

Reducing inappropriate arterial blood gas testing in a level III intensive care unit: a before-and-after observational study

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Efforts to curtail unnecessary testing in medicine are growing. This has been demonstrated by the Choosing Wisely campaign, which has support from more than 100 medical societies across 20 countries,¹ including the Australian and New Zealand College of Intensive Care Medicine² and the Society of Critical Care Medicine.³ Pathology tests are costly and contribute to the development of anaemia, which affects 95% of intensive care patients by Day 3 of admission.⁴ Almost half of all critical care patients receive red blood cell transfusions during their stay,^{5,6} with up to one-third of all transfusions attributed to this so-called anaemia of chronic investigation.⁷⁻⁹

Arterial blood gas (ABG) analysis is the most commonly ordered test in the intensive care unit (ICU),^{10,11} with reports estimating that sampling is done, on average, 4.8–8.5 times per patient per day.¹⁰⁻¹⁸ No validated guidelines are available for ABG sampling¹⁹ and ordering patterns appear to be primarily driven by cultural factors.^{14,15,20,21} Data suggest that ABG tests are commonly performed for routine surveillance. One group of researchers found that more than 60% of all ABG tests were performed at regular intervals for monitoring, after changes in ventilator settings, and before and after extubation, while only 26% were ordered in response to a respiratory event.²⁰ A survey of critical care clinicians in a tertiary 98-bed ICU in the United States found that 90% of clinicians ordered ABG tests for routine surveillance, 80% after every ventilation adjustment, 70% during spontaneous breathing trials before extubation and 65% for “convenience” when an arterial catheter was in situ.¹⁹ The presence of an arterial line has been shown to be the most powerful predictor of the number of ABG tests ordered when controlled for illness severity.^{16,22,23} Ultimately, it has been suggested that 33–66% of all ABG tests may not be clinically justified.^{14,15,17,19,20}

Staff education with or without implementing a clinical guideline has been shown to decrease the number of ABG tests performed in ICUs by 25–51%, without obvious detrimental effects on patient care.^{13-15,17-19} This effect is even greater in intubated patients¹³ and has been sustained for up to 5 years.²⁴ Therefore, the aim of this study was to

ABSTRACT

Background: Arterial blood gas (ABG) analysis is the most frequently performed test in intensive care units (ICUs), often without a specific clinical indication. This is costly and contributes to iatrogenic anaemia.

Objectives: To reduce the number of ABG tests performed and the proportion that are inappropriate.

Design, setting and participants: The indications for ABG analysis were surveyed at a 58-bed level III ICU during fortnightly periods before and after a multifaceted educational intervention which included the introduction of a clinical guideline. The number of ABG tests performed during the period July–December 2017 was compared with that for the period July–December 2018. Tests were predefined as inappropriate if performed at regular time intervals, at change of shift, concurrently with other blood tests or after a treatment was ceased on a stable patient or after ventilatory support or oxygen delivery was decreased in an otherwise stable patient. The study was enrolled on the Quality Improvement Projects Register and ethics approval was waived by the local ethics committee.

Results: There was a 31.3% bed-day adjusted decrease in number of ABG tests performed (33 005 v 22 408; $P < 0.001$), representing an annual saving of A\$770 000 and 100 litres of blood. The proportion of inappropriate ABG tests decreased by 47.3% (54.2% v 28.6%; $P < 0.001$) and the number of inappropriate ABG tests per bed-day decreased by 71% (2.8 v 0.8; $P < 0.001$). Patient outcomes before and after the intervention did not differ (standardised mortality ratio, 0.65 v 0.63; $P = 0.22$).

Conclusion: Staff education and implementation of a clinical guideline resulted in substantial decreases in the number of ABG tests performed and the proportion of inappropriate ABG tests.

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determine whether the number of unnecessary ABG tests can be reduced without compromising patient care after introducing local clinical guidelines and staff education. We hypothesised that the proportion of unnecessary ABG tests, and the total number performed per bed-day, could be decreased by at least 25% without demonstrable negative effects on patient outcomes.

