

Oxygen delivery to patients after cardiac surgery: a medical record audit

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Patients admitted to the intensive care unit after coronary artery bypass graft or cardiac valve surgery are usually given supplemental oxygen to avoid hypoxaemia. Inadequate oxygenation can compromise cardiac function, and, if prolonged, cause clinical deterioration.¹ However, oxygen delivery practices in the ICU appear to vary widely, possibly reflecting a lack of clinical evidence² or suboptimal clinical decision-making.³ Indeed, there is little published evidence to guide intensive care doctors and nurses in the objective selection and use of oxygen delivery devices.³⁻⁵

ICU nurses are responsible for detailed physiological monitoring of patients and for assessing and maintaining therapeutic interventions related to oxygen administration. An objective analysis of how intensive care nurses administer and manage supplemental oxygen for cardiac surgical patients is warranted, as a better understanding might inform the development of clinical practice recommendations to correct or prevent hypoxaemia. To the best of our knowledge, no published study has investigated this topic.

Our study aimed to describe how intensive care nurses manage the administration of supplemental oxygen to patients during the first 24 hours after cardiac surgery. A specific focus was on the types of oxygen delivery devices used and changes in oxygen flow rate or delivery device in response to abnormal physiological status (hypoxaemia, tachypnoea or bradypnoea).

Methods

The study was a retrospective audit of patient records in a 220-bed metropolitan acute-care hospital in Victoria, Australia. During the audit period, this hospital had an 8-bed Level 2 ICU⁶ that admitted about 700 patients each year; about 60% were surgical admissions. We examined the records of patients who underwent a cardiac surgical procedure between 1 January 2005 and 31 May 2008. Records were identified according to the following Australian refined diagnostic-related group (DRG)⁷ codes: cardiac valve procedure (F03Z, F04A, F04B); coronary bypass (F05A, F05B, F06A, F06B); and cardiothoracic/vascular procedures (F07Z). Records were excluded if the patient was less than 18 years of age. The study was approved by the institutional (hospital and university) human research ethics committees.

ABSTRACT

Objective: To describe how intensive care nurses manage the administration of supplemental oxygen to patients during the first 24 hours after cardiac surgery.

Methods: A retrospective audit was conducted of the medical records of 245 adult patients who underwent cardiac surgery between 1 January 2005 and 31 May 2008 in an Australian metropolitan hospital. Physiological data (oxygen saturation measured by pulse oximetry and respiratory rate) and intensive care unit management data (oxygen delivery device, oxygen flow rate and duration of mechanical ventilation) were collected at hourly intervals over the first 24 hours of ICU care.

Results: Of the 245 patients whose records were audited, 185 were male; mean age was 70 years (SD, 10), and mean APACHE II score was 17.5 (SD, 5.14). Almost half the patients (122, 49.8%) were extubated within 8 hours of ICU admission. The most common oxygen delivery device used immediately after extubation was the simple face mask (214 patients, 87%). Following extubation, patients received supplemental oxygen via, on average, two different delivery devices (range, 1–3), and had the delivery device changed an average of 1.38 times (range, 0–6) during the 24 hours studied. Twenty-two patients (9%) received non-invasive ventilation or high-flow oxygen therapy, and 16 (7%) experienced one or more episode of hypoxaemia during mechanical ventilation. A total of 148 patients (60%) experienced one or more episodes of low oxygenation or abnormal respiratory rate during the first 24 hours of ICU care despite receiving supplemental oxygen.

Conclusion: These findings suggest that the ICU environment does not protect cardiac surgical patients from suboptimal oxygen delivery, and highlights the need for strategies to prompt the early initiation of interventions aimed at optimising blood oxygen levels in cardiac surgical patients in the ICU.

Crit Care Resusc 2009; 11: 238–243

The medical record audit was completed between June and October 2008. Patient records were retrieved from the computerised document management system of the participating hospital. Each record was de-identified to maintain

patient anonymity. A single researcher (GME) collected data from each record using a purposely designed data extraction form. Data were objective and included:

- demographic data — age, sex, Acute Physiology And Chronic Health Evaluation (APACHE) II score,⁸ and Simplified Acute Physiology Score (SAPS) II score;⁹
- system data — hospital and ICU length of stay, and hospital discharge destination;
- physiological data — pulse oximetry-derived oxygen saturation (SpO₂), and respiratory rate; and
- ICU management data — oxygen delivery device, oxygen flow rate, and duration of mechanical ventilation.

