Operational Realities in the Postanesthesia Care Unit: Staffing and Monitoring for Safe Postoperative Care

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The postanesthesia care unit (PACU) is a pivotal and busy component of the modern surgical care system. The PACU has multiple missions, not only caring for patients with a myriad of primary disease states with variable acuity but also addressing multiple comorbidities. Specifically, these PACU missions may include caring for: patients recovering from anesthesia who originate from an adjacent operating room suite; patients anesthetized in remote locations for interventional radiology, cardiology, and gastroenterology procedures; and those needing extended postoperative care for whom intermediate care beds are not available.1–3 Therefore, it is not surprising that the PACU is frequently the bottleneck of the surgical care system.4 Moreover, it is unrivaled by any other inpatient unit when examined from the viewpoint of patient throughput and diversity of pathologies. Therefore, the dearth of research performed on the clinical and operational aspects of this ubiquitous and essential unit is surprising. This contrasts with the many detailed studies that have enhanced our understanding of the activities in the operating room and intensive care unit. The lack of ready understanding of the PACU has rendered it the “black box” of the surgical care system.

The introduction into the PACU of computerized patient data management systems capable of automatically capturing physiological variables (a natural evolution of anesthesia information management systems) promises to provide a wealth of new information.4,5 Epstein and colleagues6 nicely demonstrated the usefulness of computerized PACU systems by using data from such a system to analyze the temporal distribution of hypoxemic episodes. Moreover, this study portends similar studies analyzing large data sets, which should help elucidate the mysteries of the PACU. However, it is important to recognize that the function of retrospective mining of large databases is to provide direction and hypothesis generation for more focused prospective studies that can lead to improvements in patient care,7 rather than drawing direct conclusions of the usefulness of a proposed (hypothetical) change. Among the limitations of database mining is its ability to detect only associations and not causality.8

Epstein and colleagues reported that hypoxemic episodes, which are often used as a proxy for respiratory compromise, are a high-frequency event in the PACU and commonly occur in the absence of advanced respiratory care providers. Furthermore, despite the efforts of available nursing staff, timely resolution of desaturation events outside of the operating room is challenging and protracted, potentially placing patients at increased risk. However, one must put these findings in perspective because the reliability of pulse oximetry as an indicator of respiratory compromise has often been questioned, with varying rates of false-negative and false-positive results reported.9–12 Most notably, it has been difficult to establish a generally accepted “low saturation” cutoff, or the temporal duration over which a desaturation event becomes “dangerous,”10 especially because the various concentrations of supplemental oxygen administered in the PACU often make it hard to interpret oxygenation data.12 Therefore, studies are needed that track long-term patient outcomes and examine how these outcomes correlate with the length and severity of desaturation events so that insightful conclusions can be drawn regarding the potential impacts of particular desaturation events.

Even if we accept that low oxygen saturation for extended periods of time is detrimental to patient health (speaking in general terms and without specific cutoff values in mind), it is better to identify impending respiratory compromise before desaturation sets in, rather than trying to resolve it after it has occurred. Basic physiology teaches us that hypoxic episodes are a late response to hypoventilation:13 a decrease in ventilation is followed by an increase in arterial CO₂ (Paco₂) and finally a decrease in SpO₂, which is delayed further in the presence of supplemental oxygen. Over the years, there have been numerous attempts at monitoring end-tidal CO₂ as a proxy for Paco₂ with limited success.14–17 An earlier indicator of respiratory compromise than pulse oximetry, end-tidal CO₂ has proven difficult to measure in spontaneously breathing nonintubated patients, and as a result, has not come into general use in the PACU.18,19

A potential physiologic solution for assessing respiratory status is to directly monitor ventilation. Real-time ventilation monitoring has been a fundamental part of anesthesia care since the early 20th century, but only for intubated patients. Recently, continuous noninvasive respiratory volume

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monitoring that provides measurements of minute ventilation, tidal volume, and respiratory rate in nonintubated patients has become available. These measurements should provide a more timely identification of respiratory compromise and also provide staff with a real-time indicator of the effects of opioid dosing, airway maneuvers, continuous positive airway pressure/bilevel positive airway pressure, or other therapeutic interventions. Early identification of respiratory compromise using real-time respiratory volume monitoring has the potential to provide a longer window for skilled anesthesia providers to arrive, evaluate, and treat PACU patients, thus improving patient safety. Moreover, real-time respiratory volume monitoring data may help clinicians develop individualized opioid treatment regimens, identify patients at risk in the PACU, and take necessary precautions to prevent desaturation events, rather than reacting to their occurrence. Identifying at-risk patients and individualizing treatment plans might reduce the incidence of respiratory compromise in the PACU and allow for better patient management using currently available resources rather than drawing additional resources to resolve respiratory compromise after it has occurred.

The purpose and operational realities of the PACU are institution specific. Some may take the path of additional monitoring, and others may identify the need for additional clinical staff. Regardless, future studies utilizing information from large computerized databases are needed. Ideally, they should be multi-institutional, with population sizes from each institution large enough to allow for interinstitutional comparisons. The paper by Epstein et al. includes an initial effort at interinstitutional studies by including data from a second institution that confirm the major findings of the paper. Moreover, to facilitate data analysis, it is preferable to avoid using free-text and instead use “structured responses.” For example, in the study by Epstein et al., the investigators analyzed free-text, an arduous task that does not always provide the needed information. Because hypoxemic episodes are not uncommon, and in some cases, resolving them may require narcotic reversal or reintubation, it would have been advantageous to have imbedded screens containing objective questions into the computerized system to gather data on these occurrences. Such data are also important for quality improvement purposes. The study by Epstein et al. not only provides valuable clinical and administrative information about the PACU, it also demonstrates the advantages and limitations of mining large databases. Such studies will be useful to validate both new technologies and alternative staffing models in the future. As PACU information systems become more prevalent, they should provide further insights into the clinical and other aspects of PACU care.

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Anesthesiologist Staffing Considerations Consequent to the Temporal Distribution of Hypoxemic Episodes in the Postanesthesia Care Unit

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BACKGROUND: Hypoxemia, as measured by pulse oximetry (SpO2), is common in postanesthesia care unit (PACU) patients. The temporal distribution of desaturation has managerial implications because treatment may necessitate the presence of an anesthesiologist.

METHODS: We retrieved SpO2 values recorded electronically every 30 to 60 seconds from 137,757 PACU patients over n = 80 four-week periods at an academic medical center. Batch mean methods of analysis were used. Onset times of hypoxic episodes (defined, on the basis of previous studies, as SpO2 <90% lasting at least 2 minutes) were determined and resolution at 3, 5, and 10 minutes was assessed. Episodes beginning <30 minutes and ≥30 minutes after PACU admission were compared. Patients undergoing intubation in the PACU were identified by doing a free text search of electronically recorded nursing notes for phrases suggesting intubation, followed by a confirmatory manual chart review. Intervals from PACU admission to intubation were determined.

