Oxygenation targets and monitoring in the critically ill: a point prevalence study of clinical practice in Australia and New Zealand

Paul J Young, Richard W Beasley, Gilles Capellier, Glenn M Eastwood and Steve A R Webb

ABSTRACT

Background: Many critically ill patients require supplemental oxygen. However, the optimal oxygen saturation measured by pulse oximetry (Spo_2) in intensive care unit patients is unknown.

Objective: To evaluate clinical practice in Australia and New Zealand ICUs in relation to Spo_2 monitoring, prescription of Spo_2 targets by doctors, and upper and lower limits of tolerance of high and low Spo_2 levels by ICU bedside nurses.

Method: Cross-sectional, observational study conducted on 2 days in 2013 involving adult patients in Australia and New Zealand ICUs.

Results: Data from 350 adult ICU patients were included. Spo_2 alarms were less likely to be disabled in patients who were invasively ventilated than in patients not receiving supplemental oxygen (4.8% v 15.1%; $P = 0.02$). In mechanically ventilated patients and non-ventilated patients receiving supplemental oxygen, the lower prescribed Spo_2 limit and the ICU bedside nurses' stated limits for action for low Spo_2 levels were 92% (interquartile range, 90%–94%). Upper Spo_2 limits were less frequently prescribed than lower Spo_2 limits (4.9% [95% CI, 3.0%–7.7%] v 36.6% [95% CI, 31.7%–41.7%]); $P < 0.01$) and the observed Spo_2 exceeded the prescribed upper limit on 10/17 occasions (59%) when an upper limit was prescribed.

Conclusion: Our findings suggest a relatively low level of vigilance in relation to prevention of high Spo_2 compared with low Spo_2 for adult patients in Australian and New Zealand ICUs.

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The human body has adapted to the oxygen concentration of ambient air (21%) and has a normal Pao_2 of 80–100 mmHg.[1] This corresponds to oxygen saturation of 95%–99% when measured by arterial blood gas analysis (using Sao_2) or via pulse oximetry (using Spo_2). Many critically ill patients require supplemental oxygen to maintain a normal Spo_2 and, consequently, supplemental oxygen is one of the most common treatments given to patients in the intensive care unit. However, although the administration of supplemental oxygen can be life-saving, the indiscriminate use of oxygen in the ICU environment may be undesirable because it may expose patients to unnecessarily high inspired oxygen concentrations and/or hyperoxaemia, both of which might potentially be harmful.[1] As with other physiological targets, there may be a definable optimal Spo_2 target for critically ill patients[2] that minimises the harms associated with too much or too little oxygen.

The association between arterial oxygen saturations and outcomes in critically ill patients has been explored in retrospective studies.[3-7] Unfortunately, due to the potential for unmeasured confounding effects in such studies, their findings do not provide a robust evidence base to inform clinicians. There are currently only limited data from prospective studies of different oxygen strategies in critically ill patients[8] and it is not clear whether a liberal or a conservative approach to oxygen administration is the most appropriate. Moreover, there appears to be a spectrum of views about what Spo_2 is acceptable to nursing and medical staff monitoring patients in current ICU practice.[9,10] We hypothesised that high Spo_2 values would generally be tolerated in critically ill patients but that low Spo_2 values would be carefully avoided. Our aim was to evaluate clinical practice in adult ICU patients with respect to Spo_2 monitoring, the prescription of Spo_2 targets by doctors, and the upper and lower limits of tolerance of high and low Spo_2 levels by ICU bedside nurses.

Methods

We undertook an observational, cross-sectional study in 48 Australian and New Zealand centres under the auspices of the Australian and New Zealand Intensive Care Society Clinical Trials Group (ANZICS-CTG) Point Prevalence Program (PPP). Site-based contributors are listed in the Appendix (online at cicm.org.au/Resources/Publications/Journal). The PPP facilitates a 24-hour data-capture period in patients who are occupying a bed in participating ICUs in Australia and New Zealand on one of two PPP days at 10 am. Each

Table 1. Demographic and intensive care unit admission characteristics of patients

