

- covery phase of general anesthesia, *Pulse Oximetry*. Edited by Payne JP, Severinghaus JW. Dorchester, Springer-Verlag, 1986, pp 165-172
12. Pologe JA: Pulse oximetry: Technical aspects of machine design. *Int Anesthesiol Clin* 25:137-153, 1987
 13. Block FE, Detko GJ: Minimizing interferences and false alarms from electrocautery in the Nellcor N-100 pulse oximeter. *J Clin Monit* 2:203-205, 1986
 14. Kim JM, Arakawa K, Benson KT, Fox DK: Pulse oximetry and circulatory kinetics associated with pulse volume amplitude measured by photoelectric plethysmography. *Anesth Analg* 65: 1333-1339, 1986
 15. Cote CJ, Goldstein EA, Fuchsman WH, Hoaglin DJ: The effect of nail polish on pulse oximetry. *Anesth Analg* 67:683-686, 1988
 16. Sessler DI, Olofsson CI, Rubinstein EH: The thermoregulatory threshold in humans during nitrous oxide-fentanyl anesthesia. *ANESTHESIOLOGY* 69:357-364, 1988
 17. Pologe JA: The theory and principles of pulse oximetry. *J Periartol* 7:320-322, 1987

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Desaturation Noted by Pulmonary Artery Catheter Oximeter after Methylene Blue Injection

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Oxyhemoglobin saturation of mixed venous blood ($S\bar{v}O_2$) reflects a balance between oxygen supply and demand. Many physicians have used this parameter to evaluate the adequacy of oxygen transport in the critically ill and in patients undergoing major surgery.^{1,2} The saturation measured by catheter oximetry correlates well with values obtained from a laboratory co-oximeter, particularly when a three wavelength catheter is used.³

Previous reports⁴⁻⁷ have drawn attention to the association between artifactual decreases in oxyhemoglobin saturation as measured by pulse oximetry (SpO_2) and intravenously administered dyes. The effects of intravenously administered methylene blue on continuous mixed venous oximetry have not yet been described.

We report two cases in which the iv administration of methylene blue caused a significant decrease in the oxyhemoglobin saturation measured by the Opticath® pulmonary artery catheter (SxO_2), (Abbott Critical Care Systems, Mountain View, California):

CASE REPORTS

Case 1. A 54-yr-old man with bladder cancer but otherwise healthy was scheduled to undergo radical cystectomy and formation of a continent colonic reservoir.

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Anesthesia was induced with sufentanil and maintained with N_2O , O_2 , isoflurane, and sufentanil. Paralysis was provided by vecuronium. Intraoperative monitoring included electrocardiogram, precordial stethoscope, oral temperature, intraarterial blood pressure, noninvasive automated blood pressure, end-tidal CO_2 ($ETCO_2$) tension, and finger pulse oximetry (O2SATMED). The latter three integrated in the monitoring modules of the Narkomed 3 anesthesia system (North American Dräger, Telford, Pennsylvania).

After surgery started a 7.5-Fr fiberoptic pulmonary artery (PA) catheter (Opticath® model P-7110) was inserted *via* the right internal jugular vein. The fiberoptic PA catheter was connected to a saturation/cardiac output computer (Oximetrix® 3 System). The procedures recommended by the manufacturer for pre-insertion calibration and light intensity calibration were followed. During the initial portion of the operation, the SxO_2 and the SpO_2 ranged 78-85%, and 99-100%, respectively.

After completion of the resection, 100 mg (10 ml) of methylene blue was injected over 10 s *via* a peripheral iv catheter to evaluate urinary patency. Within 30 s the SxO_2 , which was 78% before the injection, decreased to 13% (fig. 1). There were no changes in other monitored parameters obtained at the SxO_2 nadir, including cardiac output, heart rate, pulmonary artery pressure, wedge pressure, and mean arterial blood pressure (table 1). The hematocrit was also unchanged. At the same time, a mixed venous specimen sent for blood gas analysis disclosed a $P\bar{v}O_2$ of 31 mmHg (calculated saturation 68%) compared with 35 mmHg (calculated saturation 78%) prior to the dye administration.

