Does Implementing Pulse Oximetry in a Critical Care Unit Result in Substantial Arterial Blood Gas Savings?

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Objectives: To examine the impact of pulse oximetry on the use of arterial blood gas and other laboratory determinations and to examine predictors of the use of arterial blood gas measurements.

Design: Before (preoximetry)/after (postoximetry) study. Setting: Thirty-bed multidisciplinary critical care unit. Patients: Consecutive admissions of 300 patients (150 before and 150 after oximetry).

Measurements: For each patient examined, the number of arterial blood gas determinations, serum electrolyte levels, complete blood chemistries, arterial lactate levels, and creatinine samples were recorded for the initial 9 days of the stay in the critical care unit. These data were stratified by nursing shift (day vs night) and by the source of the admission (medical vs surgical). Other information collected included demographic variables, the severity of illness, the length of stay in the critical care unit, and various ventilatory parameters.

Results: Introducing pulse oximetry was associated with a marginal (10.3 percent; p<0.025) reduction in the use of arterial blood gas determinations. This decrease was accounted for by changes occurring on the night shift and in the surgical patient. These findings were also observed for serum electrolyte determinations. No significant differences in the use of arterial blood gas measurements were found for medical patients. No significant differences were found in the use of arterial lactate levels, complete blood chemistries, or creatinine determinations. Significant predictors of arterial blood gas determinations included the number of days intubated, the number of ventilator orders, the number of days on an inspired oxygen content (FIO2) greater than 50 percent, and the acute physiology and chronic health evaluation II (APACHE II) score.

Conclusions: The implementation of pulse oximetry in this manner gives an idea how effective the technology will be in reducing the use of arterial blood gas determinations without guidelines for the use of pulse oximetry. As only a marginal decrease was observed in the total population of medical and surgical patients, and only on the night shift, formal and standardized guidelines for the most efficient use of pulse oximetry should be considered. If these were considered, pulse oximetry may indeed make a significant contribution to improving the efficiency of care services.

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ANOVA = analysis of variance; APACHE = acute physiology and chronic health evaluation; FIO2 = fractional concentration of oxygen in inspired gas; SaO2 = arterial oxygen saturation

The escalating imbalance of supply and demand in health care resources in critical care has created increasing pressure to improve the efficiency of providing these life-support services, one such mechanism being the assessment of both new and existing technology. A comprehensive evaluation of a new technology would include information regarding its efficacy (can it work?), effectiveness (does it work?), and efficiency (the relationship between the costs and consequences of it vs at least one other health care alternative).1

The widespread diffusion of pulse oximetry to critical care over the last few years has been accompanied by statements concerning its ability to improve both the safety of the patient and the efficiency of providing critical care services.2-7 It is argued that the safety of the patient is enhanced as pulse oximetry continuously and accurately tracks arterial oxygen saturation (SaO2), warning of dangerous desaturations before the appearance of clinical signs.2-4 It is also argued that the efficiency of providing critical care services is enhanced. Compared with the standard technique of serial arterial blood gas determinations employed when weaning from mechanical ventilation, pulse oximetry has been shown to decrease the number of arterial blood gas determinations required, with no increase in adverse occurrences for the patient.5-7

There are, however, two important caveats regarding the previous arguments. First, although pulse oximetry has been shown to be superior to clinical judgment in the detection of hypoxic events, "no published investigation has yet demonstrated that pulse oximetry makes a difference in morbidity or mortality."6 With regard to improving the efficiency of critical care services through a reduction in the use of arterial blood gas measurements, there are also con-
cerns. In each of the aforementioned studies, monitoring with pulse oximetry was incorporated into practice guidelines which dictated appropriate use of arterial blood gas samples. In essence, these data do not allow for the separation of the effects on the use of arterial blood gas measurements attributable to pulse oximetry versus those of the algorithms that accompany its use. Since it has been shown that physicians rarely follow practice guidelines once the controls associated with evaluation are lifted,9,10 we conducted the following investigation. Specifically, we hypothesized that the implementation of pulse oximetry in a multidisciplinary critical care unit without guidelines for drawing arterial blood gas samples would not substantially reduce the use of arterial blood gas determinations.

MATERIALS AND METHODS

The protocol for this evaluation was reviewed and approved by the University of Western Ontario Review Board for Health Sciences Research Involving Human Subjects.

