Critical incidents detected by pulse oximetry during anaesthesia

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The Critical Incident Technique was used to study anaesthetics given in a major tertiary care teaching hospital in order to define indications for monitoring with a pulse oximeter during anaesthesia. Anaesthetists were asked to use a pulse oximeter in every case and trained to report Critical Incidents in order to determine if the oximeter can shorten the time to detection of these events. Four thousand seven hundred and ninety-seven anaesthetics were given during a four-month period in 1986-87. A Critical Incident was recorded when an unexpected physiologic deterioration requiring intervention by the anaesthetist to prevent a likely bad outcome was signalled first by the pulse oximeter. Critical Incidents were classified by patient characteristics, physiologic change, type of anaesthetic, and the type, length, and place of surgery. Reports were received in 65 per cent of cases, and a Critical Incident occurred in 191 (six per cent) of these. Desaturation was the commonest physiologic change (151) and was further classified as to severity (mild 85-94 per cent saturation, moderate 75-84 per cent, and severe 75 per cent). Desaturations during the maintenance phase of anaesthesia were milder but more frequent than those in the induction or emergence phases. There were no severe desaturations in elderly patients or those receiving regional anaesthesia. No group was free of Critical Incidents. Since undetected hypoxaemia may lead to disastrous complications we recommend that a pulse oximeter be used for every anaesthetic.

Key words

MEASUREMENT TECHNIQUES: oximetry; OXYGEN: saturation, blood levels; ANAESTHETIC TECHNIQUES: general, regional.

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The pulse oximeter is a convenient, automatically calibrated, non-invasive clinical monitor of oxygen saturation and pulsation. Its accuracy and reliability^{1,2} have been studied in the respiratory physiology laboratory,³ intensive care unit,⁴ operating room^{5,6} (OR), and recovery room.^{7,8} Only a small number of confounding factors (IV dyes,⁹ strong incident light, especially heat lamps,¹⁰ and abnormal haemoglobins¹¹) have been found. The greatest value of the oximeter is its ability to provide an early warning of hypoxaemia. Clear indications for its use have not been developed. At the Canadian Anaesthetists' Society Annual Meeting in 1986, a panel of experts (S.G. Neil, A.M. Lam, K.W. Turnbull, and K.K. Tremper; Panel on OR monitoring) was split on whether the information given by the oximeter offset the expense for routine use in the operating room. This study assesses the clinical usefulness of oximetry during anaesthesia by investigating when and where it shortens the time to detection of critical events.

Methods

The Critical Incident Technique (CIT)¹²⁻¹⁴ was used to identify and estimate the frequency of anaesthesia related incidents that might endanger the patient. Cooper *et al.* showed that the CIT performed these functions well in the anaesthesia setting.^{13,14}

During a four-month period (October 1986 to February 1987) all inpatients and outpatients having anaesthetics at a major tertiary care teaching hospital were included in a prospective study. Patients having epidural analgesia for labour and delivery were excluded. All patients were routinely monitored with continuous ECG, temperature probe, and blood pressures determined every five minutes.

All members of the Anaesthesia Department were requested at a training session to use a Nellcor N-100 oximeter in the O.R. throughout every case and to complete a questionnaire. Three questions were posed: (1) Was the oximeter applied? (2) Was it the first warning of an unexpected problem? (3) Did false alarms occur?

When (2) or (3) were answered positively, the chart was examined in detail and the anaesthetist interviewed within two days. A Critical Incident (CI) was recorded by

the investigator if an unexpected physiologic change severe enough to require intervention by the anaesthetist to prevent a likely adverse outcome was signalled first by the oximeter. If both the investigator and the reporting anaesthetist agreed that the criteria were met, a CI was recorded. Physiologic changes which fit these criteria included oxygen saturation below 95 per cent, and changes in pulse, blood pressure, or temperature, which, *given the patient's condition*, could reasonably be expected to lead to a poor outcome. The process excluded expected physiologic changes (such as sinus tachycardia or hypertension due to light anaesthesia) corrected by ordinary anaesthetic adjustments.

We classified the CIs as to subjects' age, sex, smoking habits, ASA physical status, obesity, type of operating room suite (inpatient, outpatient, or obstetric), type of surgery (abdominal, back, cardiovascular, head and neck, limb/peripheral, obstetrics, shared airway/endoscopy, thoracic), phase of surgery (induction, maintenance, or emergence), number of other monitors applied, and type of anaesthetic (regional or general). Obstetrical anaesthesia was defined as surgery on the reproductive tract of a woman in her third trimester. All our obstetrical cases were Caesarian sections. When desaturation created CIs, they were subdivided into mild (85–94 per cent saturation), moderate (75–84 per cent), and severe (<75 per cent).