RESULTS: Fewer than half (31.2% ± 0.05%) of episodes of PACU hypoxemia lasting ≥2 minutes occurred <30 minutes after PACU admission. Most (i.e., >50%) occurred ≥30 minutes after admission (P < 0.0001). Few (<1%) anesthesia providers transporting patients to the PACU were still present in the PACU 30 minutes after arrival in the PACU. Fewer than half (37%; 95% confidence interval, 27.4% to 48.8%) of PACU intubations occurred <30 minutes after PACU admission. Most (i.e., >50%) occurred ≥30 minutes after admission (P = 0.029). Hypoxic episodes in the PACU resolved more slowly than episodes in operating rooms (P < 0.0001). After 3 minutes, 40.9% ± 0.6% were unresolved in the PACU versus 23% (99% upper confidence limit) in operating rooms, and 32.6% ± 0.5% vs 9% (99% upper confidence limit) after 5 minutes.

CONCLUSIONS: Because most (68.8%) hypoxic episodes in the PACU occur ≥30 minutes after admission, a time by which the anesthesia provider who transported the patient usually would no longer be present (>99% of cases), the PACU needs to be considered when anesthesiologist operating room staffing and assignment decisions are made.

A dverse respiratory events in the postanesthesia care unit (PACU) occur commonly, with at least 1 episode of hypoxemia measured via pulse oximetry (SpO2) reported in 35% to 55% of adult patients (Table 1).1–4 These observational reports of PACU hypoxemia1–4 date back to the late 1980s and early 1990s, a time when anesthesia practice and PACU care were quite different than they are today. PACU intubation rates of 0.09% to 0.19% have been reported.5–7 In previous studies of hypoxemia during the entire PACU admission, researchers measured incidence rates per patient, not the temporal distribution of their occurrence.5–7 The time course of when hypoxemia occurs is important for understanding issues related to PACU coverage by anesthesiologists.8–11 Therefore, we undertook this study to determine the potential influence of hypoxemia in the PACU on anesthesiologist coverage of this location. Our goal was (explicitly) not to study root causes of hypoxemia, but rather to understand the timing of such events during the PACU admission.

Understanding when hypoxemia and tracheal intubation occur in relation to the time of PACU arrival and their incidences has managerial (i.e., staffing and assignment) implications because the physical presence of an anesthesiologist may be required for treatment. This situation is in contrast to phone calls from the PACU regarding medical issues that usually can be managed remotely, such as hypertension, hypotension, or bradycardia. For example, if most (i.e., >50%) hypoxic episodes occur shortly after the patient’s arrival in the PACU, when the anesthesia provider and/or anesthesiologist who transported the patient is still present, it might not be necessary to plan additional PACU coverage by anesthesiologists. Conversely, if hypoxic episodes mostly occur after the transfer of care to the postoperative nurse has taken place, then an anesthesiologist needs to be available at all times to come urgently to the PACU if needed.

We selected a threshold of 50% because if an event occurs most of the time, managerially, one should plan for it.
would be very reasonable to propose that a smaller percentage than 50% of hypoxic episodes might be appropriate to ensure coverage for safety reasons, and we do not suggest that 50% is the appropriate cutoff. Testing for >50%, however, implies testing for lower cutoffs because if >50% of hypoxic episodes occur after the transfer of care, it follows mathematically that any threshold <50% (e.g., 1%, 5%, or 10%) will occur after the transfer of care.

We reported recently that intervals during which the anesthesiologist needs to be present (i.e., for regulatory or compliance reasons, or because of physiologic perturbations) commonly occur simultaneously in multiple operating rooms (ORs). These previous results were limited to events occurring in ORs. The results are caused by multiple cases commencing at the beginning of the day and amplified if there are some very brief cases that end while other cases are still being started. Therefore, we subsequently studied the PACU and found that communications from the PACU to anesthesiologists represented 18% of the calls received by supervising anesthesiologists. (Throughout this article we use the term “supervising” as related to overseeing the care provided by other anesthesia providers, not as a US billing term.) Consequently, the workload related to patient care in the PACU also should be considered.

Although attention has been refocused during the last 6 years on the issue of hypoxemia (Spo2 <90%) and other critical respiratory events in the PACU in the context of clinically unrecognized residual neuromuscular blockade, these studies are not sufficient to understand anesthesiologists’ coverage of the PACU because observations were limited to the first 15 or 30 minutes after patient arrival in the unit. We thus studied hypoxemia in adults throughout their PACU stays by using electronically recorded vital signs at a large medical center with many years of data. We studied individual hypoxic episodes because anesthesiologist workload in the PACU associated with the treatment of hypoxemia is related to individual hypoxic episodes, not simply to the fraction of patients experiencing hypoxemia. For example, consider the following scenario. One patient has 5 separate hypoxic episodes during the course of his or her PACU stay, 3 of which require an intervention by the anesthesiologist. Another patient has 1 hypoxic episode requiring such intervention. From the perspective of the percentage of patients experiencing hypoxemia during their PACU admission, the 2 patients are equivalent, contributing 1 to the numerator. The workload created for the anesthesiologist, however, is 3 times greater for the first patient than for the second patient.

Our first hypothesis was that most hypoxic episodes (i.e., >50% of such episodes), defined as Spo2 <90% lasting at least 2 consecutive minutes, occur <30 minutes after patient admission to the PACU. This hypothesis effectively tested whether previous studies of residual neuromuscular blockade in the PACU that focused on the first 15 and 30 minutes captured ≤50% of the hypoxic episodes experienced by patients while they were in the PACU. We selected 30 minutes, however, as the cut-off point because this was the median turnover time (i.e., from OR exit to OR entrance) from our study of 31 hospitals. To bring the next patient into the OR at 30 minutes, the provider would have left the PACU earlier than 30 minutes after arrival in the PACU. Because our PACU interval excluded the transport time from the OR to the PACU, and that interval is included in the turnover time, our selection of 30 minutes is therefore conservative. A shorter interval would increase the fraction of hypoxic episodes after departure from the PACU of the anesthesia provider who transported the patients to the PACU.

Our second hypothesis was that hypoxic episodes in the PACU would take longer to resolve than corresponding episodes in the OR we reported previously. We made this hypothesis because most patients admitted to the PACU have a natural airway and do not have an anesthesia provider available within seconds, in contrast to the situation in ORs.