Methods

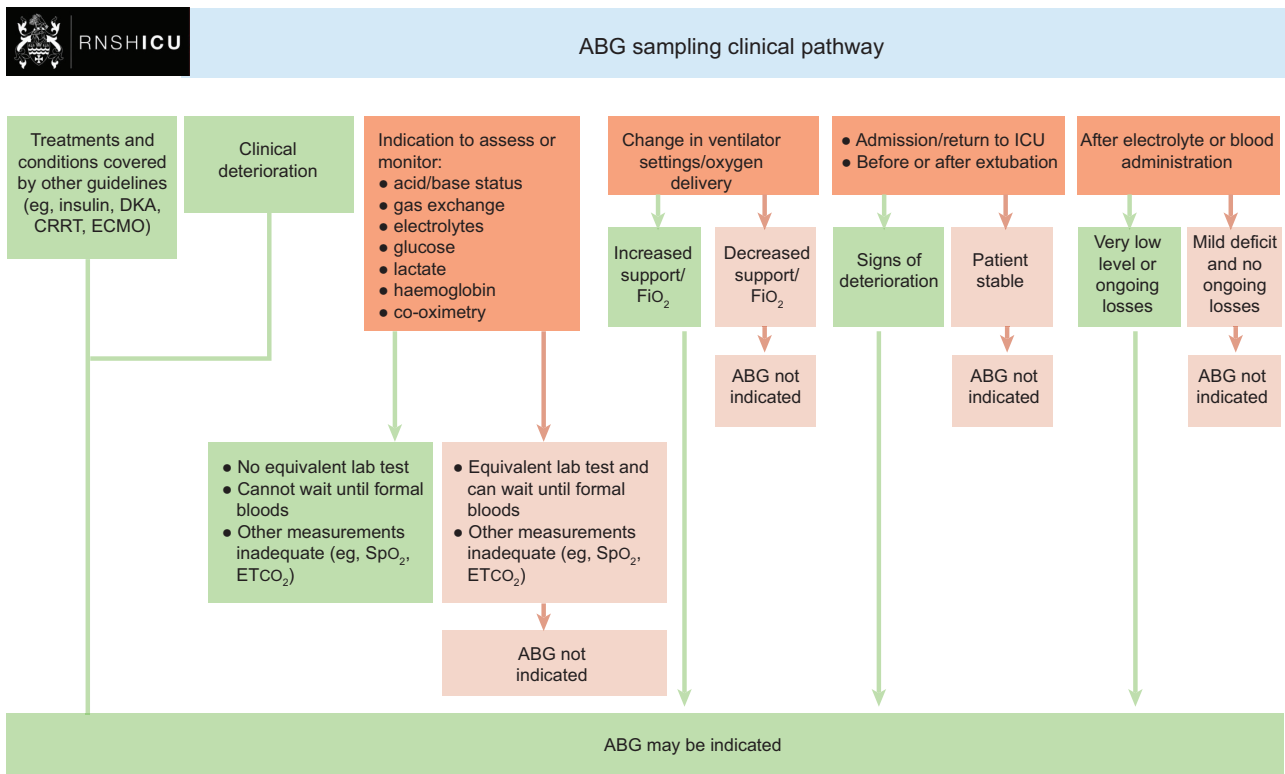
Setting

The study was conducted in the ICU of Royal North Shore Hospital in Sydney, Australia. This university-affiliated 58-bed level III ICU includes four “pods” — two 16-bed general ICUs, a 13-bed cardiothoracic ICU and a 13-bed neurosciences ICU. Royal North Shore Hospital has about 3700 ICU admissions each year across all major medical and surgical subspecialties, including trauma, spinal cord injuries and severe burns.