An unexpected alarm in the absence of any physiologic change was recorded as a False CI. Confidentiality was assured for both patients and anaesthetists. The study was not sponsored by any commercial interest.

Chi-square analysis with a five per cent confidence level was used to compare the categories of CI's. Yate's correction was used where applicable.

Results

Four thousand seven hundred and ninety-seven cases were done (Table I). Cards were marked in 65 per cent of cases and response did not depend on type of OR suite.

TABLE I Critical incidents

	Inpatient	Outpatient	Obstetric	Total
Cases	3384	1236	177	4797
Cards marked	2145	907	102	3154
Response rate	63%	73%	57%	65%
Oximeter applied	2115	887	98	3100
Application rate	98%	97%	96%	98%
CIs	149	28	14	191
CI rate	7%	3%	14%†	6%
False CIs	61	1	3	65
False CI rate	2%	0.1%*	3%	2%

*Significantly different from inpatient group.

†Significantly different from non-obstetric patients.

TABLE II Physiologic change signalled

Desaturation	151
Heart rhythm change	45
Temperature decrease	7
Blood pressure decrease	4
Blood pressure increase	3

The oximeter was applied in 98 per cent of cases where cards were marked.

Desaturation was the most frequent physiologic change signalled (Table II). The ECG is monitored routinely in our OR's but alarms are not provided on some monitors or are not routinely set, so the oximeter was the first indicator of a poorly tolerated altered heart rhythm in 45 cases. Bradycardia was most frequent, followed by tachycardia, and other arrhythmias. Temperature is also routinely monitored, without alarms, and in seven long cases the oximeter was the first indication of a temperature <35°C. A potentially dangerous unexpected blood pressure drop occurred four times and in three cases severe unexpected hypertension caused a CI by signalling loss of pulsation.

There were 191 CIs (Table I), a rate of six per cent, with the rate for outpatients significantly lower than for inpatients, and that for obstetrical surgery significantly greater than for nonobstetric. The False CI rate was two per cent, with significantly fewer in outpatients. There was at least a four per cent overall CI rate, even if no CI's occurred in cases with unmarked cards.

CIs occurred in every ASA physical class (53 in class I, 76 in II, 34 in III, and 28 in IV).

In each case of desaturation, a primary cause and the most important contributing cause (Table III) were attributed in consultation with the reporting anaesthetist. In 37 cases there was only one cause. Airway and intubation problems, including trouble maintaining a patient airway during use of mask were the commonest causes of desaturation, followed by lung disease and narcosis. Contributing causes included obesity first, then lung disease and then other illnesses such as heart disease, sepsis, or multisystem organ failure.

TABLE III

Condition	Primary cause (%)	Contributing cause (%)
Upper/lower airway spasm/oedema/ soft tissue obstruction	37 (19)	
Lung disease	29 (15)	22 (11)
Narcosis	26 (14)	
Intubation problem	22 (11)	
Obesity		28 (15)
Other illness		20 (10)

TABLE IV Factors associated with severity of desaturation

Factor	Desaturation		
	Mild 85-94%	Moderate 75-84%	Severe <75%
Total	80	42	29
Age			
- <40 yr	29	14	14
- 40-70 yr	36	20	15
- >70 yr	15	8	0*
Obesity	24	17	9
Smoking	27	17	10
ASA Class			
- I-II	52	24	13
- III-IV	20	10	7
Phase			
- Induction	21	16	12
- Maintenance	48†	14	10
- Emergence	11	12	7
Anaesthetic			
- General	71	41	29
- Regional	9	1	0‡

*Significantly different from all other ages and degrees of saturation.

†Significantly different from all other phases and degrees of saturation.

‡Significantly different from general anaesthetic.

The distribution of "factors" (Table IV) associated with mild, moderate, and severe desaturations were compared with the "total" distribution. Age did not predict a more severe desaturation; on the contrary, none of the 23 geriatric patients who desaturated reached the severe level. Obesity appeared to be a risk factor for desaturation (Table III), but did not predict severity (Table IV). Unexpected desaturations happened more often during the maintenance phase but were more often mild than during induction or emergence.

General anaesthesia was associated with all the severe desaturations (29), and this was significantly different from regional anaesthesia. There was not a higher proportion of geriatric patients given regional anaesthesia. The following factors did not predict severity of desaturation: sex, length of operation, smoking, obesity, type of surgery, ASA class, or number of additional monitors applied.