Physiological and ICU management data were collected at hourly intervals for the first 24 hours of ICU care.

Table 1. Demographic and surgical characteristics of cardiac surgical patients (n = 245)

Characteristic	No. (%) [*]
Age (years), mean (SD)	70 (10.24)
Male	185 (76%)
Surgical procedure	
Coronary bypass	166 (68%)
Cardiac valve	74 (30%)
Cardiothoracic or vascular	5 (2%)
Severity of illness scores, mean (SD)	
APACHE II [†]	17.50 (5.14)
SAPS II [‡]	30.96 (10.73)
Length of stay: ICU (days), mean (SD)	2.5 (1.5)
Length of stay: hospital (days), mean (SD)	11.3 (3.2)
Discharge destination	
Home	186 (76%)
Other health care institution	56 (23%)
Died	3 (1%)

* Unless otherwise indicated.

† APACHE = Acute Physiological and Chronic Health Evaluation.

‡ SAPS = Simplified Acute Physiology Score.

During the audit period, the ICU did not have a clinical practice guideline for the management of oxygen therapy in adult patients.

Data were examined to determine the types of oxygen delivery devices used, duration of oxygen therapy, and oxygen flow rate. Physiological status was assessed using SpO₂ and respiratory rate. Hypoxaemia was defined as SpO₂ less than 95%,⁵ tachypnoea as a respiratory rate greater than 20 breaths per min,¹⁰ and bradypnoea as a respiratory rate less than 8 breaths per min.¹¹ These physiological parameters were selected as they are widely acknowledged as key indicators of respiratory dysfunction,¹ which has a known association with adverse events such as cardiac arrest.^{1,12} Heart rate was not assessed as many patients have a temporary cardiac pacemaker or receive medications with chronotropic effects after cardiac surgery.

The descriptive analysis used the SPSS Statistical Package, version 15 for Windows (SPSS, Chicago, Ill). SpO₂, respiratory rate, and oxygen flow rate were compared between devices by analysis of variance (ANOVA) with adjustment for the within-subject clustering effect, using STATA, version 10.1 software (StataCorp, College Station, Tex).

Results

There were 249 patients who met the study inclusion criteria, and 245 medical records were audited. Three patients were excluded because of incomplete or missing records, and one patient had an error in DRG coding. Of the 245 patients studied, 185 were male and 60 female. Their mean age was 70 years (SD, 10 years), and mean APACHE II score was 17.5 (SD, 5.14). One hundred and sixty-six patients (68%) had a coronary bypass procedure, 74 (30%) had a cardiac valve procedure, and five (2%) had a cardiothoracic or vascular procedure. Of the 245 patients, 242 (99%) were discharged from hospital alive. Patient demographics and surgical characteristics are shown in Table 1.

Table 2. Usage of oxygen delivery devices (n = 245)

Oxygen delivery device	No. of patients who used device (%)		Total hours of recorded use (range)
	Immediately after extubation	During first 24 hours	
Endotracheal tube	na	245 (100%)	2169 (2–24)*
Face mask	214 (87%)	217 (89%)	1127 (1–19)
Nasal cannulas	7 (3%)	202 (82%)	1858 (1–20)
Nasopharyngeal oxygen catheter	9 (4%)	46 (19%)	371 (1–20)
High-flow oxygen or non-invasive ventilation	3 (1%)	22 (9%)	62 (1–6)
Room air	0	3 (1%)	21 (5–9)

na = not applicable. * Twelve patients (5%) were not extubated during the first 24 hours.

Table 3. Oxygen saturation, respiratory rate and oxygen flow rate for oxygen delivery devices used after extubation (n = 233)

Oxygen delivery device	Oxygen saturation*			Respiratory rate (breaths per min)			Oxygen flow rate (L/min)		
	Mean	Robust SE	95% CI	Mean	Robust SE	95% CI	Mean	Robust SE	95% CI
High-flow/NIV [†]	94.89%	0.75	93.40%–96.37%	17.26	1.07	15.14–19.38	38.42	4.6	29.18–47.65
Face mask	98.79%	0.13	98.53%–99.01%	16.08	0.23	15.62–16.54	6.55	0.13	6.29–6.81
Nasal cannulas	98.53%	0.09	98.34%–98.71%	16.07	0.18	15.70–16.44	3.31	0.05	3.21–3.41
Nasopharyngeal catheter	98.57%	0.25	98.07%–99.07%	16.41	0.34	15.74–17.09	3.3	0.11	3.07–3.52

SE = standard error. * Measured by pulse oximetry. † High-flow/NIV = high-flow oxygen therapy or non-invasive ventilation.