Study design

The processing fee and cost of consumables per ABG test were ascertained as follows. In Australia, the Medicare Benefits Schedule fee for ABG analysis is A\$33.70 per test. At our institution, the cost is A\$37.25, of which A\$35.34 is the fee charged to the ICU department by the pathology service and A\$1.91 is the cost of consumables such as syringes and gauze. Volume of blood used was estimated from the recommended discard volume (3–5 mL) and sample volume (0.5–1 mL) in the ICU and local health district blood sampling guidelines. Time spent per test was estimated from local observation and published data.^{15,19} The total number of ABG tests performed in each of the four pods during the period July–December 2017 was recorded. Subsequently, a multifaceted educational intervention was developed and implemented during the period January–June 2018. Following this, the number of ABG tests during the period July–December 2018 was recorded. Data on occupancy, demographics, illness severity and patient outcomes for the periods before and after the intervention were compared.

Figure 1. Decision flow chart included in the clinical guideline for arterial blood gas (ABG) testing



CRRT = continuous renal replacement therapy; DKA = diabetic ketoacidosis; ECMO = extracorporeal membrane oxygenation; ETCO₂ = end-tidal carbon dioxide; FiO₂ = fraction of inspired oxygen; ICU = intensive care unit; SpO₂ = pulse oximetry.

The intervention focused on exploring appropriate and inappropriate indications for testing, followed by education of clinical staff with respect to the number of ABG tests performed, and the associated financial, blood loss and labour costs. Nursing staff were educated via case-based in-service presentations, delivered by a nurse educator to small groups of clinical nurses twice a week in each pod for 12 weeks. Two presentations were made to medical and senior nursing staff at the departmental meeting. Finally, development of a local guideline for ABG testing, including an easy-to-follow decision flowchart (Figure 1), reaffirmed the importance of clinically appropriate use of ABG tests. In particular, it was emphasised that ABG tests were not warranted at scheduled time intervals, in response to reduced ventilatory support, or routinely before or after extubation.²⁵⁻²⁷ It was also emphasised that laboratory tests should be performed in preference to point-of-care tests for parameters that can be measured by both methods (eg, haemoglobin), unless an urgent result was required. There was a de-emphasis on sampling after potassium replacement or blood transfusion, except in cases of severe hypokalaemia or anaemia, or in the setting of significant ongoing losses of potassium or bleeding. Clinicians were encouraged to monitor parameters clinically where possible; for example, using pulse oximetry (SpO₂) and

end-tidal carbon dioxide (ETco₂) as surrogates for arterial oxygen (Pao₂) and carbon dioxide (Paco₂) tension in stable patients. Finally, educational posters were displayed in the ICU, and educational snippets were included in the local ICU newsletter and on closed social media groups.

To determine the indications for ABG tests, staff were surveyed during two randomly selected 2-week periods, before and after the intervention. They were asked to complete a survey alongside all ABG tests to ascertain their indication and whether they were initiated by medical or nursing staff. Indications were predefined as inappropriate if performed at regular time intervals, at change of shift, concurrently with other blood tests or after a treatment was ceased on a stable patient, or after ventilatory support or oxygen delivery was decreased in an otherwise stable patient. All other indications were considered appropriate. Responses from the surveys were assumed to be representative of the entire respective 6-month study period and were then extrapolated to overall ABG use.

Outcomes

The primary outcome of our study was the total number of ABG tests performed per bed-day. Secondary outcomes were the proportion of total ABG tests that were inappropriate and the total number of inappropriate ABG

Figure 2. Number of ABG tests per bed-day, by month, before and after the intervention