Our third hypothesis was that most PACU intubations in patients arriving with a natural airway would also take place <30 minutes after patient admission. We made this hypothesis because, under such circumstances, the transporting anesthesia provider would often still be present and the patient’s anesthesiologist available (e.g., not inducing the next patient in the OR just vacated).

If hypotheses 1 and 3 were rejected and hypothesis 2 was confirmed, then the PACU would need to be considered when determining appropriate total anesthesiologist workload in the PACU. The following sections will report the results of our analysis.

### Table 1: Details of Previous Studies of Hypoxemia in the PACU

<table>
<thead>
<tr>
<th>Spo2 hypoxemia criteria</th>
<th>Frequency of data recording</th>
<th>Monitoring duration</th>
<th># of patients studied</th>
<th>% of patients with hypoxemia</th>
<th>Reference</th>
<th>Year of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;89%</td>
<td>q 15 s</td>
<td>Entire stay</td>
<td>157</td>
<td>35%</td>
<td>1</td>
<td>1989</td>
</tr>
<tr>
<td>≤90%</td>
<td>Unstated, but at least q 20 s</td>
<td>Entire stay</td>
<td>200</td>
<td>55%</td>
<td>2</td>
<td>1990</td>
</tr>
<tr>
<td>≤90%</td>
<td>q 1 min</td>
<td>Entire stay</td>
<td>173</td>
<td>43%</td>
<td>3</td>
<td>1991</td>
</tr>
<tr>
<td>≤92% for ≥30 s</td>
<td>Unstated, but at least q 30 s</td>
<td>Entire stay</td>
<td>100</td>
<td>15% on arrival in PACU</td>
<td>4</td>
<td>1993</td>
</tr>
<tr>
<td>≤92% for ≥30 s</td>
<td>Etude stay</td>
<td>Entire stay</td>
<td>100</td>
<td>25% overall after arrival in the PACU</td>
<td>4</td>
<td>1993</td>
</tr>
</tbody>
</table>

PACU = postanesthesia care unit; Spo2 = oxygen saturation.

*Mean duration was 77 ± 48 min, range 8360 min.

Median stay was 130 min, range 35360 min.

Patient were monitored starting 5 min after arrival while receiving supplemental oxygen for at least 30 min, then were monitored for at least 45 min after oxygen was discontinued (truncated if oxygen therapy was resumed).

Data recording began within 30 s of PACU admission. Duration of stay was not stated (“…based on each patient’s clinical condition…”), but the latest initial desaturation event was noted as occurring 170 min after arrival.

Patients hypoxic on arrival were treated with oxygen and all recovered to Spo2 ≥97%.
staffing by time of day for a facility, incorporating the ability to respond to critical events in a timely fashion.

METHODS

Data Collection
The study was approved by the Vanderbilt University IRB (Nashville, TN) without requirement for written patient consent. The 3 hypotheses, definitions of hypoxemic episodes, and the statistical plan for hypotheses 1 and 2 were formulated before data analysis, informed by our previous analysis of intraoperative hypoxemia. The statistical method needed to analyze the data for hypothesis 3 was a consequence of the low frequency of intubation in the PACU, not known until after the initial data analysis. A formal power analysis was not performed because there was no incremental cost for analyzing all available data versus a subset.

We retrieved from the institution’s perioperative data warehouse (SQL Server, Microsoft, Redmond, WA) the time of PACU admission, the time the anesthesia provider completed the transfer of care to the PACU nurse (i.e., the anesthesia end time), and subsequent Spo2 values with timestamps. The Spo2 measurements were recorded at either 30-second or 60-second intervals, depending on how each patient monitor was configured. For purposes of a sensitivity analysis related to the applicability of our findings to different practice environments (see Results, hypothesis 2), we also determined whether the patient received a nondepolarizing muscle blocker (NDMB) in the OR or an opioid in either the OR or the PACU. Because the objective of the paper was to determine the staffing implications of PACU hypoxemia, not to attempt to predict which patients would experience a hypoxemic episode, we did not explore patient factors (e.g., obstructive sleep apnea) or other details of anesthesia care (e.g., use of regional versus general anesthesia) that might contribute to hypoxemia.

Oximetry values were determined by IntelliVue® MP50/70/90 series monitors (Royal Philips Electronics, Amsterdam, The Netherlands) via the use of adhesive, disposable Nellcor® sensors (Covidien, Mansfield, MA). Patients were nonambulatory while in the PACU. The oximetry values are averaged over a minimum of 10 seconds for the monitor display, and the last recorded value is transmitted to the anesthesia information management system either every 30 or 60 seconds (depending on how the monitor was configured). Invalid measurements (e.g., lack of an analyzable waveform) are not transmitted from the monitor to the database; rather, they result in a gap in measurement (see the next section for how this was handled). The alarm limit in the PACU was set at 90%.

All 137,757 patients at the main campus of Vanderbilt University Medical Center (VUMC) who were admitted to the 2 adult PACUs between Monday, January 1, 2007, and Sunday, February 17, 2013, were included. The main PACU and secondary PACU are in close proximity to each other, and patients from the 2 OR suites can be sent to either location to recover from anesthesia. VUMC also has a freestanding ambulatory surgical center, located remotely from the main campus, which was not studied. The study population included patients undergoing neuraxial anesthesia, regional anesthesia, or sedation in the ORs, not just those receiving general anesthesia. The date range studied was the most recent continuous interval of PACU data that was available at the time of data extraction, and conveniently comprised n = 80 four-week intervals (see Statistical Methods).

For assessment of the incidence of tracheal intubation in the PACU, data from October 3, 2008, through April 14, 2013, were selected, comprising 111,456 patients. The start date was the first date with the availability of electronic recording of PACU nursing notes, necessary for automated detection of patients who possibly were intubated in the PACU. The end date was when these data were extracted.

To confirm that the time anesthesia providers spent in the PACU before completing the transfer of care was not distinctive to VUMC, equivalent data from all 43,614 main hospital PACU admissions between January 2011 and December 2013 were retrieved from the anesthesia information management system at Thomas Jefferson University Hospital (Innovian™; Dräger, Telford, PA).

Definition of a Hypoxemic Episode
A hypoxemic episode was defined as a series of continuous Spo2 values <90% lasting for at least 2 minutes, identified through the application of our previously described algorithm. Specifically, when data were recorded every 30 seconds, 4 consecutive values with the Spo2 <90% defined a hypoxemic episode. When data were recorded every 60 seconds, 2 such consecutive values were required. Skips in timestamps for 2 sequentially recorded Spo2 values <90% were handled by assuming that (unrecorded) intermediary values also were <90%. For example, if the Spo2 were 88% at 9:00:00 AM, not recorded to the database at 9:01:00 AM, and 86% at 9:02:00 AM, we interpolated the value at 9:01:00 AM as <90%. If Spo2 values were missing between 2 values of <90% and ≥90%, or between 2 values of ≥90%, the missing values were considered to be ≥90%. This process was biased against hypothesis 2 (i.e., hypoxemia resolves less quickly in the PACU than in the OR) being satisfied.