	Invasively vent.		Non-invasively vent.		Not vent., on supp. O_2		Not vent., not on supp. O_2
Characteristic	*n* = 134	*P**	*n* = 8	*P**	*n* = 110	*P**	*n* = 98
Mean age, years (SD)	55.7 (16.6)	0.93	64.1 (20.3)	0.26	60.4 (16.8)	0.08	55.9 (19.7)
Male, %	60.4%	0.69	50.0%	0.73	60.9%	0.67	57.0%
Mean weight, kg (SD)	80.0 (22.1)	0.83	90.1 (14.7)	0.73	82.9 (29.5)	0.52	80.6 (19.9)
Admission source, %							
Emergency department	32.8%	0.67	0	0.19	21.8%	0.62	25.5%
Ward	20.1%	0.16	75.0%	0.01	25.5%	0.73	28.6%
Other intensive care unit	6.7%	0.79	0	1.0	3.6%	1.0	5.1%
Other hospital	12.7%	0.52	0	1.0	6.4%	0.60	9.2%
OR after emergency surg.	17.9%	0.13	25.0%	0.22	10.0%	1.0	10.2%
OR after elective surg.	9.7%	0.01	0	0.35	32.7%	0.08	21.4%
ICU readmission	5.2%	0.06	12.5%	0.56	9.1%	1.0	9.2%
Reason for admission, %							
Trauma	18.7%	0.06	12.5%	0.56	6.4%	0.60	9.2%
Sepsis	40.3%	< 0.01	25.0%	0.56	19.1%	1.0	12.2%
Mean APACHE II score (SD)	21.7 (7.4)	< 0.01	20.3 (6.4)	0.28	16.4 (7.6)	0.19	15.8 (5.8)

Vent. = ventilated. Supp. O_2 = supplemental oxygen. OR = operating room. Surg. = surgery. APACHE = Acute Physiology and Chronic Health Evaluation.
* Comparisons with patients not ventilated or on supplemental oxygen.

participating ICU enrolled patients on 7 November 2013 or 11 December 2013.

All patients aged 16 years or older were eligible for enrolment in this study if they were in a study ICU on one of the PPP days. The study cohort was prospectively divided into four groups: invasively ventilated, non-invasively ventilated, not ventilated but receiving supplement oxygen, and not ventilated and not receiving supplemental oxygen. Invasive ventilation was defined as any form of positive pressure ventilation administered via an endotracheal tube or tracheostomy tube, including T-pieces, and spontaneous breathing with positive end-expiratory pressure (PEEP) and/or pressure support. Non-invasive ventilation was defined as continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BIPAP) administered via a face mask or nasal mask; it did not include high-flow nasal prongs.

Data collected at the bedside during the PPP day included demographic data, Spo_2 recordings, physiological monitoring data, alarm limits, prescribed limits of Spo_2, and the stated threshold of each ICU nurse for action in response to low or high Spo_2 recordings. Data obtained from the medical notes (including the ICU flow chart) included patient demographic data, comorbidities, severity of illness

Table 2. Characteristics of Spo_2 alarms

	Invasively vent.		Non-invasively vent.		Not vent., on supp. O_2		Not vent., not on supp. O_2
Spo_2 alarm characteristic	*n* = 126	*P**	*n* = 8	*P**	*n* = 103	*P**	*n* = 73
Disabled, *n* (%)	6 (4.8%)	0.02	1 (12.5%)	1.0	12 (11.7%)	0.51	11 (15.1%)
High Spo_2 alarm							
Median, % (IQR)	100% (100%–100%)	0.80	100% (100%–100%)	0.61	100% (100%–100%)	0.50	100% (100%–100%)
Min %, max %	100%, 125%		92%, 105%		100%, 100%		100%, 105%
Low Spo_2 alarm							
Median, % (IQR)	90% (90%–92%)	0.44	88% (86%–90%)	0.03	90% (90%–92%)	0.39	90% (90%–92%)
Min %, max %	60%, 95%		80%, 92%		65%, 95%		65%, 95%

Vent. = ventilated. Supp. O_2 = supplemental oxygen. IQR = interquartile range. * Comparisons with patients not ventilated or on supplemental oxygen.

Table 3. Characteristics of Spo_2 target upper limits

	Invasively vent.		Non-invasively vent.		Not vent., on supp. O_2		Not vent., not on supp. O_2
Spo_2 characteristic	*n* = 134	*P**	*n* = 8	*P**	*n* = 110	*P**	*n* = 98
Upper limit prescribed by doctor, *n* (%)	7 (5.2%)	0.76	1 (12.5%)	0.33	5 (4.5%)	1.0	4 (4.1%)
Median prescribed upper limit (IQR); min %, max %	92% (92%–94%); 92%, 94%	0.90	92% (92%–92%); 92%, 92%	NA	95% (94%–95%); 90%, 100%	0.54	94% (92%–95%); 90%, 95%
Current Spo_2 value > doctor-prescribed upper limit	3 (42.9%)	0.23	0	0.20	2/5 (40%)	0.44	4 (100%)
Upper limit set by nurse							
Median nurse-set upper limit (IQR); min %, max %	100% (100%–100%); 80%,† 100%	< 0.01	100% (100%–100%); 92%, 100%	0.99	100% (100%–100%); 90%, 105%	0.11	100% (100%–100%); 95%, 105%
Current Spo_2 value > nurse-set upper limit for action	6 (5.5%)	0.26	1 (12.5%)	0.40	3 (3.2%)	0.51	1 (1.5%)