Population

Monitoring with pulse oximetry formally began in our unit in December 1989 after all staff had received a comprehensive in-service training on the benefits and limitations of pulse oximetry, as well as on how to troubleshoot common problems. To study the effect of adopting this technology on key resource utilization outcomes, we chose a pre/post natural experiment design. This design had both a prospective and retrospective phase (Table 1). The prospective or "post" phase consisted of 150 consecutive admissions to the critical care unit in each of the months of January, April, and July 1990. Charts from these postoximetry periods were contrasted with 50 consecutive admissions of patients drawn retrospectively from matching months in the preoximetry phase (January, April, and July 1989). Multiple months were chosen to control for the effects, if any, of season. While the choice of 50 observations per period was somewhat arbitrary, it is supported by two statistical considerations: first, reasonably precise estimates are obtainable from this number of observations, as the t distribution and the normal distribution are close to converging at around 50 observations; and secondly, 50 observations per group is sufficient to determine a moderate effect size (a difference of slightly more than one half of a standard deviation) between groups with 80 percent power (a = 0.05, two-tailed).11

Measurements

No procedure or test not already part of the patient's underlying therapy was instituted as a result of this protocol, and all measurements were extracted from the patient's chart by the same critical care research nurse. Information collected on each patient included demographic data (age; sex; diagnosis on admission; discharge status), the severity of illness on admission as measured by the acute physiology and chronic health evaluation II (APACHE II) score,12 the length of stay in the critical care unit (h), the length of intubation (h), and all changes in ventilation. Data on laboratory resource consumption were collected for up to the initial 9 days of each admission to the critical care unit, since this was approximately twice the average length of stay and thus indicative of general consumption of resources in our facility. Primary end points included arterial blood gas analyses, complete blood chemistries, electrolyte levels, arterial lactate levels, and creatinine determinations. The latter four indices were included to determine if the use of arterial blood gas determinations was "linked" to the use of other laboratory resources. These were compiled as 24-h totals, as well as totals for each of two 12-h nursing shifts (day and night).

Statistical Analysis

All statistical procedures were conducted using the statistical package, SPSS/PC + v4.01. At the completion of the study, descriptive statistics were compiled to ensure comparability of patients and the validity of statistical assumptions. Specifically, categorical variables were analyzed using a χ² approach or Fisher's exact test, where appropriate.13 Normally distributed continuous variables were examined using analysis of variance (ANOVA), while nonnormally distributed variables were analyzed using the Wilcoxon rank sum test.14

Laboratory resources were expressed as the number per patient per day of critical care. Specific analyses included examination of 24-h resource consumption, resource consumption by nursing shift, and resource consumption by surgical status (postoperative vs nonsurgical patients). We used two-way ANOVA,15 since it allows for the main effects of group (before vs after oximetry), time (subgroups 1, 2, and 3), and their interaction (group × time) to be assessed. Finally, in order to assess the most significant predictors associated with the use of arterial blood gas determinations, stepwise linear regression was used.16 As over 20 independent tests of significance were conducted, results were judged to be significant only if p<0.025 (two-tailed), in order to decrease the chances of falsely declaring significant differences.

RESULTS

Baseline Comparison

Table 2 contains a summary of population studied. In total, 11 patients (4 percent) were excluded from the analyses for the following reasons: 2 patients from the preoximetry group were excluded, as they had been monitored with a pulse oximeter which had been initiated in the operating room; 9 patients were excluded from the postoximetry group, as it was found that they did not receive a pulse oximeter (4 patients) or that the pulse oximeter which they did receive had

<table>
<thead>
<tr>
<th>Data</th>
<th>Preoximetry (n = 148)</th>
<th>Postoximetry (n = 141)</th>
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<tbody>
<tr>
<td>Male patients, %</td>
<td>89 (60)</td>
<td>83 (59)</td>
</tr>
<tr>
<td>Age, yr</td>
<td>61 ± 15</td>
<td>60 ± 15</td>
</tr>
<tr>
<td>APACHE II score†</td>
<td>24.2 ± 7.5</td>
<td>21.9 ± 7.8</td>
</tr>
<tr>
<td>No. survived, %</td>
<td>122 (82)</td>
<td>130 (92)</td>
</tr>
<tr>
<td>Length of stay in ICU, h</td>
<td>92.8 ± 95.6</td>
<td>93.4 ± 87.8</td>
</tr>
<tr>
<td>Length of time intubated, h</td>
<td>57.1 ± 73.9</td>
<td>63.3 ± 86.7</td>
</tr>
<tr>
<td>Postoperative patients, %</td>
<td>73 (49)</td>
<td>76 (54)</td>
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*Values are means ± SD or number of patients.
†Significant difference between preoximetry and postoximetry groups using ANOVA.