Oxygen delivery devices used

All 245 patients admitted to the ICU were intubated and ventilated after cardiac surgery. The average time to extubation was 10.03 hours (SD, 5.7; median, 9 hours). Time to extubation ranged from 2 to more than 24 hours; almost half the patients (122, 49.8%) were extubated within 8 hours of ICU admission, but 12 (5%) were ventilated beyond 24 hours.

A simple face mask was the most common oxygen delivery device used immediately after extubation (214, 87%), followed by a nasopharyngeal oxygen catheter (9, 4%) and nasal cannulas (7, 3%). Three patients (1%) received non-invasive ventilation or high-flow oxygen therapy immediately after extubation, and 22 (9%) received this within the first 24 hours after surgery. The types of oxygen delivery devices used, numbers of patients and hours of use are shown in Table 2.

On average, patients received supplemental oxygen by two different oxygen delivery devices (range, 1–3) during the 24 hours studied and had the oxygen delivery device changed an average of 1.38 times (range, 0–6). Oxygen saturation, respiratory rate and oxygen flow rate for each oxygen delivery device are shown in Table 3. The average oxygen flow rates used in this study were 6.55 L/min for face mask, 3.31 L/min for nasal cannulas and 3.30 L/min for nasopharyngeal oxygen catheter.

Abnormal oxygenation and respiratory rate

The average oxygen saturation was 98.90% (SD, 1.67%; median, 100%; range, 89%–100%). One or more episodes of hypoxaemia or respiratory rate abnormality were noted in 148 patients (60%) during the first 24 hours of ICU care. The number and type of respiratory rate abnormalities are shown in Table 4.

Hypoxaemia occurred in 57 patients (23%): 56 of these (98%) were receiving supplemental oxygen at the time. The average number of episodes for patients with hypoxaemia was 1.5 (SD, 1.06; median, 1; range, 1–5) with an average oxygen saturation of 93.01% (SD, 1.26%; range, 89%–

94%) (Table 5). Of the 57 patients who experienced hypoxaemia, 16 (28%) were undergoing mechanical ventilation; the average number of episodes of hypoxaemia during mechanical ventilation was 1.25 (range, 1–6). In response to a hypoxaemic episode, 14 patients (25%) had their oxygen flow rate increased or oxygen delivery device changed. The remaining 43 (75%) had no change to either oxygen flow rate or delivery device. The duration of hypoxaemic episodes was: 1 hour (68 episodes), 2 hours (16), 3 hours (5), 4 hours (6), and 5 hours (4). One patient had an SpO₂ of 89% during one episode.

The average respiratory rate was 14.28 breaths per min (SD, 3.9; range, 6–39). A total of 102 patients (42%) experienced one or more episodes of tachypnoea. The average number of episodes for patients with tachypnoea was 1.93 (SD, 1.51; median, 1; range, 1–9), with an average respiratory rate of 23.20 breaths per min (SD 2.31;

Table 4. Oxygen saturation and respiratory rate status during the first 24 hours (n = 245)

Physiological parameter	No. of episodes*	No. of patients
Abnormality		
None	na	97 (40%)
Abnormal oxygen saturation	159	57 (23%)
Abnormal respiratory rate	370	112 (46%)
Both abnormalities	139	21 (9%)
Oxygen saturation [†]		
SpO ₂ < 95%	159	57 (23%)
SpO ₂ < 90%	1	1 (0.4%)
Respiratory rate		
< 8 breaths per min	16	10 (4%)
> 20 breaths per min	354	102 (42%)

na = not applicable. * Episode: physiological parameter documented on the ICU vital sign observation chart on the hour.

† Oxygenation: oxygen saturation measured by pulse oximetry (SpO₂).