The SpO_2 decreased to 22% at 30 s after the methylene blue administration. The SpO_2 and SxO_2 returned to baseline within 5 and 10 min, respectively. At the end of the otherwise uneventful operation, the patient was transferred to the recovery room.

Case 2. A 67-yr-old man was admitted to the surgical emergency room after a motor vehicle accident. On admission he was hypotensive and noted to have ischemic changes on the electrocardiogram. After resuscitation his workup disclosed multiple bone fractures. The patient was transferred to the surgical intensive care unit to continue fluid resuscitation, monitoring, and respiratory support. Monitoring included electrocardiogram, intraarterial blood pressure, and SpO_2 (Nellcor® N-200). A 7.5-Fr fiberoptic PA catheter (Opticath® model P-7110) was inserted *via* the right subclavian vein and was connected to the saturation/cardiac output computer.

On the second day after admission, the patient underwent fixation of bilateral tibia and fibula fractures. Postoperatively, the patient de-

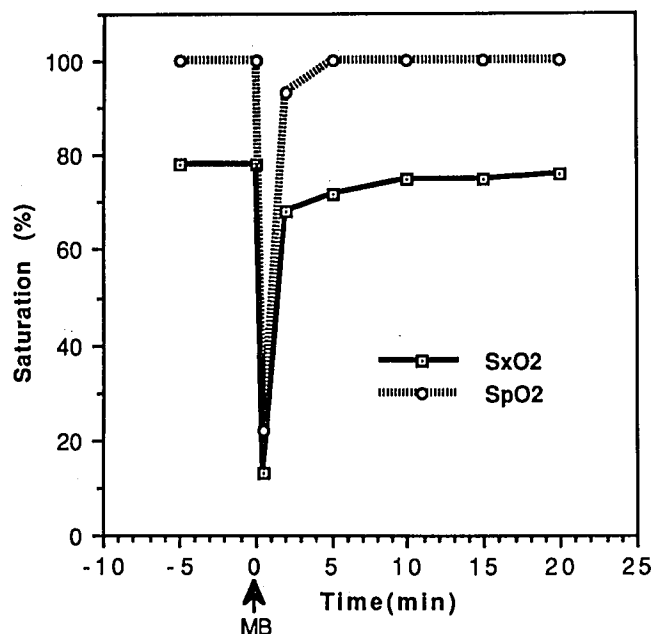


FIG. 1. Decrease in the oxyhemoglobin saturation as measured by the Opticath® (SxO₂) and oxyhemoglobin saturation as measured by pulse oximetry (SpO₂) after administration of methylene blue (MB) 100 mg iv in case 1.

veloped progressive respiratory insufficiency and dysrhythmias. A myocardial infarction was confirmed by cardiac enzyme determinations.

On the sixth day after admission, the patient was hemodynamically stable; however, it was noted that the drainage of a right chest tube had dramatically increased to 675 ml over 4 h. While waiting for a repeat chest radiograph, methylene blue 100 mg (10 ml) was administered over 10 s via the PA catheter introducer to see if it extravasated into the pleural cavity. Within 20 s of the dye administration, the SxO₂, which had been 73%, decreased to 30% while the SpO₂ was still 97%. At 30 s the SxO₂ was 51% and the SpO₂ 44%. At this time the patient was clinically stable and hemodynamic measurements, including

TABLE 1. Values for Physiologic Parameters Measured Before and 30 s After the Injection of Methylene Blue in Case 1

| Parameter | Before | After |
|--------------------------|--------|-------|
| SxO ₂ (%) | 78 | 13 |
| SpO ₂ (%) | 100 | 22 |
| HR (beats/min) | 74 | 73 |
| ETCO ₂ (mmHg) | 28 | 29 |
| MAP (mmHg) | 74 | 88 |
| MPAP (mmHg) | 14 | 15 |
| PCWP (mmHg) | 4 | 6 |
| CO (l/min) | 6.4 | 7.2 |
| Pv̄O ₂ (mmHg) | 35 | 31 |
| Hct (%) | 28 | 28 |