Vent. = ventilated. Supp. O_2 = supplemental oxygen. IQR = interquartile range. NA = not applicable. * Comparisons with patients not ventilated or on supp. O_2. † Next lowest SpO_2 value was 90%.

(Acute Physiology and Chronic Health Evaluation [APACHE]-II scores) recorded at ICU admission, and prescribed Spo_2 limits. Current physiological monitoring, alarm limits, and Spo_2 recordings were obtained by research coordinators from direct observation of the bedside monitor. The ICU bedside nurses' thresholds for action were determined from direct questioning by research coordinators.

Study groups were compared using the group of patients who were not ventilated and were receiving no supplemental oxygen as a reference. When relevant, 95% confidence intervals for proportions were calculated using the modified Wald method. Differences between means were tested using the student *t* test for normally distributed data and the Mann–Whitney test for non-normally distributed data. Differences in proportions were tested using the Fisher exact test. No assumptions were made about missing data. Data were collected prospectively by ICU research coordinators at participating hospitals. Study data were collected and managed using REDCap (Research Electronic Data Capture).[11] Statistical analysis was performed using GraphPad Prism 6.1 (GraphPad Software). Statistical significance was set at $P < 0.05$ with no adjustment for multiple measures. Ethics approval was obtained and included a waiver of consent for the PPP.

Table 4. Characteristics of Spo_2target lower limits

	Invasively vent.		Non-invasively vent.		Not vent., on supp. O_2		Not vent., not on supp. O_2
Spo_2 characteristic	*n* = 134	*P*	*n* = 8	*P*	*n* = 110	*P*	*n* = 98
Lower limit prescribed by doctor, *n* (%)	53 (39.6%)	0.41	4 (50%)	0.45	38 (34.5%)	1.0	33 (33.7%)
Median prescribed lower limit (IQR); min, max	92% (90%–94%); 80%; 95%	0.28	90% (85%–91%); 70%, 92%	0.02	92% (90%–94%); 85%, 96%	0.46	92% (92%–94%); 85%, 95%
Current Spo_2 value < doctor-prescribed lower limit	7/46; 13.2%	0.14	0	1.0	2/37 (5.4%)	1.0	1/29 (3.4%)
Lower limit set by nurse							
Median nurse-set lower limit (IQR); min, max	92% (90%–94%); 50%,* 100%	0.11	90% (89%–90%); 70%, 95%	0.02	92% (90%–94%); 80%, 96%	0.40	92% (90%–94%); 85%, 96%
Current Spo_2 value < nurse-set lower limit for action	6/121; 5.0%	0.26	0	1.0	4/99 (4.0%)	0.40	1/73 (1.4%)

Vent. = ventilated. Supp. O_2 = supplemental oxygen. IQR = interquartile range. * Next lowest SpO_2 value was 80%.

Results

A total of 467 patients were included on the two PPP days. Of these, 350 patients (75%) were 16 years or older and were included in this study. Demographic and ICU admission data for the study cohort are shown in Table 1. At the time the patient assessments were undertaken by the research coordinator, 252 of 350 patients (72%) were ventilated and/or receiving supplemental oxygen. Compared with patients who were not ventilated and were not receiving supplemental oxygen, invasively ventilated patients had a higher APACHE-II illness severity ($P < 0.01$), were less likely to have been admitted following elective surgery, and were more likely to have sepsis ($P < 0.01$). In other respects, the baseline characteristics of the patient groups were similar.

Monitoring data for Spo_2 levels were available for 310 patients (Table 2), representing 94% of all patients ventilated or receiving supplemental oxygen (95% CI, 90.3%–96.4%) and 74% of all patients who were not receiving oxygen (95% CI, 65%–82%) ($P < 0.01$). Alarms were less likely to be disabled in patients who were invasively ventilated than in patients who were not receiving supplemental oxygen (4.8% v 15.1%; $P = 0.02$). The median upper limit Spo_2 alarm set in all groups was 100% (interquartile range [IQR], 100%–100%). Only one patient had a set upper limit Spo_2 alarm of less than 100%. This patient was receiving non-invasive ventilation and the set upper Spo_2 limit was 92%. The lower limit Spo_2 alarms were set at around 90% in all groups (Table 2).