Table 5. Physiological status and duration of hypoxaemia or tachypnoea during the first 24 hours

Physiological parameter	No. of patients	Physiological status		Episode duration (h)	
		Mean value (SD)	Range	Mean (SD)	Range
Hypoxaemia (SpO ₂ < 95%)	57	93.0% (1.26%)	89%–94%	1.5 (1.06)	1–5
Tachypnoea (RR > 20 breaths per min)	102	23.2 (2.31) breaths per min	21–39 breaths per min	1.93 (1.51)	1–9

RR = respiratory rate.

range, 21–39 breaths per min) (Table 5). In response to a tachypnoeic episode, 13 patients (13%) had their oxygen flow rate increased, 19 (19%) had their oxygen delivery device changed, and 14 (14%) had both an increase in flow rate and a change in delivery device.

Ten patients (4%) had a documented episode of bradypnoea. Nine of these experienced this during weaning from mechanical ventilation, with no identified change in device or oxygen flow following extubation. The other patient had no change in either the oxygen flow rate or oxygen delivery device in the following hour.

Discussion

This retrospective audit of how intensive care nurses manage the administration of supplemental oxygen to patients during the first 24 hours after cardiac surgery had three major findings. First, despite the almost continuous administration of supplemental oxygen during this period, 148 patients (60%) experienced one or more episodes of hypoxaemia or a respiratory rate abnormality. Second, few patients had their oxygen flow rate or delivery device changed when such an episode was documented, suggesting that many episodes remained untreated. Finally, following extubation after cardiac surgery, most patients received supplemental oxygen via low-flow oxygen delivery devices (face mask, nasal cannulas or nasopharyngeal oxygen catheter).

The high incidence of hypoxaemia or a respiratory rate abnormality after cardiac surgery is clinically important, as respiratory dysfunction and hypoxaemia have a clear relationship with adverse events.¹⁰ Postoperative pulmonary dysfunction manifesting as hypoxaemia, increased work of breathing, and an ineffective cough are expected consequences of cardiac surgery.¹³ Our findings show that tachypnoea or hypoxaemia occurred in 60% of patients (148 patients). Reasons for this high incidence are unclear, but tachypnoea or hypoxaemia may be a consequence of postoperative pulmonary complications (eg, atelectasis, pleural effusion or phrenic nerve injury¹⁴), unrelieved pain, poor body positioning, presence of chest tubes,¹³ recent chest physiotherapy or movement. Hence, it is necessary to

identify and treat the underlying causes of tachypnoea in the absence of hypoxaemia in patients following cardiac surgery.

A more concerning finding was the apparent lack of intervention (change in oxygen flow rate or delivery device) when hypoxaemia or a respiratory rate abnormality occurred. This is especially true in the 16 patients (7%) who experienced one or more episodes of hypoxaemia during mechanical ventilation. Recent studies suggest hypoxaemia and a high respiratory rate are strong predictors of an adverse event during the postoperative period.^{15–17} Failure to appropriately manage hypoxaemia or tachypnoea increases the risk. The role of the ICU nurse in implementing pre-emptive measures to lessen the impact of postoperative pulmonary complications was not investigated in this study.

Nurses working in critical care areas such as the ICU are expected to be competent in detecting and managing respiratory dysfunction because of their key role in decisions about oxygen administration.^{3,18} Indeed, it could be considered that intensive care nurses are better educationally prepared, at postgraduate level, to detect respiratory dysfunction and respond in a timely and proficient manner, than general nurses. Yet, hypoxaemia or respiratory rate abnormalities occurred in 60% of patients despite being cared for in an ICU, with high nurse–patient ratios and specialist nursing staff. Further, the duration of hypoxaemia or tachypnoea may reflect worsening respiratory function or the inability to escalate oxygen therapy adequately in response to prolonged periods of abnormal oxygenation or respiratory rate. While the aim of this study was not to investigate how intensive care nurses make decisions about oxygen administration, the small number of patients who had an identifiable increase in oxygen flow rate or the use of an alternative oxygen delivery device indicates that these decisions were suboptimal. As such, it is important to explore intensive care nurses' knowledge and clinical decision-making to target improvements in the management of oxygen therapy in the ICU.³

Low-flow oxygen delivery devices were the most commonly used devices during the first 24 hours of ICU care after cardiac surgery. This finding is in keeping with current practice for the use of supplemental oxygen delivery devices

to treat mild to moderate hypoxaemia in adults.¹⁸ Yet, the use of face masks, nasopharyngeal oxygen catheters or nasal cannulas did not achieve the desired outcome in 57 patients (23%) who experienced hypoxaemia, and 98% of hypoxaemic episodes occurred when the patient was receiving supplemental oxygen. Further research is needed to clarify whether use of oxygen delivery devices that can maintain higher oxygen saturations or deliver higher oxygen flow rates is warranted.