SxO₂ = oxyhemoglobin saturation as measured by the Opticath®; SpO₂ = oxyhemoglobin saturation as measured by pulse oximetry; HR = heart rate; ETCO₂ = end-tidal carbon dioxide; MAP = mean arterial pressure; MPAP = mean pulmonary artery pressure; PCWP = pulmonary capillary wedge pressure; CO = cardiac output; Pv̄O₂ = mixed venous blood oxygen tension; Hct = hematocrit.

cardiac output, heart rate, pulmonary artery pressure, wedge pressure, and mean arterial pressure, were unchanged compared with the measurements obtained prior to the injection. The hemoglobin concentration was also unchanged. However, a mixed venous specimen sent for blood gas analysis disclosed a Pv̄O₂ of 33 mmHg (calculated saturation 59%) compared with 39 mmHg (calculated saturation 68%) prior to the injection. The SpO₂ and SxO₂ returned slowly to baseline within 5 and 15 min, respectively. No dye appeared in the right chest tube drainage, and the chest radiograph was later interpreted as showing appropriate intravascular catheter placement.

DISCUSSION

Presently available *in vivo* continuous catheter oximetry monitors work based on the principle of reflection spectrophotometry. By analyzing the light reflected by the blood at different wavelengths, the ratio of hemoglobin to oxyhemoglobin can be determined.

The Oximetrix® 3 System used by the Opticath® has three light-emitting diodes contained in an optical module, which provide the light sources for three selected wavelengths 670, 700, and 800 nm. Light from each of these diodes is sequentially transmitted at a rate of 244 pulses/s through a single optical fiber to illuminate the blood flowing past the catheter tip. This illuminating light is absorbed, refracted, and reflected depending upon the color and, therefore, oxyhemoglobin concentration of the blood. The reflected light is collected by a second fiber and returned through the catheter to a photodetector in the optical module. The relative intensities of the signals, representing the light levels at the three different wavelengths, allow two independent light ratios to be computed in the processor. The digital signal filtering and the methods utilized to determine and combine the light intensity ratios are proprietary. These ratios have been previously correlated to oxyhemoglobin saturations measured by a bench co-oximeter in laboratory preparations and in critically ill patients. Once the saturation is determined, the average for the preceding 5 s is displayed. §**

Methylene blue has been used in a variety of clinical situations including plastic, gynecologic, and urologic operations and for the treatment of methemoglobinemia. Methylene blue has a significant light absorbance in the 600–700 nm wavelength range⁷ (fig. 2). The range includes two of the three light wavelengths (670 and 700 nm) emitted by the Oximetrix® 3 System. If methylene blue absorbs some of the light emission, then less light

§ Sperinde JM, Senelly KM: The Oximetrix® Opticath® oximetry system: Theory and development, *Continuous Measurement of Blood Oxygen Saturation in the High Risk Patient*, vol 2. Edited by Fahey PJ. San Diego, Beach International, 1985, pp 59–80; and **Oximetrix® 3 SO₂/CO Computer Operating Manual. North Chicago, Illinois, Abbott Critical Care Systems, 1986.

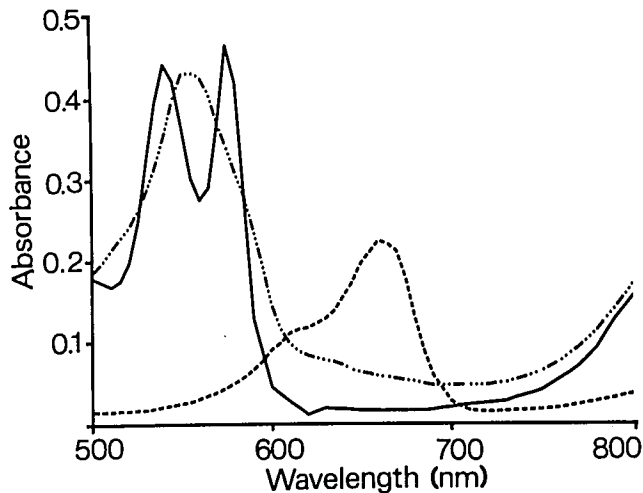


FIG. 2. Light absorbance spectra of methylene blue (---), hemoglobin (-·-·-·-·-), and oxyhemoglobin (—). (Reprinted from Gorman ES, Shnider MR: Effect of methylene blue on the absorbance of solutions of haemoglobin. *Br J Anaesth* 60:439-444, 1988, with permission.)

will be reflected and the monitoring system will display a lower saturation.

