

The incidence and predictors of hypoxaemia during induction of general anaesthesia for caesarean delivery in two South African hospitals: a prospective, observational, dual-centre study

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Background: Caesarean delivery is the most commonly performed surgery in Africa. Morbidity and mortality linked to tracheal intubation represent a growing national health concern, yet there is minimal data relating to airway management in this group of patients.

Methods: We conducted a prospective, observational, dual-centre cohort study with the aim of quantifying the incidence of hypoxaemia (SpO₂ < 90%) at induction of general anaesthesia for caesarean delivery. We further aimed to explore body mass index, operator inexperience, predicted difficult airway, Cormack-Lehane grading and the absence of planned mask ventilation as predictors of hypoxaemia in our population. Airway complications were also quantified.

Results: We included 363 patients in our study. The incidence of hypoxaemia was 61/363 (16.8%, 95% CI 13.29–21.02). High body mass index (> 30 kg/m²) and Cormack-Lehane grade (4) were predictive of hypoxaemia during induction. The failed intubation rate was 1.4% (95% CI 0.57–3.28) and the regurgitation rate was 0.8% (95% CI 0.27–2.54). There were no pulmonary aspirations and no surgical airways were required.

Conclusion: The incidence of hypoxaemia during general anaesthesia for caesarean delivery is high. Future studies should examine methods to reduce the incidence of hypoxaemia, either through improved training or via specific interventions in this high-risk group.

Keywords: caesarean delivery, general anaesthesia, hypoxaemia, obstetric anaesthesia, airway management

Introduction

Caesarean delivery (CD) is the most commonly performed operation in Africa and is associated with an unacceptably high maternal mortality (1 in 200 CD).¹ The rate of CD in South Africa has been reported to be as high as 25.7%, and junior doctors, such as community service medical officers, are frequently required to administer anaesthesia for CD in resource-limited settings. In the South African 2014–2016 Saving Mothers report, anaesthesia-related mortality rose to over 3%, with more than half of these deaths related to airway management issues.² As a result, the report specifically identified skilled airway management during CD as an area of national concern.

Obstetric airway management carries a higher risk of both difficult and failed intubation, with the latter occurring during general anaesthesia for CD in 1 in 443 (0.2%) cases worldwide.³ Failed intubation in this situation is associated with poor maternal and neonatal outcomes, with the lowest maternal oxygen saturation being an independent predictor of neonatal intensive care admission.³ Much of this risk is accounted for by maternal pregnancy-associated anatomical and physiological changes. These include reduced gastric emptying, airway oedema, difficulty with laryngoscope insertion due to increased breast size, and rapid desaturation due to reduced functional

residual capacity (FRC) and increased oxygen demand.⁴⁻⁷ These risk factors may be compounded by human factors in difficult environments.⁸

There are inadequate data in the South African context capturing 'near-misses' such as hypoxaemia during intubation. Descriptive outcome data may assist in developing mechanisms to both predict and minimise airway complications. The aim of this study was to establish the incidence and predictors of hypoxaemia during endotracheal intubation for CD.

Methods

We conducted a dual-centre, prospective, observational cohort study at Edendale (regional level) and King Edward VIII (tertiary level) Hospitals in KwaZulu-Natal, South Africa. Both hospitals have departments of anaesthesia led by specialist anaesthesiologists and with access to videolaryngoscopy.

Patient selection

All patients beyond 28 weeks gestation presenting for elective or emergency CD and requiring a general anaesthetic (GA) were included. Cases where the GA was administered after delivery of the neonate were excluded. Recruitment occurred from September 2017 until January 2019.

Technical information

The primary outcome of the study was the incidence of hypoxaemia ($\text{SpO}_2 < 90\%$) during airway management (defined as the time from induction of anaesthesia until confirmation of definitive airway placement) in patients undergoing CD under GA. The secondary outcomes were to assess predictors for developing hypoxaemia and to describe airway complication rates. Airway complications included failed intubation, pulmonary aspiration, and the need for a surgical airway.

Data were collected by completion of a purpose-designed case record form (CRF). The CRF comprised three sections. Section 1, completed prior to induction of anaesthesia, recorded general patient details and an airway assessment. Section 2 recorded detailed airway management information and was completed after induction. The third section recorded maternal and neonatal outcomes and was completed at the end of the case. Completed CRFs were forwarded to one of the study investigators. Data were verified by investigators prior to entry into the database. Patient names were not recorded, but a unique study number was allocated to each participant. Data were entered into a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA) by one of the study investigators.