The onset time of each unique hypoxemic episode was identified. For an episode to be counted as unique (as opposed to the continuation of an ongoing episode), there had to be at least 3 previous minutes with all Spo2 ≥90% or the episode had to have started within 3 minutes of the first recorded Spo2 in the PACU. An annotated example of a patient demonstrating several hypoxemic episodes and transient desaturation episodes is shown in Figure 1.

We did not analyze 1-minute episodes because of the transient nature of such events, their questionable clinical relevance, and concern that many might be measurement artifacts (e.g., as the result of patient movement). From the perspective of our staffing analysis, this was a conservative approach, because the inclusion of such episodes would have increased the PACU workload related to management of hypoxemia.

Anesthesiologists were considered to be the physicians supervising the anesthetic care of 1 to 4 patients, whereas anesthesia providers were those providing direct patient care (i.e., residents, Certified Registered Nurse Anesthetists, or Student Registered Nurse Anesthetists).
PACU Hypoxemia and Staffing Considerations

**Figure 1.** Examples of hypoxic episodes and transient desaturations. For this case, SpO2 values (open blue circles) were recorded in the database at 1-min intervals. The start of a hypoxic episode (filled red circles) is defined as episodes of continuous arterial desaturation (red lines) measured by pulse oximetry, of <90% lasting at least 2 min. Transient episodes of desaturation <90% are marked with filled purple circles. The oxygen saturation (SpO2) values at † represent a severe hypoxic episode starting 2 min after arrival to the postanesthesia care unit (PACU) that resulted in intubation. The episode was resolved by 8 min, so it would have been marked as unresolved 5 min after its start and resolved at 10 min. The SpO2 values ‡ and ‡ were considered to be transient desaturation episodes (i.e., lasting 1 min) and were not counted as hypoxic episodes for the purpose of the study, although episode ‡ does not appear to be an artifact. Our criteria thus potentially underestimate the overall incidence of hypoxemia in the PACU. Episode ‡ was counted as a single hypoxic event, even though the SpO2 transiently increased to 90% (third to last data point in the series), because the duration above the threshold was <180 s.

**Temporal Distribution of Hypoxic Episodes (Hypothesis 1)**

The total numbers of episodes of hypoxemia during each minute after PACU admission were determined. The cumulative percentages of all such episodes occurring up to the first 180 minutes of the PACU stay were calculated and used to test whether most hypoxic episodes occurred <30 minutes after admission to the PACU (see Statistical Methods).

The interval in minutes from admission to the PACU to the onset of each hypoxic episode was categorized as having begun <30 or ≥30 minutes after arrival to the unit. The 30-minute cut point not only matches previous studies but also is the median turnover time reported from 31 hospitals (i.e., when the anesthesia provider would be bringing the next patient into the OR and thus could not still be present in the PACU). The previous studies of NDMB influence on hypoxemia limited evaluation to 15 or 30 minutes.

**Resolution of Hypoxic Episodes (Hypothesis 2)**

The continued presence of hypoxemia for each hypoxic episode was determined according to whether the SpO2 remained <90% at 3, 5, and 10 minutes after its onset, based on the recorded timestamps. If a recorded value was not present at the timestamp corresponding to these intervals, the next available timestamp was used, and the episode considered not resolved until a value ≥90% was found. For example, if a hypoxic episode started at 10:00:00 AM and lasted until 10:06:00 AM, but no SpO2 values from 10:05:00 AM to 10:05:59 AM were recorded to the database (e.g., the waveform was unreliable, so the monitor did not transmit the value), the episode was considered unresolved at 5 minutes. The duration of this hypoxic episode was thus considered to have lasted from 10:00:00 AM until 10:05:59 AM.

Hypoxic episodes within patients are correlated. Therefore, a sensitivity analysis was performed by selecting a single random episode of hypoxemia from each patient. The analysis of the time course of resolution of hypoxemia was repeated using the specified intervals.

On the basis of the previous studies cited in the Introduction (Table 1), † the incidence rates of hypoxemia may differ among hospitals. We therefore performed a sensitivity analysis to determine potential limitations of our findings due to differences in the types of anesthetic drugs used. The calculations were repeated with patients stratified according to the following 4 groups: (1) received an NDMB in the OR and received an opioid in the OR or PACU; (2) received an NDMB but no opioid; (3) did not receive an NDMB but received an opioid; and (4) received neither an NDMB nor an opioid. Importantly, this sensitivity analysis for anesthesiologist staffing to manage hypoxemia analyzed PACU events, not patients, and thus cannot be used to infer the cause of hypoxemia.

**Evaluation of the Timing of PACU Intubation (Hypothesis 3)**

Electronic nursing notes, entered as free text, were parsed using Transact-SQL (Microsoft) to identify patients who possibly had been intubated in the PACU. We searched for the presence of any of the following case-insensitive character strings: ‘%intubat%’; ‘%cpr%’; ‘%arrest%’; ‘%code%’; and ‘%RRT%’. The symbol % represents a variable length string comprising any characters (e.g., ‘Pt received intubated and placed on the vent’ would have been captured since it includes the string ‘intubat’). The medical records containing identified comments were reviewed manually to identify patients who had a tracheal tube inserted during their stay in the PACU. The complete electronic perioperative records of such patients were reviewed to determine the time of intubation in the PACU, to ascertain whether the patient arrived at the PACU already intubated or with a natural airway, and to identify documented reasons for intubation.

For the temporal distribution of intubations in the PACU, we only considered patients arriving in the PACU with a natural airway, not those arriving with a tracheal tube in situ and subsequently failing extubation while still in the PACU. The rationale for this was that at the studied hospital, if a patient were taken to the PACU still intubated, this was because of medical reasons (e.g., the patient was cold, was still partially paralyzed, and was narcotized). The extubation event would be deferred until an anesthesiologist or anesthesia resident was available to evaluate that the patient met extubation criteria. Thus, for these patients, there would not be a managerial decision, because extubation would not take place until an anesthesiologist or anesthesia resident was available to direct attention to the patient.

Similar to the choice of a cut point of 30 minutes as described in hypothesis 1 (described previously), we also characterized intubations as having occurred <30 or ≥30 minutes after PACU arrival.
Statistical Methods

Hypothesis 1 was that most (i.e., >50%) hypoxic episodes occur <30 minutes from the time of patient admission to the PACU. This hypothesis is managerially important because, if rejected (i.e., ≤50% of such episodes occur >30 minutes after PACU arrival), it would mean that PACU coverage by anesthesiologists would need to be ensured beyond the time when most transporting anesthesia providers have left the PACU (see Results). We tested “most” (i.e., 50%) because, managerially, if one knows that something is going to happen most of the time, then one needs to plan for its occurrence (see Introduction).