Other factors contributing to the decrease in Sx_{O_2} when methylene blue was injected must be excluded. $S\bar{v}O_2$ may decrease when there is an imbalance between oxygen consumption and delivery caused by a decrease in cardiac output, hemoglobin, or arterial oxyhemoglobin saturation or an increase in oxygen consumption. These interactions can be explained by the Fick equation solved for $S\bar{v}O_2$:

$$S\bar{v}O_2 = Sa_{O_2} - \left(\frac{\dot{V}_{O_2}}{CO * Hgb * 1.39 * 10} \right)$$

where Sa_{O_2} = arterial oxyhemoglobin saturation, Hgb = hemoglobin concentration, CO = cardiac output, and \dot{V}_{O_2} = oxygen consumption.

We did not observe changes in cardiac output, heart rate, pulmonary artery pressure, wedge pressure, mean arterial pressure, or hemoglobin concentration when the Sx_{O_2} decreased after the iv administration of methylene blue 100 mg in our two patients. In the second case, the immediate (within 20 s) decrease in Sx_{O_2} before the Sp_{O_2} decreased significantly suggests that this phenomenon occurred as the dye passed through the pulmonary artery and altered the light absorbancy characteristics of the blood as it passed by the catheter fiberoptic bundle the first time. This occurred before the blood containing methylene blue could have transversed the myocardial capillaries and thus affect cardiac function or the systemic capillaries and thus affect oxygen utilization. Later, however, a lesser portion of the decrease may have resulted

due to a decrease in $P\bar{v}O_2$ and a true decrease in $S\bar{v}O_2$ secondary to increased systemic oxygen utilization.

Sidi *et al.*⁶ noted a transient but significant decrease in cardiac output and an increase in both systemic vascular resistance and pulmonary vascular resistance within the first 30 s of administering 5 mg/kg of iv methylene blue to dogs anesthetized with barbiturate. In another study in awake dogs, Imai *et al.*⁸ reported that methylene blue 4 mg/kg followed by an infusion at a rate of $0.15 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ had no significant effect on either cardiac output or oxygen consumption during the first 25 min of the infusion. However, the measurements were performed after 4 min of starting the dye administration; therefore, earlier changes in these parameters cannot be ruled out. These doses are about 3 times the dose given to the patients discussed here. In a study in human volunteers, Scheller *et al.*⁵ noted that methylene blue 50 mg administered iv was well tolerated. No change in heart rate or blood pressure was observed in any of the subjects, but no other hemodynamic measurements were available.

Methylene blue has been effectively used in the treatment of methemoglobinemia⁹ but can also cause hemolysis and methemoglobin production.⁶ Methemoglobin decreases the oxygen carrying capacity of the blood and can also shift the oxygen hemoglobin dissociation curve to the left.¹⁰ We did not measure either oxyhemoglobin or methemoglobin with a bench co-oximeter because methylene blue may also interfere with the accuracy of these measurements.^{††} Nonetheless, methemoglobinemia is an unlikely explanation for the observed decreases in Sx_{O_2} and/or $P\bar{v}O_2$ because similar and even larger doses than the ones used in our patients have failed to produce clinically significant amounts of methemoglobin.¹¹⁻¹³

The Sx_{O_2} returned to baseline within 10-15 min in our two patients. The quick return to normal Sx_{O_2} readings most likely reflected the dilution of the dye and its rapid extensive uptake by body tissues.^{13,14}

In conclusion, methylene blue administered iv decreased the oxyhemoglobin saturation readings of the Opticath® pulmonary artery catheter. Most of this decrease is probably due to the high light absorbance of this dye in the wavelength range emitted by the monitoring system.

