British Journal of Anaesthesia **83 (5)**: 747–9 (1999)

Continuous auditory monitoring—how much information do we register?

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We have studied response times of 30 anaesthetists to a standardized episode of arterial oxygen desaturation in a simulated patient, randomized to the use of either a fixed or variable pitch pulse oximeter. We wished to determine if a variable auditory signal was important in detecting adverse events. A variable pitch pulse signal had a shorter time to recognition of desaturation ($P<0.0001$), with a mean response time of 32 s, compared with 129 s for the fixed pitch signal.

Br J Anaesth 1999; **83**: 747–9

Keywords: equipment, pulse oximeters; oxygen, saturation; equipment, alarms; computer, simulation; anaesthetist, activity

Accepted for publication: June 3, 1999

Non-invasive pulse oximetry monitoring has improved the detection and prevention of adverse events in both the operating theatre and recovery room.[1–4] Many countries include the pulse oximeter in their standards of minimal monitoring.[5] All devices in current use allow threshold alarm limits to be set for heart rate and arterial oxygen saturation and produce regularly updated visually displayed values. Most also provide the facility to monitor the pulse continuously by producing an audible beep of a pitch that varies in response to an increase or decrease in oxygen saturation. We have observed that medical and nursing staff frequently disable the pulse beep. In this study, we have assessed how the character of the signal from this continuous monitoring system affects the time required to detect hypoxaemia during a standardized hypoxaemic episode simulated using the METI (Medical Education Technologies Inc.) human patient simulator.

Methods

Anaesthetists

Thirty-one anaesthetists of varying clinical experience consented to adopt the role of anaesthetist for a routine standardized clinical case scenario presented on the human patient simulator. Without their knowledge, they were randomized by the toss of a coin to group A (to use variable pitch oximetry) or group B (to use fixed pitch oximetry).

Equipment

All theatre equipment was working fully before the study. The equipment comprised an Ohmeda Excel anaesthetic machine with pipeline gas supplies of air, oxygen and nitrous oxide. Isoflurane was available from a Penlon vaporizer on the back bar. A circle system with absorber was connected to the common gas outlet that could be switched to a 2-litre bag limb for manual ventilation. Throughout the study, the simulated patient was monitored using a Hewlett-Packard Merlin system (Model M1165A) with four visible waveforms: electrocardiograph (ECG), plethysmograph, agent monitoring and capnography. On-screen numerical values were provided for non-invasive arterial pressure (3-min cycle), arterial oxygen saturation, inspired and expired oxygen, carbon dioxide, nitrous oxide and anaesthetic agent concentrations. Group A was provided with a system that produced a pulse beep that varied in pitch with arterial oxygen saturation. Group B used exactly the same system but with a beep of equivalent sound intensity derived from the ECG signal that did not vary in pitch with saturation. The pulse oximeter low saturation alarm threshold was set to 85% for both groups, thereby allowing response to pitch variation to be assessed before the threshold alarm sounded.

The patient

Each anaesthetist was asked to relieve a colleague who had completed induction of anaesthesia and had transferred the patient to theatre. A standard verbal ‘handover’ backed up by a type-written summary gave the following information to each anaesthetist on arrival in theatre:

A 35-yr-old male with a perianal abscess has consented to surgical incision and drainage. He is healthy, apart from

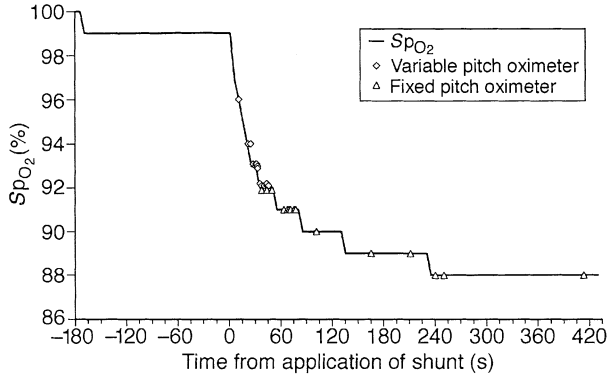

Fig 1 Arterial oxygen saturation *vs* time after application of a 40% shunt to the simulated patient's lung function (Sp_{O_2} value). This standardized scenario was then replayed to 30 anaesthetists randomized in equal numbers to use variable or fixed pitch oximetry. The time taken from the onset of shunt until the anaesthetist intervened by increasing $F_{I_{O_2}}$ to greater than 0.5 was recorded for each subject.

a symptomatic hiatus hernia and is not currently receiving any form of medication. He has no known allergies and has been starved for 6 h. After preoxygenation, he has received a standard i.v. rapid sequence induction with thiopental 350 mg and succinylcholine 100 mg, followed by tracheal intubation with a 9.0-mm internal diameter cuffed tube. Anaesthesia is being maintained using a fresh gas mixture of nitrous oxide 2 litre min^{-1}, oxygen 1 litre min^{-1} and 2% isoflurane, which he is breathing spontaneously via a circle system. Analgesia has been supplemented with morphine 10 mg i.v.

