study. The assessors and actors used during the simulation were not blinded to the purpose of the study or identity of the candidates, leading to potential bias. Assessors were also present in the simulation room, which may have affected the performance of the less confident candidates. Previous studies avoided these problems
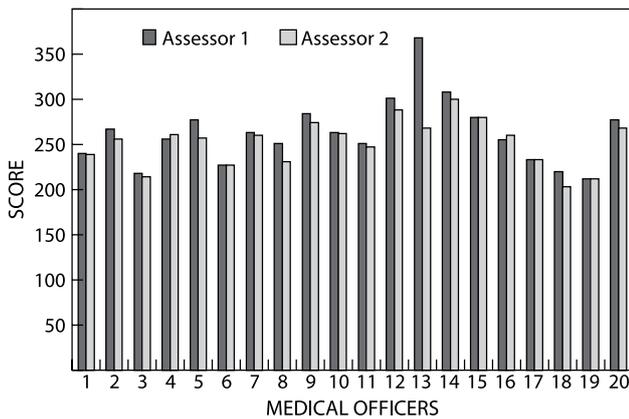
Figure 2: Medical officer total score during the simulation assessment by the two assessors.

by video-recording the assessments and having the recordings reviewed by blinded assessors.[8,9,10] This was not done in this study as recording equipment and expertise were not available.

The Delphi technique was challenging to perform with some respondents reporting difficulty in allocating time to complete each round, and difficulty in assigning a weight to each task. Some questioned whether the weighting should be based on clinical evidence, likelihood of negative consequences, current standards of care or simply their own practice. No specific approach was prescribed and this may have contributed to a lower concordance level. A fourth Delphi round may also have improved the concordance but was not performed due to time constraints.

The face validity of the simulator and simulation environment were given low scores by the medical officers. Factors which may have contributed to this were: (i) the mannequin being male with non-pregnant physical characteristics; (ii) a non-operational anaesthetic machine (no gas supply available); (iii) the environment not resembling an operating theatre; and (iv) the limited verbal responses from the mannequin. Previous studies overcame this limitation by placing a speaker in the mannequin with verbal responses given by a controller in another room.[8,10] This was not possible in this study's simulation venue.

The study had a potential selection bias as 5 of the 27 medical officers approached, and 2 of the 22 interns approached opted not to participate. The effect of this self-selection is not quantifiable. In addition, although none of the candidates reported having prior knowledge of the study details, there was a potential for details of the simulation to be discussed within the anaesthetic department and thereby introduce performance bias. This may be the cause of the gradual improvement in intern performance over the simulation period, and the better performance of the second group of interns who were assessed two months after the first group.

It is important to note that the assessment tool developed is a measure of global performance and is therefore limited in that the candidate may achieve an adequate overall score but perform unacceptably poorly in subsections. There are no allowances made for acts of omission or commission that should result in immediate failure. An additional subjective assessment of performance by the assessor, combined with the standardised

mark sheet, could overcome these problems. Lastly, as there is no evidence that simulator-based performance translates into clinical practice, this assessment tool should only be used to aid conventional assessment modalities.

Conclusion

This study succeeded in developing a valid and reliable assessment tool for measuring intern anaesthetic competence. It offers a standardised assessment process to identify strengths and weaknesses of interns in managing an obstetric anaesthesia complication that contributes annually to the high maternal mortality rate in South Africa. Insights gained from its application in intern training and assessment may lead to refinements in institutional intern training programmes, contributing to improved anaesthetic skill in community service doctors and establishing a national standard for assessment of intern competency. Its use may also be extended to the training and assessment of district doctors as part of in-reach training programmes, as well as nursing staff during team simulation training.