The fraction of hypoxic episodes occurring within 30 minutes of PACU admission was calculated separately for each of the n = 80 four-week periods. Following the time series method of batch means, the mean of these 80 fractions was compared conservatively with >0.50 (i.e., “most”) by us of the Student 1-group, 2-sided t test. As a sensitivity analysis evaluates how much less.

To test hypothesis 2 (i.e., hypoxic episode from each patient and then calculated the point estimates for resolution of hypoxemia during each of the 80 four-week bins for resolution of hypoxemia at various times from outset. In effect, this is a sensitivity analysis for each of the 80 proportions. Because only one episode is selected, and the probability of an episode during a period is greater for a patient with 1 preceding episode than a patient with 0 preceding episodes, selecting a single episode will result in fewer incidences of unresolved hypoxemia. The sensitivity analysis evaluates how much less.

To test hypothesis 3 (i.e., the timing of intubation with respect to PACU arrival), we compared the occurrence rate of intubation <30 minutes to the occurrence rate of intubation ≥30 minutes using the exact binomial test. Unlike the preceding hypoxemia data (where individual patients could experience multiple episodes of desaturation), there was only 0 or 1 PACU intubation event per patient, and PACU intubation events were rare (i.e., many days typically elapsed between occurrences). Confidence intervals for the binomial proportions were calculated using the method of Blyth-Still-Casella (StatXact-10, Cytel Software Corporation, Cambridge, MA).

RESULTS

Hypothesis 1: Temporal Distribution of Hypoxic Episodes

Among all unique hypoxic episodes in the PACU, 66.9% ± 0.5% were single occurrences in a patient (n = 24,146 unique hypoxic episodes). Among all PACU patients, 11.3% ± 0.02% experienced at least 1 hypoxic episode in the PACU (n = 137,757 PACU patients). There was a mean of 0.62 ± 0.001 hypoxic episodes per PACU patient.

There were few hypoxic episodes in the PACU at the start of the day, the period when there are the most simultaneously occurring critical portions of OR cases (Fig. 2). The hourly incidence of hypoxic episodes was closely correlated to the PACU census (Fig. 3).
More than 50% of the 24,146 hypoxemic episodes occurred >30 minutes after arrival (69.8% ± 0.05%, Fig. 4). Hypothesis 1 was rejected ($P < 0.0001$).

We repeated the analysis by using $\text{SpO}_2$ thresholds of <85% and <80% to define hypoxemic episodes to evaluate the timing of more serious desaturation. There were 3803 hypoxemic episodes when the $\text{SpO}_2$ hypoxemia threshold was <85%, with 45.1% ± 1.2% occurring <30 minutes after PACU arrival ($P = 0.0001$ to reject hypothesis 1). There were 1414 hypoxemic episodes when the $\text{SpO}_2$ hypoxemia threshold was <80%, with 52.9% ± 1.5% occurring at <30 minutes after PACU arrival ($P = 0.03$ to accept hypothesis #1).

Quantile-Quantile plots for the $n = 80$ proportions of desaturation occurring <30 minutes after PACU arrival were normally distributed for the thresholds tested.

We confirmed that our decision to use 30 minutes after PACU admission as the cut point for inferring presence of the transporting anesthesia provider and availability of the supervising anesthesiologist was appropriate because >99% of transporting providers had left the PACU by 30 minutes after entering the unit with their patients (Fig. 5, A and B).

**Hypothesis 2: Resolution of PACU Hypoxemic Episodes and Comparison with Resolution of OR Hypoxemic Episodes**

When all hypoxemic episodes were considered, hypoxemia remained unresolved at 3, 5, and 10 minutes after onset in 40.9% ± 0.6%, 32.6% ± 0.5%, and 26.3% ± 0.4% of episodes, respectively (Fig. 6A). The durations of continued hypoxemia were similar whether the episodes began <30 or ≥30 minutes after admission to the PACU (Fig. 6A, Table 2). More PACU hypoxemic episodes remained unresolved at 3 and 5 minutes after our previously reported

Figure 3. Correlation between hypoxemic episodes and postanesthesia care unit (PACU) census. The mean number of hypoxemic episodes is plotted versus the mean number of patients, binned by hour of the day. Error bars represent the standard errors from the batch means of the $n = 80$ four-week intervals. The Pearson $r$ was calculated for each 4-week period, the Fisher transformation was taken, the mean ± SE of the $n = 80$ transformed correlations were calculated, and then the inverse Fisher transformation calculated. The displayed regression fit is with a forced intercept of 0, because a census of 0 patients would result in 0 hypoxemic events. The $P$ value for the correlation is <0.0001. The slope of 1.3 for the relationship between the PACU census and the number of hypoxemic episodes is not inconsistent with the average of 0.62 hypoxic episodes per patient in the Results. Consider the following simple example with the census at 4 AM and 4 PM on 1 day. At 4 AM, there are 5 patients and 1 hypoxic episode, and at 4 PM there are 25 patients and 17 hypoxic episodes. The simple average of episodes/patient admitted is $(1 + 17)/(5 + 25) = 18/30 = 0.6$. However, the slope of the line between the two means is $(17−1)/(25−5) = 16/20 = 0.8$. If there had been 0 episodes at 4 AM and 18 at 4 PM, then the simple average remains at 0.6, but the slope now becomes $(18−0)/(25−5) = 18/20 = 0.9$.

Figure 4. Occurrence of hypoxemic episodes during each minute since arrival in the postanesthesia care unit (PACU). The cumulative percentage of hypoxemic episodes ($\text{SpO}_2 < 90\%$ for at least 2 min) as a function of their onset time after admission to the PACU is shown by the dark green line. The percentage in each 1-min bin of all episodes occurring within 0 and 180 min of PACU admission is shown by the blue circles. The $x$-axis was truncated at 180 min for convenience of the display. This was a conservative choice, as had we extended the interval, this would have resulted in an increased number of hypoxemic episodes occurring later than 30 min. The displayed curve (blue line) was fit to the data using the R procedure `loess` with span = 0.1 and degree = 1 (The R Foundation for Statistical Computing, Vienna, Austria). The shaded area represents the approximate 99% confidence interval for the fit (Mills, B. Sab-R-metrics: Basics of LOESS Regression. http://princeof-slides.blogspot.com/2011/05/sab-r-metrics-basics-of-loess.html. Accessed September 15, 2013). The figure shows that although the peak occurrence of hypoxemic episodes occurs shortly after arrival, most (69.8% ± 0.05%) hypoxic episodes occur after the patient has been in the PACU for at least 30 min ($P < 0.0001$ compared with <0.50), a time by which the anesthesia provider transferring care to the PACU nurse would rarely still be present in the PACU. The secondary peak in occurrence also occurs later than 30 min.
Hypothesis 1: Transporting Anesthesia Providers

The percentage of transporting anesthesia providers still present at different times in the PACU is shown in Figure 5. Panel A shows the data for 120,524 cases in the analyzed dataset from the main campus of Vanderbilt University Medical Center (VUMC), where both timestamps were available. At 30 min after exit from the OR, 98.4% (361/366,816) of providers were still present in the OR (95% confidence interval, 98.0% to 98.7%), while 98.2% (480/486,924) of providers were still present in the PACU (95% confidence interval, 97.8% to 98.6%). The difference in the percentage of providers still present between the OR and the PACU was significant (P < 0.0001).