Discussion

The pulse oximeter consists of a probe, a small dedicated computer, and a cable connecting the two.¹⁵ The probe may be clipped on a finger-tip, toe, nose, or ear (any of these sites was used for OR monitoring if it produced a strong pulse signal and registered the correct pulse rate, although subtle differences have been shown between finger and ear in pulse volume¹⁶ and in saturation during heavy exercise³). The probe transmits rapidly alternating

beams of red light at two wavelengths through the patient's appendage to a photo cell which transmits pulsatile signals to the computer. The pulse and saturation are derived, based on the differential absorption of the two wavelengths by saturated and reduced haemoglobin at successive times during the pulsation of arterial blood into the tissue. Adjustable alarms warn of high or low pulse rate or saturation level and of blood pulsations insufficient for proper functioning of the device. A "beep" is sounded for each pulse detected and the pitch of the "beep" varies with the saturation. Pulse rate and saturation are also displayed visually. Tytler⁴ found the pulse oximeter accurate within one digit ($\pm 1.0\%$) of a laboratory *in vitro* oximeter. Yelderman and New¹ studied healthy volunteers breathing at low FiO_2 and found a high correlation ($R = 0.98$) with *in vitro* saturation. We considered it unethical to pause during a critical incident to draw arterial blood for blood gas analysis where it would not be clinically indicated (in the midst of an airway problem, upon discovering and before correcting a disconnection, etc) and relied upon five assurances of the specificity of an hypoxic warning. First, all the cited studies¹⁻¹¹ show that if the pulsations are indicated as sufficient, and the indicated pulse rate matches the patient's, the oximeter only indicates hypoxia falsely in the presence of the cited rare confounding factors. These did not occur in our study. More importantly, three criteria were met in every case. First, all patients had a normal saturation prior to induction; second, all had a problem which explained the desaturation; third, all reverted to a normal saturation when the problem was corrected. Finally, where blood gas assays were clinically indicated they inevitably corroborated the oximeter.

Reported false CIs (Table I) were caused by surgical cautery, cable disconnect, and movement of the probe.

The CIT is a problem solving technique, not a descriptive science. It relies on reports of relatively infrequent events (anecdotes) which conventional science discards by measures of central tendency. The exact quantification of events pursued by conventional scientific measurement is impossible in a method which must rely on reporters' cooperation, memory, judgement, understanding, and ongoing interest in the study. However, the CIT has been repeatedly validated¹⁷ and found to be useful in anaesthesia studies.^{13,14}

Objectivity, as measured by inter-observer agreement, has been shown to be best when certain conditions are met.¹² (1) *The situation/behaviour to be reported should be strictly specified.* We limited the situation to surgical anaesthesia and specified the behaviour: anaesthetist's response to an oximeter alarm. (2) *The reporting is clearly relevant to the aim of the activity under investigation.* Our reporters (anaesthetists) considered the study

important to the aim of patient safety. (3) *The events reported have a major effect on the aim of the activity.* The potential dangers of CIs as defined are well known. (4) *The reporters selected are familiar with the activity.* Anaesthetists were chosen as reporters for this study rather than, for example, clerical staff. (5) *The reporters are trained in the collection of CIs.* We provided daily "training" in the form of frequent informal coaching as well as the initial training session.

A test of sample size adequacy¹² was also applied. After classification of the first 50 CIs into types of incidents, subsequent CIs should generate fewer than five new classes per 100. Otherwise, additional sets of 100 CIs should be collected until a set requires fewer than five new classes. All types of CIs found in the last 100 incidents in our study were represented in the initial 50. Therefore the sample size is adequate to allow conclusions.

While the CIT cannot provide us with the true number of CIs that occurred during the study, it has the advantage of permitting study of a large data base of relatively rare events (like hypoxia) inexpensively.

If the investigator can be reasonably assured that the study is free of *spurious* reports (we checked the chart and interviewed the anaesthetists), it can be said that CIs have at least a certain frequency. Then judgement must be used to decide if that rate is a significant problem (or benefit) with respect to the stated goal of the activity studied. In our case patient safety was the goal of interest in the activity OR anaesthesia. If the oximeter shortens the time to detection of a correctable CI, particularly hypoxia, then organ damage will likely be decreased, and we would expect that in a larger sample population bad outcomes will be avoided. The rates of CIs uncovered in this study represent significant patient problems with potentially bad outcomes.

No group of patients was immune from CIs, regardless of ASA physical status category, type or length of surgery, surgical suite (inpatient, outpatient or obstetrics), or type of anaesthetic (general or regional). Obstetrics patients were at greatest risk for a CI.

That no severe desaturation occurred in the elderly patients is a surprise and possibly indicates that they are anaesthetized as cautiously as the very ill but were in fact not very ill.