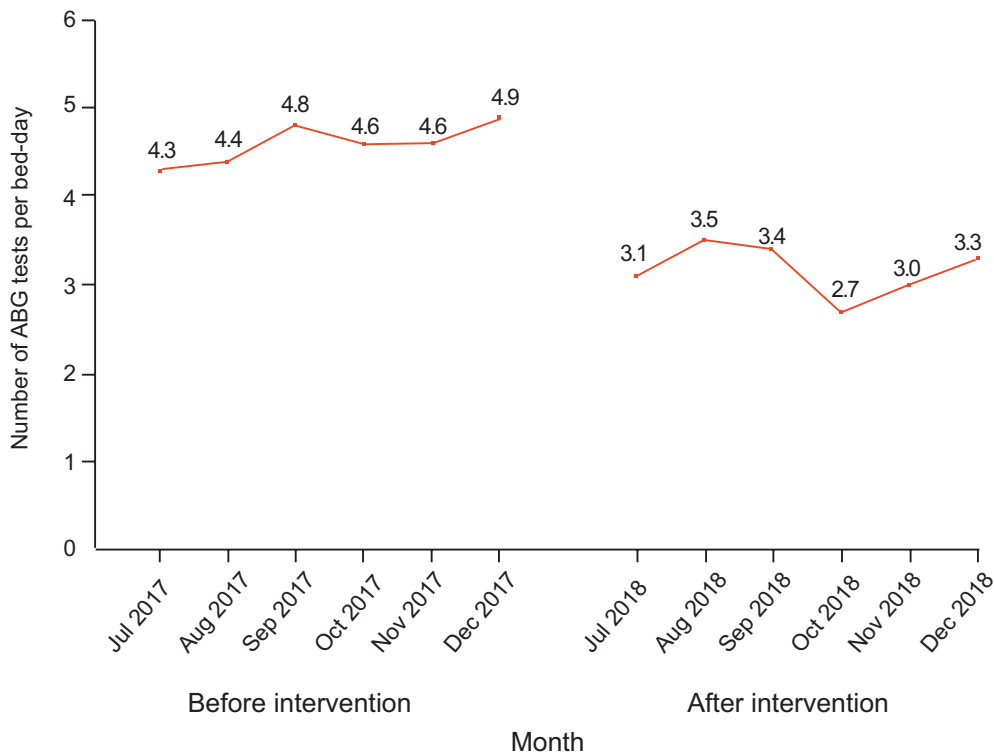


Figure 3. Number of arterial blood gas (ABG) tests performed and number of bed-days for general intensive care unit 1, by month, before and after the intervention

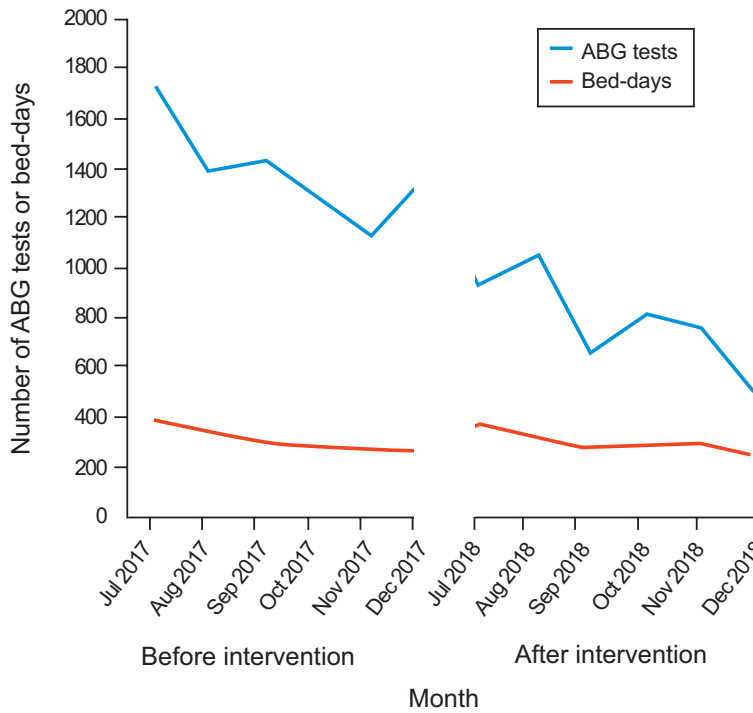
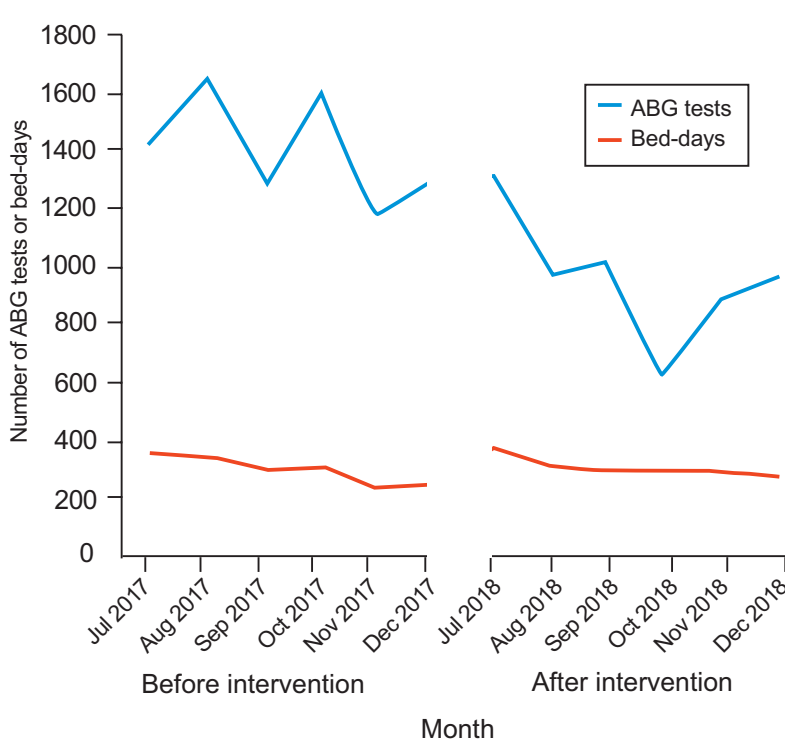