Subjects were asked to take over the case in theatre and continue the anaesthetic while waiting for the surgeon to scrub, keeping an anaesthetic record in the normal way. Four minutes after starting the scenario, a 40% shunt was applied to the simulated patient's lung function. With no intervention, this results in a decrease in arterial oxygen saturation from 99% to 88% (Fig. 1). We measured the time taken from application of the shunt until recognition and appropriate reaction by the anaesthetist. Start time was measured as the moment the shunt was applied. End time was defined as the point when the anaesthetist set the fractional concentration of inspired oxygen to greater than 0.5.

Statistical analysis

Response times from individual anaesthetists were compared using the Mann–Whitney *U* test.

Results

We recruited 31 anaesthetists. One anaesthetist (a specialist registrar) was subsequently withdrawn because he never used nitrous oxide and turned it off immediately on taking over the case, thereby transiently increasing the fractional concentration of inspired oxygen to 1.0 before introducing air to the fresh gas mixture. Of the remaining 30, equal numbers were randomized to both groups. There was little difference in seniority of anaesthetists between groups: group A (variable pitch) comprised one consultant, seven specialist registrars and seven senior house officers while group B (fixed pitch) comprised three consultants, five specialist registrars and seven senior house officers.

Response time ranged from 10 to 45 s for group A and from 37 to 423 s for group B (Fig. 1). Mean response time for group A was 32 s (interquartile range 28.5–38.5 s) and 129 s (65–188 s) for group B. Mean arterial oxygen saturation at the point of intervention was 93% in group A and 90% in group B. Group B took significantly longer to recognize desaturation ($P<0.0001$) than group A.

Discussion

The importance of pulse oximetry in the detection and prevention of adverse events has been well documented. Tinker and colleagues,[1] in a study of 1097 anaesthetic malpractice actions, concluded that 314 incidents, nearly all of which resulted in death or brain damage, could have been prevented had pulse oximetry or pulse oximetry with capnography been used. In another study examining the incidence of unanticipated intensive care admissions, Cullen and colleagues[2] found that after introduction of pulse oximetry, the incidence of these admissions decreased significantly. Cooper and colleagues[3] assessed the incidence of less severe anaesthetic events defined as 'unanticipated, undesirable, possibly anaesthesia related side effects that required intervention in the recovery room'. After introduction of pulse oximetry, significantly fewer patients experienced such events. Findlay, Spittal and Radcliffe[4] found that pulse oximetry, measurement of arterial pressure (non-invasive), ECG and clinical observation identified 90% of all reported critical incidents in their series. They also found that the use of these monitors detected more critical incidents than clinical observation alone or all other remaining forms of monitoring together.

We have shown that the effectiveness of a pulse oximeter depends on the form in which the information is presented to the clinician. Both groups were presented with clear visual representations of measured arterial oxygen desaturation and a pulse beep, but without a signal that varied its pitch with desaturation, the response time of group B was much longer. To appreciate the value of different monitors, we need to know not only which monitors were the first to identify a critical incident but also what aspect of the signal was useful.[6] The operating room environment places many demands on the faculties of the anaesthetist who may often be attending to more than one task at a time. Monitors with pre-set threshold alarms allow clinicians the reassurance to focus attention where it is most required. An audible alarm can alert a preoccupied anaesthetist even when the visual alarm signal is out of sight. Response times to auditory alarms are significantly less than responses to a visual alarm.[7] However, among the monitors currently used in anaesthetic practice the pulse oximeter is unique in that it

can provide *continuous* auditory information on the level of oxygen saturation by changing the pitch of its beep, and provide continuous background information to the anaesthetist on the rate and rhythm of the patient's heart rate and arterial oxygen saturation whether or not the anaesthetist is looking at the monitor.

We found that a variable rather than a fixed pitch pulse oximeter tone allowed faster detection of hypoxaemia. This difference was present despite the fact that the study took place in the simulator where experience has shown that subjects tend to be very vigilant and where the only distraction for the anaesthetist was keeping an anaesthetic chart. The difference could be more obvious in the more distracting environment of a real anaesthetic room/operating theatre or while the anaesthetist is engaged in practical tasks such as inserting lines or epidural catheters. While it has long been recognized that auditory alarms increase the effectiveness of visually displayed warnings of alarm limits that have been exceeded, the value of auditory components to the continuously monitored signal has not been as clearly demonstrated. Using the pulse tone from the pulse oximeter rather than the ECG, with the variable tone switched on, is a simple and cheap way of improving patient safety.

This concept could be extended to other forms of monitoring, such as end-tidal carbon dioxide concentration, although the already complex noise environment of theatre[8] and the 'irritation factor'[9] of any such signal would have to be considered carefully.

Acknowledgement

We thank Mr Alan Jones, facilities manager of the Bristol Medical Simulation Centre, for assistance.

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