In panel B, the incidence of unresolved PACU hypoxemic episodes at 5 minutes was 0.25% (286/111,456) (99% binomial confidence limit, 0.19% to 0.31%) of cases. The data from VUMC demonstrate that our use of a cut point of 30 min to infer presence of the PACU nurse was completed. The median and mode duration of provider presence in the PACU was 5 min at both hospitals. The similar distribution of times at TJUH demonstrates that the behavior of the transporting anesthesia providers at VUMC is not unique to that hospital, but likely representative of the situation in the PACUs serving the main ORs at other academic medical centers.

Hypothesis 2: Hypoxemia Duration

The incidence of hypoxemic episodes after the transfer of care to the PACU was 2.87% (1342/46,482) (95% confidence interval, 2.8% to 2.9%) of cases. The data from VUMC demonstrate that the behavior of the transporting anesthesia providers at VUMC was conservative, as a shorter interval would have resulted in an increase in the prevalence of hypoxemic episodes after the transfer of care to the PACU nurse was completed. The median and mode duration of provider presence in the PACU was 5 min at both hospitals. The similar distribution of times at TJUH demonstrates that the behavior of the transporting anesthesia providers at VUMC is not unique to that hospital, but likely representative of the situation in the PACUs serving the main ORs at other academic medical centers.

Hypothesis 3: Temporal Distribution of Tracheal Intubation in the PACU

The incidence of tracheal intubation occurring while the patient was in the PACU among all PACU patients was 0.10% ± 0.01% (n = 111/111,456), not different from previous reports of 0.1% to 0.2% (Table 4). Reasons for intubation, as noted in the patient’s medical record, are listed in Table 4. Contrary to our hypothesis 3, among the 85 patients admitted to the PACU with a natural airway who were subsequently intubated, most intubations occurred ≥30 minutes after the patients arrived into the PACU (n = 53/85, 63%; 95% confidence interval, 51.2% to 72.6%; P = 0.029).

DISCUSSION

In this study, we demonstrate that most hypoxemic episodes (70%) and most PACU intubations (63%) occur ≥30 minutes after patients arrive in the PACU. We previously determined in a study of 31 hospitals that the median turnover time between cases was 30 minutes. Because it takes time for the anesthesia provider and/or anesthesiologist to see the next patient, verify paperwork, and transport the patient to the OR, it would be unusual for the provider who transported the previous patient still to be present in the PACU 30 minutes after arrival, and thus immediately available to manage these delayed occurrences. Thus, 30
minutes is a conservative interval, because typically the provider would have left before this time (Fig. 5, A and B). An implication of the high incidence of prolonged, unresolved hypoxemic episodes in the PACU at ≥ 30 minutes is that anesthesiologists need to consider potential requirements for their physical presence in the PACU when OR staffing and assignment decisions are made. The observation that the frequency of hypoxemic episodes in the PACU is directly related to the PACU census (Fig. 3) provides some guidance.

It is unclear whether PACU coverage by anesthesiologists would need to be planned if there were >1%, >5%, or >10% of hypoxemic episodes ≥ 30 minutes after PACU admission (see Introduction). Our finding that most (>50%) episodes of hypoxemia occurred ≥ 30 minutes after patients arrived in the PACU, it is a mathematical consequence that any percentage that is lower than 50% also will occur ≥ 30 minutes after PACU arrival.

Our previous analysis of simultaneous critical ports of cases in ORs did not address the PACU directly, although we subsequently found a considerable number of pages originating from the PACU. Although many of these calls can likely be handled remotely (e.g., a brief phone call regarding the dose of insulin for an elevated blood glucose), intervention for treatment of hypoxemia may require physical presence. The time course of most PACU hypoxemic episodes overlaps with the second busiest interval in the OR for anesthesiologists, that being when there are both

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**Figure 6.** Resolution of hypoxemic episodes. The percentages of hypoxemic episodes still ongoing (i.e., oxygen saturation [SpO₂] <90%) after 3, 5, and 10 min from onset are shown for all hypoxemic episodes (panel A) and, as a sensitivity analysis, for a single random hypoxemic episode from each patient’s admission (panel B). Continuing hypoxemia for episodes having their onset <30 min after postanesthesia care unit (PACU) arrival (dark blue) and ≥30 min after arrival were clinically similar. Nearly a quarter of hypoxemic episodes were still ongoing as late as 10 min after their onset. SEs were calculated using n = 80 four-week periods.

**Table 2. Differences Between Percent Unresolved Hypoxemic Episodes Occurring <30 min and ≥30 min After PACU Admission (Hypothesis 1)**

<table>
<thead>
<tr>
<th>Minutes after onset of hypoxemic episode</th>
<th>Mean difference</th>
<th>P&lt;sub&gt;c&lt;/sub&gt;</th>
<th>Lilliefors test P&lt;sub&gt;d&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>7.48% (5.93% to 9.03%)</td>
<td>&lt;0.0001</td>
<td>0.44</td>
</tr>
<tr>
<td>5</td>
<td>3.17% (1.85% to 4.51%)</td>
<td>&lt;0.0001</td>
<td>0.19</td>
</tr>
<tr>
<td>10</td>
<td>−2.54% (−3.83% to −1.24%)</td>
<td>0.0002</td>
<td>0.06</td>
</tr>
</tbody>
</table>

CI = confidence interval; PACU = postanesthesia care unit.

*Hypoxemic episode = at least 2 consecutive minutes with SpO₂ <90%.

Mean difference between the % of hypoxemic episodes unresolved at the listed interval that started <30 min from arrival in the PACU (early) and those starting ≥30 min after arrival (late).

P<sub>c</sub> value for paired Student t test (n = 80 batched periods) comparing % unresolved for early onset hypoxemic episodes and late onset hypoxemic episodes.