Figure 4. Number of arterial blood gas (ABG) tests performed and number of bed-days for general intensive care unit 2, by month, before and after the intervention



tests per bed-day. Data are presented as mean ± standard deviation and median (interquartile range) for normal and non-normal continuous data, respectively, and as number (%) for categorical data. Mann–Whitney *U* tests, *t* tests and χ^2 tests were used as appropriate. Multivariable regression was performed to determine the effect of study period on ICU mortality and ICU length of stay when adjusted for age, sex, urgency of admission and APACHE (Acute Physiology and Chronic Health Evaluation) III scores. *P* values less than 0.05 were deemed significant. All statistical analyses were performed using R version 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria). The study was enrolled in the local Quality Improvement Projects Register and the need for ethics approval was waived by the local ethics committee.

Results

Numbers of ABG tests

In the 6 months before the intervention, 33 005 ABG tests were performed, compared with 22 408 in the 6 months after — a reduction of 32.1%. When adjusted for occupancy (7208 v 7135 bed-days), there was a 31.3% reduction from 4.6 to 3.1 ABG tests per bed-day (*P* < 0.001) (Figure 2). Each of the four pods achieved a decrease of at least 20% in the number of ABG tests performed per bed-day; the general ICUs demonstrated 32.2% and 39.9% reductions (Figure 3 and Figure 4), the neurosciences ICU 34.4% (Figure 5) and the cardiothoracic ICU 20.1% (Figure 6).

Numbers of inappropriate ABG tests

After implementation of the clinical guideline, the proportion of inappropriate ABG tests fell by 47.3% (absolute proportions, 54.8% v 28.9%; *P* < 0.001), as shown in Table 1. When adjusted for occupancy (570 v 528 bed-days) and for the number of ABG tests performed (2869 v 1397) before and

Figure 5. Number of arterial blood gas (ABG) tests performed and number of bed-days for the neurosciences intensive care unit, by month, before and after the intervention