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Appendix 1. Final assessment tool with mean scores from each round

Tasks	Mean scores		
	Round 1	Round 2	Round 3
Airway trolley check			
Bag-valve mask present and functional	0	5	5
Introducer	0	4	4
Gum elastic bougie	0	5	5
Facemask	0	5	5
Magill forceps	0	4	4
Guedel airway	0	5	5
Artery clip	0	3	3
Alternate airway (LMA size 3 or 4)	0	5	5
Laryngoscope handles (1 short, 1 long)	0	5	5
Laryngoscope blades (size 3 and 4)	0	5	5
Endotracheal tubes (size 6, 6.5, 7)	0	5	5
Strapping	0	4	4
KJ jelly	0	3	3
HME filter	0	3	3
Emergency drugs			
Suxamethonium 100 mg	0	5	5
Ephedrine 50 mg diluted to 5 or 10 mg/ml	0	5	5
Atropine 0.5 mg	0	5	5
Phenylephrine (PE) diluted to 50 or 100 ugml	0	5	5
Oxytocin 10iu available	0	5	5
Check availability of 2nd line uterotonics	0	4	4
Thiopentone 25 mg/ml or propofol 10 mg/ml	0	4	4
General theatre preparation			
Availability of wedge	4	4	4
Availability of adrenaline and defibrillator	4	4	4
Functioning of operating table	4	4	4
Neonatal equipment			
Indicate that neonatal equipment must be checked	0	3	4
Preoperative assessment			
Medical and surgical history	4	4	4
Obstetric history	0	3	3
Details of current pregnancy + labour	0	4	4
Current medication	4	4	4
Anaesthetic history	5	5	5
Drug allergies	5	5	5
Airway assessment	5	5	5
Systemic examination	5	5	5
Examine back/lumbar spine	0	4	4
Investigations (finger-prick haemoglobin)	4	4	4
Check fasting status	0	4	4
Indicate that contra-indication to spinal not present	0	4	4
Preoperative care			
Insertion of IVI line (18G or larger)	5	5	5
Normal saline or Ringer's lactate IVI fluid for infusion	4	5	5
Administer sodium citrate	4	4	4
Administer metoclopramide	3	3	3
Administer antibiotic	3	3	3

(Continued)

Appendix 1. (*Continued*)

Tasks	Mean scores		
	Round 1	Round 2	Round 3
Uterine displacement	4	4	4
Explain anaesthetic procedure	4	4	4
Measure blood pressure	5	5	5
Apply pulse oximeter	5	5	5
Apply ECG	4	4	4
WHO surgical checklist	4	4	4
Spinal technique			
Appropriate positioning	0	4	4
Aseptic technique	5	5	5
Prevent chlorhexidine contamination	0	4	4
Lignocaine local to skin	0	3	3
25G or 26G pencil-point needle	3	4	4
L3/L4 or L4/L5 interspace	4	4	4
1.8 ml heavy marcaine 0.5% + fentanyl 20 ug	5	5	5
Fluid loading (at least 500 ml)	0	4	4
Immediate post-spinal management			
Uterine displacement	5	5	5
Neck flexed, head on pillow	4	4	4
Intravenous fluid running	5	5	5
NiBP to cycle every 1 minute	4	4	4
Apply pulse oximeter	5	5	5
Apply ECG	4	4	4
Communicate and focus on patient	4	4	4
Facemask oxygen	3	3	3
Assess height of spinal block (using ice/spray)	0	3	3
Management of hypotension			
Free-running fluid bolus (open drip fully)	0	5	4
Vasoactive drug bolus (5–10 mg ephedrine or 50–100 ug PE)	5	5	4
Communicate with patient	4	4	3
Facemask oxygen (whether applied before or now)	0	4	4
Check level of block (ice/spray/squeeze hand)	0	4	4
Check ABCs	0	5	5
Management of severe hypotension			
Vasoactive drug bolus (20 mg ephedrine or 100 ug PE)	5	5	5
Manual displacement of uterus	5	5	5
Free-running fluid bolus	5	5	5
Check ABCs	0	5	5
Management of cardiac arrest			
Inform team of cardiac arrest	5	5	5
Call for help and defibrillator	5	5	5
Instruct team member to start chest compression	5	5	5
Manual displacement of uterus (if done or done now)	0	5	5
Bag mask ventilation initially	0	4	4
Intubate	0	4	4
IPPV on FiO2 100%	0	4	4
Administer adrenaline bolus 1 mg	5	5	5
Instruct surgeon to deliver foetus	5	5	5
Leave wedge in situ	0	4	4