Table 1—Summary of the Study Design

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<thead>
<tr>
<th></th>
<th>Preoximetry</th>
<th>Postoximetry</th>
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<tbody>
<tr>
<td></td>
<td>1989 (n = 150)</td>
<td>1990 (n = 150)</td>
</tr>
<tr>
<td>January</td>
<td>(n = 50)</td>
<td>(n = 50)</td>
</tr>
<tr>
<td>April</td>
<td>(n = 50)</td>
<td>(n = 50)</td>
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<td>July</td>
<td>(n = 50)</td>
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<td>(n = 50)</td>
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been mechanically faulty and therefore had been removed, but not replaced (5 patients). No significant differences between subgroups were detected, and thus data are presented as the mean ± SD, or number, for the preoximetry versus the postoximetry groups. Furthermore, no significant differences were detected between groups, with the exception of the APACHE II scores on admission. As the preoximetry group had higher APACHE II scores than the postoximetry group (p<0.025), in order to reduce any confounding effect on all remaining analyses, APACHE II scores were included as a covariate in all ANOVAs.

**Use of Laboratory Resources**

The use of laboratory resources was examined first by 24-h totals, then by nursing shift, and finally by surgical status. Table 3 illustrates the impact of pulse oximetry on the use of arterial blood gas and electrolyte determinations for the total population, as well as by nursing shift. The postoximetry group demonstrated a significant drop in 24-h arterial blood gas determinations (p<0.025) and serum electrolyte levels (p<0.01); however, when the analysis was stratified by nursing shift, it was the night shift that accounted for the reduction in both arterial blood gas (p<0.01) and electrolyte determinations (p<0.01) in the postoximetry group. Similar findings were noted when the analysis was restricted to the postoperative patients (Table 4). No significant differences were detected in any of the analyses for medical patients, nor for complete blood chemistries, arterial lactate levels, or creatinine determinations (not shown).

Results of the stepwise linear regression analysis appear in Table 5. Significant predictors of the use of arterial blood gas determinations included the number of ventilator orders, the APACHE II score on admission, the number of days intubated, and the number of days where the inspired oxygen concentration (FiO2) was greater than 50 percent.

**DISCUSSION**

A comprehensive assessment of technology includes the determination of efficacy, effectiveness, and efficiency. Previous studies have demonstrated that pulse oximetry, in conjunction with an algorithm for its appropriate use, substantially reduced the use of arterial blood gas determinations. Since these evaluations were conducted under relatively controlled conditions, we contend that they estimate one aspect of the efficacy of pulse oximetry; however, there is no guarantee that efficacious technologies will be effective when used under less controlled circumstances. This notion is supported by both behavioral and utilization review studies of medical practice demonstrating that patterns of practice revert toward prestudy conditions once controls are lifted or guidelines are published.

Our interest was to determine if the beneficial results of the previous studies could be replicated if pulse oximetry were to be introduced with only a strong educational component. Thus, no attempts were made to implement or police explicit guidelines provided a priori to the nursing staff, respiratory technicians, or the medical staff for the appropriate use of arterial blood gas samples once monitoring with pulse oximetry began. A before/after study design was used to address this question. While there are drawbacks to this type of design (eg, differences in APACHE II scores between the two main groups), its use in this evaluation was unavoidable, as recent clinical guidelines support the use of continuous SaO2 monitoring for all patients experiencing respiratory failure. With provisions made for the implementation of pulse oximetry at each bedside, it was therefore deemed unethical to randomly assign patients to not receive...
portion of our arterial blood gas samples. Use was inversely related to the number of days intubated and the number of days on an FIO2 greater than 50 percent, while use was positively related to the number of ventilator orders. This is not surprising, as traditionally each step in the weaning process has been accompanied by an arterial blood gas sample to assess the patient’s oxygenation and ventilatory status. Thus, we argue that although pulse oximetry has been shown to be an efficacious weaning tool, its use under the circumstances of this study was primarily in addition to rather than instead of arterial blood gas samples. Again, there is evidence that without explicit indications for its use, any technology is prone to be used in this manner.21

A finding not expected was the reduction in electrolyte determinations, which paralleled those of arterial blood gas samples. Fewer determinations were made in the postoximetry group, on the night shift, and in the surgical patient. It is possible that the implementation of pulse oximetry indirectly influenced these findings. This would be possible if electrolyte determinations are also forgone when an arterial blood gas sample is avoided.

In summary, we found that the implementation of pulse oximetry in a multidisciplinary critical care unit accompanied only by a strong educational component resulted in marginal reductions in arterial blood gas samples. Without explicit guidelines, there is the possibility that the use of pulse oximetry will be in addition to, rather than instead of, some arterial blood gas determinations. Thus, if pulse oximetry is to be universally implemented in the critical care setting, attention must be given to the establishment of formally constructed indications for arterial blood gas analysis which incorporate the most appropriate use of pulse oximetry. Finally, as there are as yet no formally conducted economic evaluations of pulse oximetry, this too must receive the required degree of attention so that critical care practitioners can make a more informed decision regarding the implementation of this technology.

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