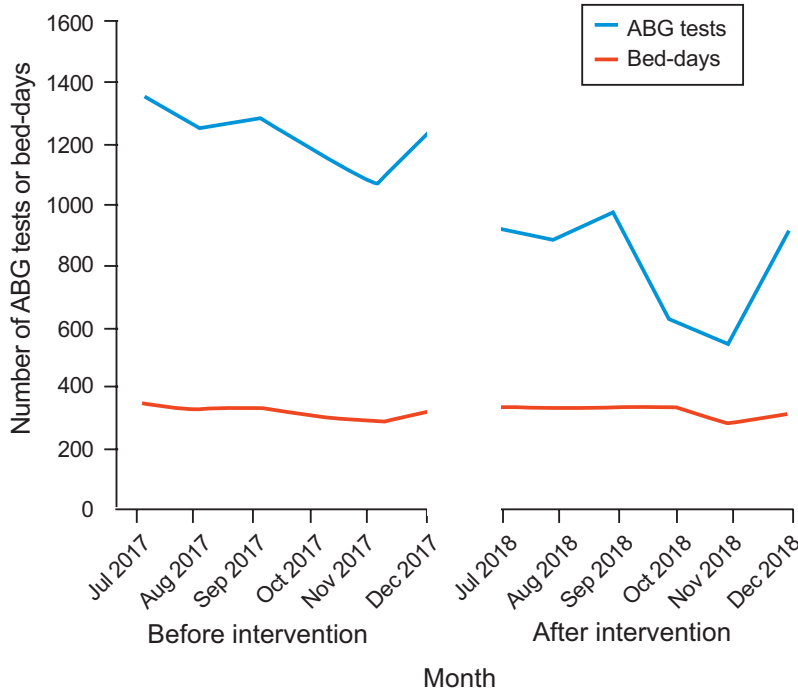
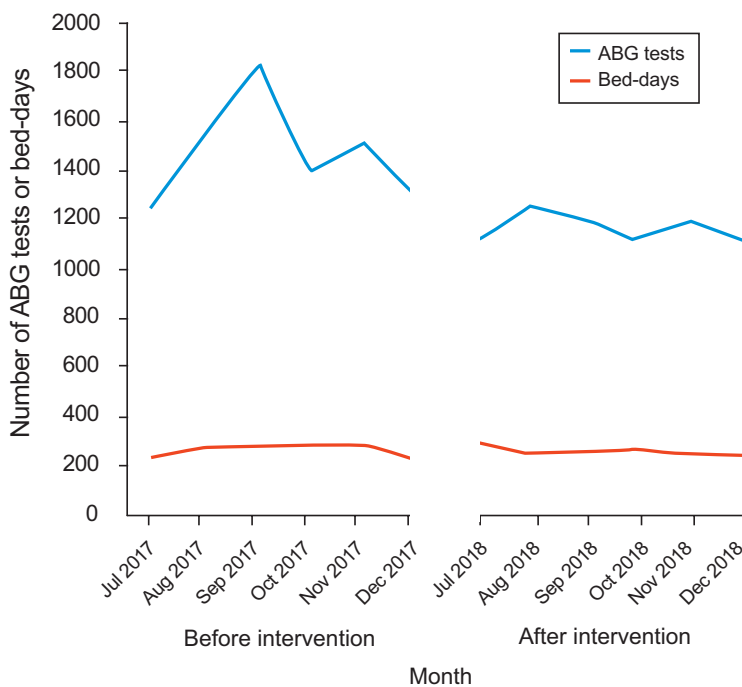


Figure 6. Number of arterial blood gas (ABG) tests performed and number of bed-days for the cardiothoracic intensive care unit, by month, before and after the intervention



after the intervention, there was a 71% absolute reduction in the number of inappropriate ABG tests performed per bed-day (2.8 v 0.8; $P < 0.001$).

Clinician-initiated tests

The number of doctor-initiated ABG tests per bed-day was 0.48 before the intervention and 0.58 after the intervention, corresponding to a proportion of doctor-initiated tests increasing from 10% to 22%. The number of nurse-initiated ABG tests per bed-day decreased from 4.4 to 2.0, corresponding to a change from 88% to 77% of all tests. Fewer than 2% of all survey responses did not specify the clinician initiating the test.

Cost implications

Based on our calculation of A\$37.25 per sample, the estimated annual cost of ABG tests before the intervention was A\$2.45 million. These samples involved the use of 330 litres of patient blood and 5500 hours of labour (about three full-time equivalent nursing staff). A 31.3% reduction in the number of ABG tests represents annual savings of A\$770 000, more than 100 litres of blood and one full-time equivalent member of staff in labour costs.