Spo_2 targets were only prescribed in a minority of patients (Table 3 and Table 4). Upper Spo_2 limits were prescribed less frequently than lower Spo_2 limits (4.9% [95% CI, 3.0%–7.7%] v 36.6% [95% CI, 31.7%–41.7%]; $P < 0.01$). Patients receiving no supplemental oxygen had similar prescribed Spo_2 limits to invasively ventilated patients, non-invasively ventilated patients, and non-ventilated patients receiving supplemental oxygen. Bedside nurses had similar thresholds for action in relation to low and high Spo_2 in the groups receiving oxygen compared with the group of patients who were not receiving supplemental oxygen.

In the small number of patients for whom upper limits of Spo_2 were prescribed by doctors, limits were generally between 90% and 95%. The observed Spo_2 exceeded the prescribed upper limit on 10/17 occasions (59%) when an upper limit was prescribed (Table 3). The upper limits set by bedside nurses for action in relation to high Spo_2 levels were 100% (IQR, 100%–100%) in all groups.

The lower Spo_2 limits prescribed by clinicians and set by bedside nurses were 92% (IQR, 90%–94%) for all patient groups except for the non-invasively ventilated patients, for whom the limit was generally slightly lower (Table 4).

Discussion

Key findings

We conducted a cross-sectional, observational study to evaluate current practice in Spo_2 targets and monitoring. In accordance with our hypothesis, we showed that high Spo_2 levels appear to be less rigorously monitored and avoided than low Spo_2 levels. In particular, we showed that upper-limit Spo_2 alarms are effectively never used because they are always set at or above the maximum physiologically possible value of 100%. We also showed that bedside ICU nurses generally did not specifically state that they would act on a high Spo_2 value. Upper limits for Spo_2 were prescribed by ICU doctors infrequently and, even when they were prescribed, the observed Spo_2 values often exceeded the prescribed limits.

In contrast to upper Spo_2 limit alarms, lower Spo_2 limit alarms were used commonly and acceptable lower Spo_2 limits were prescribed by doctors more often than upper Spo_2 limits. For most patients, lower prescribed Spo_2 limits were about 92% and lower Spo_2 alarm limits were about 90%.

Relation to previous work

Our study is the first to evaluate clinical ICU practice in Spo_2 alarms, physiological monitoring and prescribed Spo_2 targets in a broad cohort of ventilated and non-ventilated ICU patients. Our findings suggest a relatively low level of vigilance in relation to prevention of high Spo_2 compared with low Spo_2 and are consistent with the existing literature.

Previous studies have shown that hyperoxaemia occurs commonly in critically ill patients who are receiving mechanical ventilation.[3,4,12,13] Survey findings suggest that most ICU nurses and doctors have some concern about oxygen toxicity in mechanically ventilated patients,[9,10] but that there is a clear difference between self-reported practice and actual practice of oxygen therapy.[14]

Our data are similar to data from a cross-sectional, observational study, conducted as part of the ANZICS-CTG PPP in 2013, of 178 non-ventilated patients receiving oxygen.[15] In this study, oxygen saturation targets were prescribed in 28 patients and 98.3% of patients had Spo_2 monitoring.[15] No data were provided on acceptable targets or alarm limits, but the mean highest Pao_2 was in the hyperoxaemic range, at 129 mmHg (range, 58–681 mmHg) and the mean lowest Pao_2 was 88 mmHg (range, 35–383 mmHg).[15]

Clinical implications and significance

Clinical teaching and current ICU practice generally emphasises that avoidance of hypoxaemia is more important than

concerns about hyperoxaemia or exposure to high Fio_2.[16] Investigation of a strategy for precise control of arterial oxygen levels has been identified as a high research priority in critically ill patients[17,18] but there is currently insufficient evidence to guide clinical practice.[1] The acceptable lower Spo_2 limits observed in our study were less than the minimum Spo_2 of 94% that is currently recommended for acutely ill medical patients by the British Thoracic Society (BTS).[19] Similarly, the upper Spo_2 limit of 98% suggested by the BTS does not appear to be adhered to in current Australian and New Zealand ICU practice. However, the BTS guidelines in relation to Spo_2 targets are not supported by high-level evidence and were not specifically intended for use in mechanically ventilated ICU patients.[19]

Strengths and limitations

Our study provides contemporary, prospective, multicentre, bi-national, cross-sectional observational data in relation to monitoring of oxygen therapy in a broad cohort of critically ill patients. We directly questioned ICU bedside nurses in order to determine when they would act on high and low Spo_2 levels. Although our results may reflect what nurses say they would do rather than what they actually do, we verified concurrent monitor settings by direct observation and compared stated responses to concurrent patient Spo_2 levels. A consistent message emerged that hyperoxaemia is less rigorously avoided than hypoxaemia.