The average oxygen flow rates used in this study were low relative to the oxygen flow capacity of the delivery devices. The average oxygen flow rate used with a face mask was 6.55 L/min (95% CI, 6.29–6.81 L/min), barely above the minimum flow rate of 6 L/min recommended to prevent re-breathing of carbon dioxide.^{5,19,20} Despite the 15 L/min capacity of the flow meters used, most intensive care nurses did not use higher oxygen flow rates, even in the presence of hypoxaemia or respiratory rate abnormalities. The average oxygen flow rates of 3.31 L/min for nasal cannulas and 3.30 L/min for nasopharyngeal catheters reflect current recommendations for these devices.⁵ The reason for the low average oxygen flow rate relative to the oxygen flow capacity of the devices remains unclear. Local oxygen flow rate practices relative to local targeted SpO₂ norms may be at play. The triggers that intensive care nurses use to increase oxygen flow rates have yet to be fully investigated.²¹

Overall, this study critically examined the routine practice of administering oxygen to ICU patients after cardiac surgery and identified suboptimal levels of clinical care. Given that this finding raises questions about everyday ICU practice, the method may be useful to apply to other routine ICU practices that might superficially appear unimportant. Examples include infection control practices for central venous catheter care,²² and clinical decision-making by intensive care nurses about oxygen administration.⁴

Our study had a number of limitations that should be considered when interpreting the results. First, the external validity is limited by the single-centre design and consequent homogeneous patient population; generalisability might also be limited by the relatively low scores for severity of illness and small sample size. Thus, the study findings may not reflect oxygen administration practices in other organisations or to cardiac surgical patients with more severe illness.

Second, the decision to define hypoxaemia as SpO₂ < 95% might be viewed as unnecessarily strict. However, this is the standard definition of hypoxaemia in most medical and nursing texts^{11,23} and aligns with recent recommendations of the British Thoracic Society.²⁴ Further, in the absence of prospective observational studies showing that an SpO₂ target in the range 90%–94% is as safe in postoperative cardiac surgical patients as SpO₂

> 95%, it would be prudent to continue to target the higher SpO₂ level.

Third, data were collected from the on-the-hour recorded vital signs; no data were available on SpO₂ and respiratory rate in the intervening periods. Anecdotal evidence indicates that intensive care nurses document only dramatic physiological variations other than the routine on-the-hour vital sign recordings. Thus, the values documented in this study may have underestimated the incidence of hypoxaemia and respiratory rate abnormalities.

Although the possibility of conducting a prospective rather than retrospective medical record audit was considered a priori, a prospective study might have resulted in intensive care nurses changing their oxygen delivery practices and documentation of decisions.²⁵ Specific limitations of this and other retrospective medical record audits include the possibility of incomplete documentation, missing records, unrecoverable or unrecorded information, and variation in use of medical and nursing abbreviations,²⁶ or identified care delivered but not documented.

Recommendations and conclusion

Hypoxaemia or respiratory rate abnormalities affected almost two-thirds of patients in this study. Of major concern is that 98% of hypoxaemic episodes occurred when patients were receiving supplemental oxygen, but oxygen delivery devices or flow rates were changed in only 25% of those with documented hypoxaemia and 53% of those with a respiratory rate abnormality. These findings suggest that the ICU environment does not protect cardiac surgical patients from suboptimal management of these physiological abnormalities. Our findings highlight the need for strategies to prompt the early initiation of interventions aimed at correcting respiratory dysfunction for cardiac surgical patients in the ICU. A first step could be the accurate uptake of recently published guidelines for emergency oxygen use in adult patients,²⁴ and the adoption of practical approaches to selecting and managing low-flow oxygen delivery devices.⁵

Further investigation into how intensive care nurses manage oxygen therapy is warranted to identify the context-specific factors that influence oxygen administration to cardiac surgical patients in the ICU. Prospective observational and interventional studies of intensive care nurses' management of the administration of supplemental oxygen in relation to physiological abnormalities are needed to better understand the nature and duration of physiological abnormalities; identify the triggers for, or barriers to, changes to oxygen delivery devices or flow rates; and inform the development of clinical practice guidelines for postoperative oxygen management in this patient group.

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