Patient outcomes

No significant differences in patient demographics, severity of illness, urgency of admission, period of mechanical ventilation or mortality rates were seen between the two study periods (Table 2). Multivariable regression did not identify any significant differences in ICU mortality when adjusted for age, sex, urgency of admission and APACHE III score (odds ratio, 1.001; 95% CI, 0.726–1.380; $P = 0.995$). Similarly, there was no difference in ICU length of stay when adjusted for the same factors (odds ratio, 1.069; 95% CI, 0.754–1.513; $P = 0.709$).

Discussion

Summary of findings

Following our intervention, the annual expected number of inappropriate ABG

Table 1. Indications for ABG tests reported in the surveys conducted before and after the intervention

Reason and subcategory	Before intervention		After intervention	
	Number (%) ABG tests (n = 709)	Per bed-day	Number (%) ABG tests (n = 417)	Per bed-day
Deterioration	57 (8.0%)	0.40	74 (17.7%)	0.47
Guide current treatment	275 (38.8%)	1.95	210 (50.4%)	1.33
Change infusion	120 (16.9%)	0.85	127 (30.5%)	0.81
Change oxygen delivery*	65 (9.2%)	0.46	18 (4.3%)	0.11
Change ventilator settings*	57 (8.0%)	0.40	18 (4.3%)	0.11
Other	24 (3.4%)	0.17	38 (9.1%)	0.24
None selected	9 (1.3%)	0.07	9 (2.2%)	0.06
After treatment ceased	76 (10.7%)	0.54	44 (10.6%)	0.28
After extubation*	21 (3.0%)	0.15	3 (0.7%)	0.02
After electrolyte replacement*	38 (5.4%)	0.27	25 (6.0%)	0.16
After blood transfusion*	12 (1.7%)	0.09	15 (3.6%)	0.10
Other*	2 (0.3%)	0.02	1 (0.2%)	0.01
None selected*	3 (0.4%)	0.02	0	0
Other	298 (42.0%)	2.11	85 (20.4%)	0.54
Abnormal previous results	67 (9.4%)	0.47	27 (6.5%)	0.17
With formal blood tests*	52 (7.3%)	0.37	9 (2.2%)	0.06
Start/change shift*	66 (9.3%)	0.47	8 (2.0%)	0.05
Not done for __hours*	73 (10.3%)	0.52	23 (5.5%)	0.15
Prepare for transport	5 (0.7%)	0.04	1 (0.2%)	0.01
Other	33 (4.7%)	0.24	17 (4.1%)	0.11
None selected	2 (0.3%)	0.02	0	0
None selected	3 (0.4%)	0.02	4 (1.0%)	0.03
Total	709 (100%)	5.02	417 (100%)	2.65

ABG = arterial blood gas. * Reasons deemed inappropriate.

educational interventions, including the development of a clinical guideline, can significantly decrease both the proportion of inappropriate ABG tests and the total number of ABG tests performed in ICUs. More than 50% of our pre-intervention ABG tests were inappropriate, while other studies have found that 33–66% of all ABG tests were unnecessary. Following our education program, we identified a 47% relative reduction in the proportion of inappropriate ABG tests, which is consistent with 28–57% reductions seen in other studies.^{14,15,17-20} Interestingly, no previous studies have specified an absolute reduction in the number of inappropriate ABG tests per bed-day, which we believe is a useful indicator given the large decrease in the denominator (total number of ABG tests) after the intervention. Similar to findings of other small studies in North America and Europe, this initial Australian study demonstrated no detectable negative impacts on patient outcomes.

tests declined from 40 180 to 11 565. This type of reduction has benefits to hospital finances and resource allocation and is likely to be beneficial to patients. We observed a marked decline in nurse-initiated tests and a corresponding rise in doctor-initiated tests, which was likely achieved by empowering nurses to apply their clinical judgement to ABG testing, with the aid of a guideline and algorithm. This effect was sustained throughout the same period in the following year (July–December 2019), during which there were 3.1 ABG tests performed per bed-day (23 212 ABG tests and 7442 bed-days) (unpublished data).