P<sub>d</sub> value for fit to a normal distribution for the observed differences of % unresolved for early-onset hypoxemic episodes and late-onset hypoxemic episodes. P ≥ 0.05 is indicative of no difference between the observed and expected fit.
multiple second cases of the day starting and lunch breaks (Fig. 2). During this interval, 2 unrelated events overlap: the number of anesthesiologists available may be reduced as the result of cross-coverage during lunch relief, and the first “wave” of patients (from the first case starts) is in the PACU.

A troubling result of our study is that 26.3% of hypoxemic episodes remained unresolved for as long as 10 minutes after admission to the PACU. The cumulative percentage of hypoxemic episodes (oxygen saturation \([S_{PO_2}] < 90\%\) for at least 2 min) according to their onset time after PACU admission is shown by the dark green line. The percentage of hypoxemic events for each minute after PACU admission as a fraction of the total number of hypoxemic episodes for the group is plotted as open blue circles. A LOESS curve (solid blue line) with the approximate 99% confidence interval (shaded blue area) was fit to the data as described for Figure 4. In the legend for each panel, the fraction of all patients represented in the group is displayed, as is the percentage of patients in the group that experienced at least 1 hypoxemic episode in the first 180 min of their PACU stay.

### Table 3. Use of NDMB and Opioid and Association with Hypoxemic Episodes by 4-Week Bin

<table>
<thead>
<tr>
<th>Percentage for combination of opioid and NDMB</th>
<th>Received opioid in OR or PACU</th>
<th>Received NDMB in OR</th>
<th>Yes or No</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of all 137,757 studied patients(^a)</td>
<td>Yes</td>
<td>Yes</td>
<td>69.58% ± 0.53%</td>
</tr>
<tr>
<td>% in opioid/NDMB subgroup with ≥1 hypoxemic episode(^a)</td>
<td>Yes</td>
<td>13.12% ± 0.23%</td>
<td></td>
</tr>
<tr>
<td>% of all 137,757 studied patients(^b)</td>
<td>No</td>
<td>Yes</td>
<td>9.57% ± 0.61%</td>
</tr>
<tr>
<td>% in opioid/NDMB subgroup with ≥1 hypoxemic episode(^b)</td>
<td>No</td>
<td>2.93% ± 0.01%</td>
<td></td>
</tr>
</tbody>
</table>

NDMB = nondepolarizing neuromuscular blocker; OR = operating room; PACU = postanesthesia care unit.

\(^a\)There were 80 four-week periods used for calculation of the mean ± SE. The total number of patients evaluated = 137,757. The percentages in this row represent the patients who received the indicated combination of opioid and NDMB, calculated using the method of batch means over the \(n = 80\) four-week periods (see Methods). For example, from row 1, among all 137,757 studied patients, an average of 23.69% received an opioid in either the OR or the PACU, but did not receive an NDMB in the OR.

\(^b\)The percentages listed are the incidences of hypoxemic episodes in patients receiving the specified combination of opioid and NDMB, calculated using the method of batch means over the \(n = 80\) four-week periods (see Methods). For example, from row 4, among all patients who did not receive an opioid in either the OR or the PACU and who did not receive an NDMB in the OR, the average incidence of at least 1 episode of hypoxemia was 6.74%.
PACU Hypoxemia and Staffing Considerations

Table 4. Reasons for Tracheal Intubation in the Postanesthesia Care Unit from the Electronic Medical Record

<table>
<thead>
<tr>
<th>Reason for tracheal intubation*</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypoxemia</td>
<td>49</td>
</tr>
<tr>
<td>Unresponsiveness</td>
<td>42</td>
</tr>
<tr>
<td>Increased work of breathing</td>
<td>29</td>
</tr>
<tr>
<td>Agitation</td>
<td>17</td>
</tr>
<tr>
<td>Hypoventilation</td>
<td>25</td>
</tr>
<tr>
<td>Inadequate respiratory effort</td>
<td>24</td>
</tr>
<tr>
<td>Airway obstruction</td>
<td>18</td>
</tr>
<tr>
<td>Hemodynamic instability</td>
<td>15</td>
</tr>
<tr>
<td>Airway protection</td>
<td>9</td>
</tr>
<tr>
<td>“Coded”</td>
<td>7</td>
</tr>
<tr>
<td>Bronchospasm</td>
<td>5</td>
</tr>
<tr>
<td>Volume overload</td>
<td>3</td>
</tr>
<tr>
<td>Aspiration</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
</tr>
</tbody>
</table>

*Of the 111,456 consecutive patients evaluated, 85 (0.08%) arrived with a natural airway and underwent tracheal intubation while still in the postanesthesia care unit (PACU). All reasons, as noted in the electronic medical record, in descending order of frequency, are listed for these 85 patients. Many patients had multiple indications listed for intubation. Categorization of the reasons for intubation in the PACU occurred following review of the patients’ electronic medical records. These descriptions are provided as qualitative observations about the population of patients intubated in the PACU, but are unrelated to hypothesis 3. There were an additional 23 patients admitted to the PACU with a tracheal tube in situ who were reintubated following extubation in the PACU, yielding an overall incidence of PACU intubation = 0.10%. Of these 23 patients, 80% were reintubated within 30 min of extubation in the PACU.

after their onset, in contrast to an ongoing incidence of <9% at 5 minutes when such episodes occur in the OR. Several factors may contribute to slower resolution of hypoxemia in the PACU than in the OR, including the higher airway skill levels of anesthesiologists, spontaneous ventilation versus controlled ventilation, and 1:1 provider to patient coverage in ORs versus typically 1:2 in the PACU.

Physical presence for diagnosis and treatment of hypoxemia may not require that an anesthesiologist arrives for initial management. The American Society of Anesthesiologists Standards for Postanesthesia Care make anesthesiologists responsible for “general medical supervision and coordination of patient care in the PACU” and mandate that anesthesiologists must “assure the availability in the facility of a physician capable for managing complications and providing cardiopulmonary resuscitation for patients in the PACU.” At some hospitals, first response duties are delegated to a Certified Registered Nurse Anesthetist or an anesthesia resident; a respiratory therapist might also be included on the first responder team. Regardless, an anesthesiologist still needs to be immediately available for backup, if needed.

In the absence of an anesthesiologist assigned daily for dedicated PACU coverage, PACU nurses need to know who is available to respond to a call for assistance. Silent paging using visual displays dispersed throughout the OR suite; overhead paging, or blast pages to all anesthesiologists are options. If the practice has an anesthesia information management system, the level of activity in ORs can be determined in near real time, allowing an automated determination of anesthesiologists who are likely available. Anesthesia staffing and assignment decisions should be made to avoid situations in which all anesthesiologists are engaged in non-preemptive tasks, and thus no anesthesiologist is available to respond to an emergency in the PACU.