The investigators did not prescribe any specific technique for the administration of a GA for CD. Standard unit practices were followed. Decisions regarding airway management were at the discretion of the anaesthesia team responsible for each case, based on the clinical scenario.

Statistical analysis

We estimated the incidence of hypoxaemia ($\text{SpO}_2 < 90\%$) to be approximately 20%. Our sample size calculation showed that we required 246 patients for a precision of 5% with 95% confidence intervals. We also aimed to assess five variables as predictors of hypoxaemia. To avoid model over-fitting, it is suggested to have at least 10–15 events per variable tested in a regression model.^{9,10} To evaluate five variables, we therefore required a minimum of 50 events and 250 patients. We elected to enrol at least 350 patients, to allow for a lower than expected incidence of hypoxaemia.

Baseline patient characteristics were reported as mean (standard deviation [SD]) for continuous normally distributed variables, median for data not normally distributed, and count (per cent) for categorical variables. Comparisons between normally distributed data were done using Student's t-test, with the Wilcoxon-Mann-Whitney test used for data not normally distributed. Categorical data were analysed using the chi-square test. For all analysis a p -value of < 0.05 defined statistical significance, and the acceptable power was 80%.

To address the primary outcome, we calculated the proportion of patients who became hypoxaemic ($\text{SpO}_2 < 90\%$) expressed as a percentage with associated 95% confidence interval. For the secondary outcomes we performed multivariate binary logistic regression using five candidate variables to determine their association with the primary outcome. We sought to

evaluate the following variables as possible predictors of hypoxaemia: body mass index (BMI), predicted difficult airway, experience of intubator, absence of *planned* mask ventilation, and best Cormack-Lehane (C-L) grade. Predicted difficult airway was defined as a global assessment by the attending anaesthesiologist (Yes/No), and also through specific questions (thyromental distance < 6 cm, inter-incisor gap < 3 cm, Mallampati score III or IV). Planned mask ventilation referred to a pre-induction decision by the attending anaesthesiologist to use mask ventilation following induction of anaesthesia, rather than as a rescue technique in response to hypoxaemia and difficulty with intubation. We converted BMI (threshold > 30 kg/m²) and experience (threshold < 12 months) to binary variables for this analysis. We also compared the overall assessment of airway difficulty by the attending anaesthesiologist with an objective assessment of documented clinical signs by the same clinician.

Results

The patient recruitment process is illustrated in Figure 1. The final analysis included 363 patients. Mean (SD) patient age was 26.6 (6.48) years. Mean (SD) patient weight and BMI were 77.6 (17.7) kg and 30.3 (6.99) kg/m² respectively. Mean gestational age was 37 (SD 3.51) weeks.

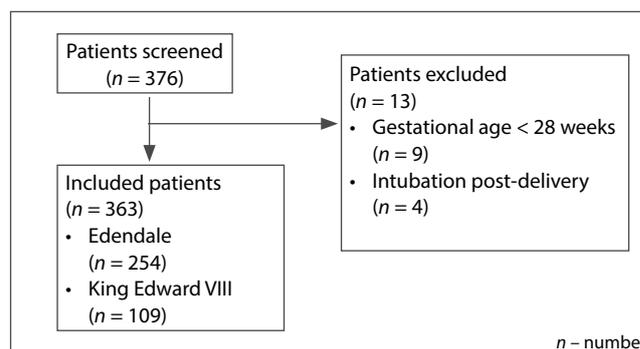


Figure 1: Patient flow diagram

Hypertensive disorders of pregnancy (including gestational hypertension, preeclampsia and eclampsia) were found in 118/363 patients (32.5%, 95% CI 27.87–37.51). There were 149/363 patients (41.0%, 95% CI 36.08–46.20) presenting in the active phase of labour, with 314/363 (86.5%, 95% CI 82.57–89.66) requiring non-elective CD.

Difficult mask ventilation was predicted in 23/363 patients (6.3%, 95% CI 4.24–9.37), while difficult laryngoscopy was predicted in 82/363 patients (22.59%, 95% CI 18.57–27.19). However, based on the details of the documented airway assessment on the CRF, difficult laryngoscopy should have been predicted in 115/363 patients (31.7%, 95% CI 27.08–36.66).