Comparison to other studies

These results support findings from previous studies (many of which are several decades old) showing that simple

Strengths and weaknesses

A limitation of this study is that it was observational in nature and conducted over two periods. The same period of the year was analysed before and after the intervention, to avoid seasonally related variation in results. During the study there were no easily identifiable confounders, such as major changes in staffing or protocols other than introduction of the ABG clinical guideline. The study was a single-centre and non-blinded trial, but the intervention was easily achievable, inexpensive, and provided encouraging results across a heterogeneous patient cohort. The cardiothoracic ICU predictably had the smallest reduction in ABG tests performed per bed-day owing to existing protocols that govern patients who have undergone cardiac surgery, which mandate regular ABG tests in the first 48 hours after

Table 2. Occupancy, demographics, severity of illness and outcomes data for patients represented in the surveys conducted before and after the intervention

	Before intervention	After intervention	P
Total ICU admissions	1891	1859	0.601
Total ICU bed-days	7231	7246	–
Sex, male	1113 (58.9%)	1111 (59.8%)	0.595
Age, median (IQR)	66 (53–76)	65 (52–75)	0.197
Emergency admission	1249 (66.0%)	1184 (63.7%)	0.139
APACHE III score, median (IQR)	45 (32–63)	47 (34–63)	0.089
Length of stay in days, median (IQR)	2.1 (1.1–4.4)	2.2 (1.1–4.5)	0.299
Mechanical ventilation	579 (30.6%)	606 (32.6%)	0.205
Length of mechanical ventilation in days, median (IQR)	0.9 (0.5–3.0)	0.9 (0.4–3.0)	0.455
Dialysed	59 (3.1%)	77 (4.1%)	0.113
Died in ICU	119 (6.3%)	114 (6.1%)	0.892
SMR (APACHE III), median (IQR)	0.65 (0.56–0.76)	0.63 (0.54–0.74)	0.220

APACHE = Acute Physiology and Chronic Health Evaluation; ICU = intensive care unit; IQR = interquartile range; SMR = standardised mortality ratio.

surgery. To assess the economic impact of our intervention, we performed a simple cost-minimisation analysis,²⁸ making the assumption that the clinical effect of decreasing the number of inappropriate ABG tests would be minimal. Our outcome data suggest that this type of analysis was appropriate, although future investigators could consider performing a more formal cost–benefit health economic evaluation, including the collection of more granular data such as volume of blood sampled, time taken to perform tests and the need for blood transfusion.

Local implications

Titration of insulin infusions accounted for 22% of the total number of ABG tests in the period after the intervention. About 10% of our ICU patients are receiving an insulin infusion at any given time, and local policy mandates second-hourly ABG tests for these patients owing to concerns regarding the reliability of bedside glucometers in critically ill patients.²⁹ This alone would account for 15 000–20 000 samples annually, or about 40% of our ABG tests in the period after the intervention. When combined with other protocol-mandated ABG tests, such as for patients on continuous renal replacement therapy and those with diabetic ketoacidosis, the potential for further reductions in the number of tests at our institution is limited.

Wider relevance

Our 58 ICU beds represent 2.4% of all ICU beds in Australia and New Zealand.³⁰ We recognise that there is variety in patient acuity, clinical practice and health care costs across

the two countries, but if a similar proportional 31.3% reduction in ABG tests could be achieved across all ICUs in Australia and New Zealand, savings could be made of up to A\$33 million, 4400 litres of blood and 40 full-time equivalent staff (73 000 hours of labour). Furthermore, this framework could be applied to other critical care areas such as coronary care units and to rationalising ordering of other common tests in ICU, such as laboratory blood tests.

Conclusion

In conclusion, education of staff and introduction of a clinical guideline significantly reduced the number of ABG

tests performed and the proportion and overall number of inappropriate ABG tests. This effect was sustained on re-analysis 12 months after the initial intervention.

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Competing interests

None declared.

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