Our motivation for performing this study was to address staffing and assignment issues related to the timing of hypoxic episodes in the PACU (Fig. 3). We performed several sensitivity analyses to evaluate qualitatively whether patients had received an opioid or an NDMB, thereby determining whether the findings were generalizable to other patient populations (Table 3, Fig. 7). Although the differences in the incidences of hypoxemia among subgroups were highly significant statistically, the values were clinically similar. Thus, PACU coverage to address hypoxemia needs to be ensured, regardless of the prevalence of use of opioids or paralytic drugs. By no means do these sensitivity analyses imply that opioids and NDMB are the only factors to which hypoxemia is related, nor that these are causal factors. Patients receiving NDMB but not opioids accounted for <5% of hypoxic episodes. Furthermore, most hypoxic episodes in the PACU occurred ≥30 minutes after patient arrival, suggesting also that these episodes were not primarily related to residual neuromuscular blockade. Studies published in the last 6 years in which quantitative assessment of residual blockade in the PACU was performed and its presence related to respiratory complications truncated their observation periods at ≤30 minutes. Our study results suggest that causal analyses of the impact of residual neuromuscular blockade on respiratory events should extend the evaluation of Spo2 beyond the first 30 minutes in the PACU, and also control for opioid use.

Our study has a number of limitations. First, this is a study of adult patients at a single busy academic hospital, and findings may not be broadly applicable. For example, we expect that findings would be quite different at an ambulatory surgery center. The observation, however, that the PACU intubation rate in this study was nearly identical to results published from several other institutions makes us more confident that the VUMC PACUs are fairly representative of general surgical practice in a mixed inpatient/outpatient adult setting. Other facilities can apply our results simply by determining the times of the day with the largest numbers of patients in the PACU (Fig. 2) because the numbers of hypoxic episodes is proportional to the PACU census (Fig. 3). Our results should not be applied to pediatric populations because our study was restricted to adults.

Another limitation is that some of the hypoxemic episodes identified might have been artifacts. Observation of the graphs of Spo2 versus time of randomly selected hypoxic episodes, however, gave us confidence that we were capturing real episodes (example in Fig. 1). Also, the requirement for at least 2 minutes of continuous desaturation, rather than a single value, made it less likely that we were greatly overidentifying hypoxic episodes. Likely, many transient desaturations (e.g., Fig. 1, episodes 2 and 3) were real, not measurement artifacts, and simply responded quickly to interventions by the PACU nurses (e.g., telling the patient to take a deep breath, or replacing a disconnected oxygen...
mask or cannula). Direct observational studies would be needed to address this issue.

A third limitation is that we considered all episodes of hypoxemia meeting our criteria as equivalent, without characterizing them as mild, moderate, or severe. For example, from our Figure 1, one could infer fairly that episode 1, which occurred on PACU arrival and resulted in intubation, was more severe than episode 4. We are unaware, however, of any automated methods that can process free text and other medical record data to characterize hypoxic episodes reliably, necessary for analyzing large datasets such as ours. Nonetheless, one cannot argue that hypoxic episodes occurring later in the PACU course were less severe than episodes presenting relatively soon after PACU arrival, based on the finding that the timeline of intubation parallels that of the hypoxic episodes.

A fourth limitation is that during the dataset interval at the studied hospital, an anesthesia resident was assigned each day to cover the PACUs and to respond to codes and airway emergencies outside the OR. During nonholiday weekdays, this resident primarily stayed in the main PACU; at other times, his or her typical physical location was variable. Such dedicated coverage of PACUs by a physician may not be provided at other facilities. The data available did not permit analysis of resident or anesthesiologist involvement in the treatment of the hypoxic episodes in the PACU. Consequently, our results are conservative (i.e., may underestimate the incidence of hypoxic episodes that would otherwise have occurred). There may have been preemptive treatment of minor degrees of desaturation (e.g., <1 minute below 90% in duration or prior to decreasing below 90%).

Finally, we limited consideration of anesthesiologists’ PACU workload to episodes of hypoxemia because these events frequently require the presence of an anesthesiologist for diagnosis and treatment. To the extent that other medical emergencies (e.g., severe hypertension, dysrhythmias) require the physical presence of the anesthesiologist for diagnosis and/or treatment, the need to ensure the availability of anesthesiologists to cover the PACU would be amplified. We were being conservative (i.e., deliberately underestimating the findings) by excluding other medical conditions that sometimes cannot be handled remotely.12,13

In conclusion, because most hypoxic episodes and intubations in the PACU occur ≥30 minutes after PACU admission, and physical presence of the anesthesiologist may be required, potential PACU workload should be considered when anesthesiologist OR staffing and assignment decisions are made.

**RECUSE NOTE**

Dr. Franklin Dexter is the Statistical Editor and Section Editor for Economics, Education, and Policy for the Journal. This manuscript was handled by Dr. Sorin J. Brull, the Section Editor for Patient Safety, and Dr. Dexter was not involved in any way with the editorial process or decision.

**DISCLOSURES**

**Name:** Richard H. Epstein, MD, CPHIMS.

**Contribution:** This author helped design the study, conduct the study, analyze the data, and write the manuscript. This author attests to the integrity of the original study data and data analysis reported in this manuscript and is the archival author.

**Attestation:** Richard H. Epstein has approved the final manuscript.

**Conflicts of Interest:** Richard H. Epstein is the president of Medical Data Applications, Ltd., which receives licensing fees from the University of Iowa for software used by the Department of Anesthesia’s Division of Management Consulting.

**Name:** Franklin Dexter, MD, PhD.

**Contribution:** This author designed the study, conduct the study, analyze the data, and write the manuscript. This author attests to the integrity of the original study data and data analysis reported in this manuscript.

**Attestation:** Franklin Dexter has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.

**Conflicts of Interest:** The Division of Management Consulting, Department of Anesthesia, University of Iowa, performs some of the analyses described in this article for hospitals. Franklin Dexter has tenure and receives no funds personally, including honoraria, other than his salary and allowable expense reimbursements from the University of Iowa. Income from the Division’s consulting work is used to fund research.

**Name:** Marcos G. Lopez, MD.

**Contribution:** This author helped conduct the study, analyze the data, and write the manuscript.

**Attestation:** This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.

**Conflicts of Interest:** Marcos G. Lopez has no conflicts of interest to declare.

**Name:** Jesse M. Ehrenfeld, MD, MPH.

**Contribution:** This author helped design the study and write the manuscript.

**Attestation:** This author has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.

**Conflicts of Interest:** This author has no conflicts of interest to declare.

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