Anaesthesia induction times were recorded as occurring during normal working hours (08h00–18h00) or after-hours (18h00–08h00), with 139/363 inductions (38.3%, 95% CI 33.41–43.42) occurring after-hours. The maximum end-tidal oxygen (EtO_2) exceeded 80% in 300/363 patients (82.6%, 95% CI 78.3–86.2) at the time of induction. Rapid sequence inductions were

conducted in 287/363 patients (79.1%, 95% CI 74.56–82.96) with the remainder reported as modified rapid sequence inductions. Cricoid pressure was applied in all but one patient (99.7%, 95% CI 98.06–99.96) during induction.

A traditional direct laryngoscope (DL) was used in 353/363 laryngoscopies (97.2%, 95% CI 94.95–98.51), while a video-laryngoscope (VL) was used in 12/363 intubations (3.3%, 95% CI 1.88–5.74). In one case, intubation was first attempted with DL but then completed with VL. In another case, initial laryngoscopy was with a VL, but the endotracheal tube could not be passed through the vocal cords despite a Grade 1 C-L view. A traditional DL was then used, and the endotracheal tube correctly placed. A malleable stylet was used in 30/363 intubations (8.3%, 95% CI 5.83–11.59) and a bougie in 34/363 (9.8%, 95% CI 6.76–12.84). No fibre-optic intubations were required or attempted.

Endotracheal tubes were the primary airway device planned in all cases. However, a rescue device was required in 5/363 attempted intubations (1.4%, 95% CI 0.57–3.28), all of which were supraglottic airways (SGAs): this equates to a failed intubation rate of 1 in 73 attempted intubations. No surgical airways were required. There were 3/363 reports of passive regurgitation (0.8%, 95% CI 0.27–2.54), none of which resulted in clinical evidence of pulmonary aspiration.

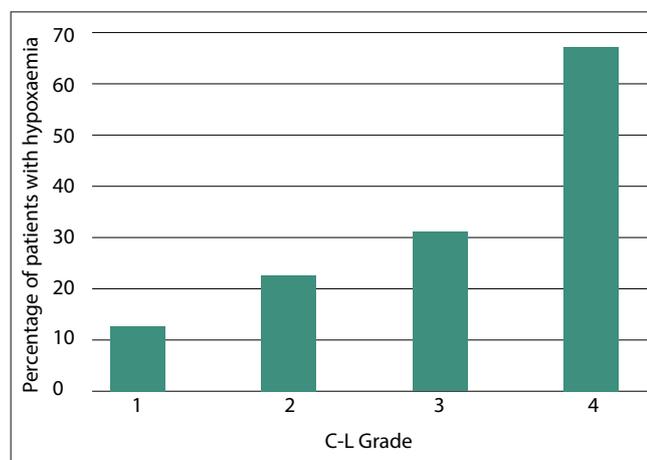


Figure 2: Incidence of hypoxaemia (SpO₂ < 90%) in relation to Cormack-Lehane grading in patients undergoing general anaesthesia for caesarean delivery

SpO₂ – arterial oxygen saturation, C-L – Cormack-Lehane

There were no maternal deaths and no maternal CPR was required. There were eight maternal ICU admissions as part of their perioperative management. Twenty-two infants were stillborn (22/380, 5.8%); of the remaining deliveries, 25 infants had 5-minute Apgar scores < 7 (25/358, 7.0%), and 71 neonates were admitted to neonatal ICU postoperatively (71/358, 19.8%).

The incidence of hypoxaemia (SpO₂ < 90%) was 61/363 (16.8%, 95% CI 13.29–21.02). The results of the multivariate binary logistic regression analysis are shown in Table I. This analysis suggested that high BMI (> 30 kg/m²) and Cormack-Lehane laryngoscopy grade (4) are risk factors for hypoxaemia during induction of general anaesthesia for CD.

The association of C-L grade and peri-induction hypoxaemia is further illustrated in Figure 2.

Discussion

Our study showed that the incidence of hypoxaemia during induction of GA and airway management for CD was approximately one in six patients (16.8%), with a failed intubation rate of 1 in 73. Our analysis suggested that high BMI (> 30 kg/m²) and Cormack-Lehane laryngoscopy grade (4) are risk factors for hypoxaemia during induction of GA for CD.