Regional anaesthesia was no protection from a CI, but appears to protect from severe desaturation. The small number of cases does not allow a firm conclusion.

The False CI rate was lowest in outpatients ($p < 0.05$). Thus, the oximeter was least troublesome in the patients with fewest problems. None of the anaesthetists involved considered the oximeter a time-consuming, troublesome, or distracting monitor.

We did not formally study how often other monitors

warned before the oximeter, but this appeared to happen rarely.

Cooper's reporters failed to return questionnaires for 30 per cent of patients.⁸ The 35 per cent of our cases with unmarked cards may contain cases done by: (a) anaesthetists who are fearful of reporting their practices and who have more CIs than the others; (b) the same incidence of CIs in cases where the anaesthetists simply forgot to respond; (c) fewer CIs and anaesthetists who forgot to respond because nothing went wrong. The last of these gives the lowest possible CI rate, four per cent. No anaesthetist objected to the study or refused to report; on the contrary, those who forgot to report were always apologetic. We conclude that the oximeter gives the earliest warning of events which increase risk during anaesthesia in at least four per cent of cases and that no group of anaesthetized patients is immune to these risks.

Cooper *et al.*, in a study intended to devise and test an indirect measure of quality of anaesthetic care, found fewer anaesthetic complications pertinent to recovery room care⁸ in the final period of their study when a pulse oximeter was used. However, their data show gradual overall decline in these clinical complications, and Cooper *et al.* state that confounding factors make it impossible confidently to credit the decline to the oximeter.

Our study does not determine if complications are decreased by the oximeter, but shows that in four per cent of cases the time to discovery of an increased risk of complication is shortened. This use of a more sensitive measure than Cooper's explains our more definite findings.

The Canadian Medical Protective Association settles three to five hypoxia related cases per year at over \$1M each.* Assuming only a five-year lifespan for a \$6000 oximeter and a generous 20 per cent annual repair bill, it costs \$2400/year to equip an OR with this monitor. For an OR doing 20 cases per week for 50 weeks a year, it costs \$2.40 per case for monitoring with pulse oximetry.

Recommendations

We have shown that every anaesthetic in every group of adult patients for all kinds of surgery in inpatient, outpatient, or obstetrical settings carries the risk of a patient hazard such as hypoxia that is first detected by the pulse oximeter. Since the worst outcomes (cerebral hypoxia for example) depend upon severity and duration of hypoxia, early detection of problems by an oximeter should be of great practical benefit in preventing these disastrous results. Hypoxia is associated with the most tragic and costly outcomes of anaesthesia and is the only physiologic change poorly detected by other means.^{18,19} Clinical signs are not as sensitive as the oximeter in

*A. Dunn, Toronto, Ontario, personal communication.

detecting hypoxia. Arterial blood gas analysis is intermittent and results are not usually immediately available. Therefore an oximeter should be available for every OR, and, in addition to conventional monitors, should be used in every case.

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Résumé

La technique des incidents critiques (Critical Incident Technique) était utilisée afin d'étudier les agents anesthésiques administrés dans un centre hospitalier tertiaire d'enseignement afin de définir les indications d'une surveillance avec un saturimètre (pulse oximeter) durant l'anesthésie. Les anesthésiologistes devaient utiliser le saturimètre dans chaque cas et devaient être entraînés à rapporter les incidents critiques afin de déterminer si l'oxymètre pouvait diminuer le temps de détection de ces incidents. 4797 anesthésies furent administrées durant quatre mois en 1986-87. Un incident critique est enregistré aussitôt quand on détectait avec le saturimètre une détérioration physiologique subite requérant l'intervention de l'anesthésiologiste pour prévenir la possibilité d'une complication. Les incidents critiques étaient classifiés d'après les caractéristiques du patient, les changements physiologiques, le type d'anesthésie et le type, la durée, et place de la chirurgie. Les rapports ont été reçus dans 65 pour cent des cas et un incident critique est survenu dans 191 (six pour cent) de ceux-ci. La désaturation était le changement physiologique le plus commun (151) et elle fut de plus classifiée selon sa sévérité (légère 85 à 94 pour cent saturation, modérée 75-84 pour cent, et sévère <75 pour cent). Les désaturations durant la phase de maintien de l'anesthésie étaient légères mais plus fréquentes que celles qui sont survenues lors de l'induction ou de la phase de l'émergence. On a noté aucune désaturation sévère chez les patients âgés et chez ceux subissant une anesthésie régionale. Aucun groupe n'était libre d'incident critique. Étant donné que l'hypoxémie non détectée peut aboutir à des complications désastreuses on recommande que le saturimètre soit utilisé avec chaque administration de l'anesthésie.