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†† IL 282 CO-Oximeter Operator's Manual. Lexington, Massachusetts, Instrumentation Laboratory Inc, 1977.

REFERENCES

1. Baele PL, McMichan JC, Marsh HM, Hill JC, Southern PA: Continuous monitoring of mixed venous oxygen saturation in critically ill patients. *Anesth Analg* 61:513-517, 1982

2. Nelson LD: Application of venous saturation monitoring, *Critical Care*. Edited by Civetta JM, Taylor RW, Kirby RR. Philadelphia, JB Lippincott, 1988, pp 327-334
3. Gettinger A, DeTraglia MC, Glass DD: *In vivo* comparison of two mixed venous saturation catheters. *ANESTHESIOLOGY* 66:373-375, 1987
4. Kessler MR, Eide T, Humayun B, Poppers PJ: Spurious pulse oximeter desaturation with methylene blue injection. *ANESTHESIOLOGY* 65:435-436, 1986
5. Scheller MS, Unger RJ, Kelner MJ: Effects of intravenously administered dyes on pulse oximetry readings. *ANESTHESIOLOGY* 65:550-552, 1986
6. Sidi A, Paulus DA, Rush W, Gravenstein N, Davis RF: Methylene blue and indocyanine green artifactually lower pulse oximetry readings of oxygen saturation. *J Clin Monit* 3:249-256, 1987
7. Gorman ES, Shnider MR: Effect of methylene blue on the absorbance of solutions of haemoglobin. *Br J Anaesth* 60:439-444, 1988
8. Imai N, Paley JI, Barold HS, Liang C: Effect of methylene blue on cardiac output response to exercise in dogs. *J Appl Physiol* 61:2012-2017, 1986
9. Wendel WB: The control of methemoglobinemia with methylene blue. *J Clin Invest* 18:179-185, 1938
10. Darling RC, Roughton FJW: The effect of methemoglobin on the equilibrium between oxygen and hemoglobin. *Am J Physiol* 137:56-68, 1942
11. Finch CA: Methemoglobinemia and sulfhemoglobinemia. *N Engl J Med* 239:470-478, 1948
12. Stossel TP, Jennings RB: Failure of methylene blue to produce methemoglobinemia in vivo. *Am J Clin Pathol* 45:600-604, 1966
13. Lamont AS, Roberts MS, Holsworth DG, Atherton A, Shepherd JJ: Relationship between methaemoglobin production and methylene blue plasma concentrations under general anaesthesia. *Anaesth Intensive Care* 14:360-364, 1986
14. DiSanto A, Wagner JG: Pharmacokinetics of highly ionized drugs: III. Methylene blue. *J Pharm Sci* 61:1090-1094, 1972

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Direct Cortical EEG Monitoring during Temporary Vascular Occlusion for Cerebral Aneurysm Surgery

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Anesthetic management of cerebral aneurysm clipping includes maintenance of an acceptable transmural pressure to prevent rupture of the aneurysm, especially during surgical manipulation. Systemic hypotension has been widely practiced to achieve this goal. Recently, there has been a trend toward increasing use of temporary vascular occlusion to secure surgical control of anatomically difficult lesions,^{1,2} thereby avoiding systemic hypotension.

Although highly desirable during vascular occlusion, monitoring of brain function with either somatosensory evoked potentials or standard scalp recording of EEG presents certain limitations during craniotomy for aneurysm clipping.³ We have therefore begun to use direct cortical recording using subdural strip electrodes. We report here results of cortical EEG monitoring during two cases of temporary vascular occlusion and the implications for patient management.

METHODS

The EEG data collection system consisted of a device producing a compressed spectral array (CSA) (Neurotrac®, Interspec Inc., Conshohocken, Pennsylvania) and an Apple Macintosh II computer. Either one or two channels of analog EEG data were processed and displayed. We examined multiple spectral descriptors, but present here only the ratio of power in the theta and delta bands to the power in the alpha and beta bands, $(D + T)/(A + B)$. The equipment and analysis algorithms are similar to systems described previously.^{4,5}

The EEG electrodes were Cortac® subdural strips (PMT Corp., Minneapolis, Minnesota). Each strip con-

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