The ability to safely manage the obstetric airway constitutes a core competency in anaesthesia. Specific challenges are the result of anatomical and physiological changes of pregnancy: increased BMI, elevated diaphragm, enlarged breasts, airway oedema, a reduced FRC, and increased oxygen consumption.^{5,7} These changes lead to increased risks of aspiration, rapid desaturation and failed intubation.¹¹ A 2015 literature review found that the failed intubation rate has remained unchanged since 1970, at 2.3 per 1 000 (1 in 443) GAs for CD.³ Associated maternal mortality from failed intubation was 2.3 per 100 000 GAs, with death the result of aspiration or hypoxaemia.³ The UK Obstetric Surveillance System (UKOSS) published a study in 2012 that reported a failed intubation rate of 1 in 225.¹² In comparison, we found a failed intubation rate of 1 in 73 in this study. It is also concerning that less than half of the Cormack-Lehane Grades 3 or 4 were predicted (7/16) as difficult laryngoscopy on overall assessment. In contrast to this, most patients (76/83) who were predicted to be difficult by clinicians were in fact C-L Grade 1 or 2. Preoperative airway assessment thus had low sensitivity (44%)

Table I: Multivariate binary logistic regression analysis of candidate variables for hypoxaemia during induction of general anaesthesia for caesarean delivery

	Patients (n = 363)	Odds ratio	Standard error	p-value	95% CI
BMI (> 30 kg/m ²)	153 (42.1%)	2.19	0.67	0.01	1.21–3.99
Absence of planned mask ventilation	76 (20.9%)	0.48	0.20	0.08	0.21–1.09
Predicted difficult airway	115 (31.7%)	1.26	0.39	0.47	0.68–2.32
C-L Grade					
1 (reference)	262 (72.2%)	1.0	-	-	-
2	85 (23.4%)	1.67	0.55	0.11	0.88–3.17
3	13 (3.6%)	2.61	1.71	0.14	0.72–9.42
4	3 (0.8%)	20.11	25.79	0.02	1.63–248.26
Experience (< 12 months)	202 (55.6%)	1.72	0.52	0.08	0.95–3.12

n – number, CI – confidence intervals, BMI – body mass index, C-L – Cormack-Lehane

and low specificity (78%) in our study, which is consistent with existing airway assessment studies.¹³ The unanticipated difficult airway thus remains a real threat to the anaesthesiologist. Additionally, in 33 patients, despite documenting clinical signs that signified potentially difficult laryngoscopy (such as a thyromental distance < 6 cm), the anaesthesiologist recorded that laryngoscopy was not predicted to be difficult. We also noted that in only 64/363 intubations (17.6%) was either a malleable stylet or bougie used by the attending anaesthesiologists. A malleable stylet should ideally be placed in the endotracheal tube for all obstetric intubations.

In South Africa, a high proportion of obstetric anaesthesia is provided by junior doctors, or doctors with limited anaesthetic training and experience. The most recent National Committee for Confidential Enquiries into Maternal Deaths in South Africa (NCCEMD) found that 56% of anaesthesia-related deaths were at district-level (secondary) hospitals, with over half of these deaths resulting from a failure to protect the airway.² This is despite the fact that the vast majority of CDs at district hospitals are being performed under spinal anaesthesia. The report states that "It appears clinicians are giving spinal anaesthesia without the ability to give general anaesthesia and protect the airway."² Airway skills are predominantly attained in South Africa through a two-month anaesthesia rotation as an intern, and subsequently only briefly covered in the ESMOE course (Essential Steps in the Management of Obstetric Emergencies). It is apparent that our training is not achieving its ultimate goal: patient safety and improvement of outcomes.¹⁴

There have been several suggested amendments to obstetric airway management techniques, to reduce the risk of hypoxaemia during intubation. Ramping the patient at 20–30 degrees during intubation has multiple proposed benefits that include an increased FRC leading to an increased apnoea time before desaturation, reduced interference due to breast tissue, improved view during laryngoscopy, and reduced risk of regurgitation.^{6,15,16} Pre-oxygenation with 100% O₂ is still regarded as standard practice^{5,6,15-17} as this offsets the 20% reduction in FRC coupled with a 20% increase in oxygen demand during pregnancy.⁵ Historically, pre-oxygenation has been achieved using three minutes of tidal volume breathing with 100% O₂. Recent evidence suggests that two minutes is adequate.⁶ An alternative method is taking four to eight vital capacity breaths of 100% O₂.¹⁷ Pre-oxygenation should be considered adequate when an end-tidal oxygen (EtO₂) concentration of > 90% is achieved.⁶ This clear and simple indicator should be adopted as standard of care. In this study we found that only four of every five patients reached an EtO₂ of > 80%.