Previous data have shown that tolerance of low Spo_2 in mechanically ventilated patients tends to increase as the Fio_2 increases.[12,20] We did not evaluate the relationship between Fio_2 and upper and lower Spo_2 limits in this study because our sample size was too small to allow this to be done in a statistically robust manner.

We chose to focus on Spo_2 levels rather than Sao_2 or Pao_2 because Spo_2 is the variable which is continuously monitored. However, we acknowledge that if liberal oxygen administration is harmful, the Pao_2 and/or the Fio_2 may be more important than the Spo_2.

We noted that for a small number of patients, the lower Spo_2 alarm limit was extremely low (eg, 60%). We speculate that these very low limits were chosen to effectively bypass the alarm system rather than because these values were regarded as physiologically acceptable. However, we did not collect information on why particular limits were chosen and cannot be certain of the reasons.

Conclusion

We found a relatively low level of vigilance in relation to prevention of high Spo_2 compared with low Spo_2 for adult ICU patients. A better understanding of current oxygen therapy practice in the ICU is a fundamental first step in the development of future interventional trials.

Competing interests

None declared.

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Appendix 1. Participating Sites and Investigators

This appendix was part of the submitted manuscript and has been peer reviewed. It is posted as supplied by the authors.

Site/Institution	Principal Investigator/s	Research Co-ordinator/s
The George Institute for Global Health	Parisa Glass Naomi Hammond Ashleigh Myburgh John Myburgh Dorrilyn Rajbhandari Ian Seppelt Nicola Watts	
Canberra Hospital	Sean Chan	Helen Rodgers Amy Harney Katie Milburn
Royal Children's Hospital, Brisbane	Anthony Slater	Debbie Long Tara Williams
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Royal Children's Hospital	Warwick Butt	Carmel Delzoppo
Mater Children's Hospital	Andreas Schibler Christian Stocker	Sara Mayfield
Concord Hospital	David Milliss	Helen Wong

Nepean Hospital	Ian Seppelt	Leonie Weisbrodt Anne Ritchie Maria Nikas Rebecca Gresham
North Shore Private Hospital	Anthony Delaney	Dena-Louise Hogben Laura Davies
Prince of Wales Hospital	Prof Yahya Shehabi	Nicola Straiton
Royal North Shore Hospital	Prof Simon Finfer	Frances Bass Naomi Hammond Anne O'Connor Elizabeth Yarad Simon Bird
St George Hospital	Prof John Myburgh Manoj Saxena	Jennene Miller Rebecca Sidoli Deborah Inskip
St Vincent's Hospital, Sydney	Priya Nair	Serena Knowles
Westmead Hospital	Vineet Nayyar	Christina Skelly Jing Kong
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	David Knight	
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Waikato Hospital	Rob Frengley	Mary La Pine John Durning
Wellington Hospital	Dick Dinsdale	Lynn Andrews Sally Hurford Anna Hunt
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Tauranga Hospital	Troy Browne Rachel Atkin	Jennifer Goodson
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Lyell McEwin Hospital	Rajaram Ramadoss	Josette Wood
The Queen Elizabeth Hospital	Sandra Peake	Catherine Kurenda JoAnne McIntrye
Royal Adelaide Hospital	Stephanie O'Connor	Sonya Kloeden Justine Rivett
Austin Hospital	Rinaldo Bellomo	Glenn Eastwood Leah Peck Helen Young
Bendigo Hospital	Jason Fletcher	Julie Smith
Cabrini Hospital	Jonathan Barrett	Gabrielle Hanlon
Geelong Hospital	Claire Cattigan	Tania Salerno Allison Bone Tania Elderkin

The Northern Hospital	Dr Angaj Ghosh John Green Andrew Casamento	Mary Park Olga Burgess
Royal Melbourne Hospital	Christopher Macisaac	Deborah Barge Andrea Jordan
St Vincent's Hospital, Melbourne	John Santamaria	Roger Smith Jennifer Holmes
Western Health	Craig French	Samantha Bates
Albury Hospital	Charles Mashonganyika	Clare Maher