Newer adjuncts have been suggested to increase the time before onset of hypoxaemia. These generally involve the principle of bulk flow to achieve oxygen delivery to the alveoli during apnoea and include maintaining a tight seal with the facemask and high flow 100% oxygen (> 10 L/min), high flow nasal cannula oxygen (> 15 L/min), and naso-pharyngeal catheters delivering oxygen directly to the hypopharynx.^{6,15}

While the use of cricoid pressure has been a standard feature of RSI for decades, its routine use remains strongly debated. Despite the debate, it is still widely advocated in obstetric GA for the purpose of reducing regurgitation risk.^{6,15,17} Problems with cricoid pressure include potential difficulty with mask ventilation, poor laryngoscopic view, difficulty with endotracheal intubation, and difficulty with insertion of an SGA.^{6,15} There should be a low threshold to reduce or release cricoid pressure if any of the above difficulties are encountered.^{6,15}

Recent Difficult Airway Society (DAS) guidelines in obstetrics suggest considering low pressure (< 20 cmH₂O) mask ventilation with cricoid pressure after induction.⁶ This represents a departure from traditional teaching. Potential benefits include the reduced likelihood of hypoxaemia and an early indicator of whether bag-mask ventilation is possible.⁶ We included the absence of planned mask ventilation (as opposed to rescue mask ventilation) to assess if this predicted hypoxaemia, but did not show this relationship. It is possible that our study was underpowered to detect this difference. The use of planned mask ventilation was also not randomised: it may be that higher risk patients were chosen for this intervention.

There were several weaknesses in our study. The anaesthesia team involved in each case also performed the data collection, and data entry errors may have occurred. Missing data fields in the CRF had to be completed retrospectively, where appropriate. Certain data fields required assessment by the anaesthesiologist conducting the preoperative assessment and the endotracheal intubation and were thus reliant on the individual clinical skills. An appendix with definitions and pictures was provided on the CRF to standardise these assessments. It was not always possible to identify the reasons for hypoxaemia or failed intubation from the data recorded. Finally, there was no standardisation of anaesthesia technique, and inter-individual variability may have contributed to our findings.

A strength of our study is that it provides a baseline audit of day-to-day practice of GA for CD across two high volume obstetric units in KZN, and involved doctors educated in multiple academic centres across South Africa. This allows for future interventional studies to be conducted to identify modifications in technique to improve the safety of GA for CD in this context. Further studies should aim to consider improvements in training methods, as well as assessing practices, such as the standard use of VLs, the use of high flow nasal oxygen therapy, and targeting higher EtO₂ prior to induction of anaesthesia. Additionally, alternative predictive tests for difficult intubation should be sought.

There is little evidence in the South African context concerning the incidence of adverse events during endotracheal intubation for CD. While mortality is reported, there is limited data on the specific contributing issues. Similarly, data on 'near misses' such as hypoxaemia are lacking. The findings of our study suggest that hypoxaemia is common, but that there are factors that can alert the anaesthesiologist to patients at risk. Specifically, high BMI patients should be approached with caution,

and meticulous preparation is required prior to induction. Encountering a high C-L grade implies an 'in-progress' high-risk airway. In this instance, the intubator should consider calling for senior assistance early as well as amending their technique with earlier bag mask ventilation or insertion of an SGA in an attempt to avoid hypoxaemia. By targeting a reduced incidence of hypoxaemia, we may achieve the ultimate goal: improving maternal and fetal outcomes.

Conflict of interest

The authors did not receive any financial support and do not have any conflict of interests to declare.

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Ethics approval

KZN Department of Health (KZ_2017RP32_238) was obtained. The University of KwaZulu-Natal Bio-Ethics Committee granted ethical approval (BE347/17).

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