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Conjunctival oxygen monitoring in postoperative respiratory failure and shock

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Introduction

There have been a variety of calculated variables used to assess tissue perfusion and oxygenation in critically ill patients, including O_2 delivery, O_2 consumption, and O_2 extraction. In postoperative and posttrauma patients, rapid shifts of body fluids as well as changes in cardiac and respiratory function, may lead to undetected episodes of hemodynamic instability if appropriate monitoring systems are not used. Yet, conventional monitoring techniques such as electrocardiography, temperature, arterial blood pressure, heart rate, urine output, and CVP are often of limited use for titrating therapy or predicting hemodynamic deterioration (1, 2).

The conjunctival oxygen ($PcjO_2$) sensor, which continuously and noninvasively monitors tissue oxygenation in a capillary bed only four to six cell layers beneath the palpebral conjunctival surface, was shown to reflect tissue perfusion and oxygenation during hyperoxia, hypoxia, and hemorrhagic shock in dogs (3). Furthermore, intraoperative $PcjO_2$ monitoring was found to be an effective method for assessing carotid oxygen delivery during carotid arterial surgery; reduced $PcjO_2$ was clearly demonstrated with systemic hypotension, as well as during periods of decreased carotid arterial blood flow secondary to mechanical causes (4).

In the present study, we assessed the clinical utility of continuous $PcjO_2$ monitoring while optimizing hemodynamic and oxygen transport variables in 11 patients with postoperative respiratory failure; five of these patients also suffered from varying degrees of circulatory shock. This study represents the first clinical report comparing noninvasive $PcjO_2$ monitoring with conventionally employed invasive monitoring techniques.

Materials and methods

Clinical material

The subjects for this study were 11 critically ill ICU patients with acute postoperative respiratory failure, 5 of whom also suffered from circulatory shock (Table 1). All of these patients manifested a clear deterioration of their ventilatory status as evidenced by respiratory arrest or severe hypoxemia requiring mechanical ventilation. All patients were on controlled ventilation with a Bennett MA-1 ventilator and had radial and balloon-tipped pulmonary artery catheters in place. The patients were studied as early as possible in the course of their respiratory distress to evaluate the utility of $PcjO_2$ monitoring during times when frequent therapeutic interventions were required. Thus, $PcjO_2$ monitoring was performed during periods of ventilator adjustment and with administration of intravenous fluids, blood, blood components, vasopressors and vasodilators.

Conjunctival O_2 sensor

The conjunctival oxygen sensor (Orange Medical

Table 1. Clinical Data.

Patient initials	Age/ sex	Diagnosis	Operation	Complications	PaO_2/FiO_2	Cardiac index (Mean ± SD)[a]	Blood volume index[b]	Out-come
S.S.	38/f	UGI hemorrhage, gastroesophageal varices, cirrhosis, ascites, chronic pancreatitis	Portal-caval shunt, cholecystectomy	ARDS, CHF, renal failure, sepsis	64/0.7	3.70 ± 0.48	2.37	Died
S.M.	73/F	Pancreatic cancer, obstructive jaundice, cholangitis	Percutaneous biliary drainage	Respiratory arrest, sepsis	70/0.4	2.59 ± 0.38	2.83	Died
J.O.	52/F	Perforated duodenal ulcer, necrotizing, granulomatous hepatitis	Vagotomy and Antrectomy	Hepatic failure, ARDS, ?sepsis	81/0.7	2.80 ± 0.22	2.47	Died
C.L.	31/M	MVA, blunt abdominal trauma, liver disruption	Exploratory laparotomy, evacuation of hepatic hematoma	ARDS, hemorrhagic shock	64/1.0	1.37 ± 1.19	2.81	Died
M.F.	38/M	UGI hemorrhage, osophageal varices, cirrhosis, ascitis	Portal-caval shunt	ARDS, hepatic failure	32/0.7	7.16 ± 1.41	2.71	Died
T.B.	36/M	Crush injury to abdomen, avulsed cecum	Exploratory laparotomy, right hemicolectomy; drainage of multiple intraabdominal abcesses	Sepsis, renal failure, ARDS	73/0.7	4.05 ± 0.53	2.56	Died
Y.H.	47/F	Systemic lupus erythematosus, diverticulitis	Exploratory laparotomy, sigmoid colectomy; drainage of intraabdominal abcess, colostomy	Sepsis, renal failure, ARDS, multiple enteroculaneous fistulae	64/0.7	4.62 ± 0.19	2.34	Died
F.P.	40/M	Gunshot wound to liver, gall bladder and colon	Exploratory laparotomy, colectomy, cholecystectomy; drainage of multiple intraabdominal abcesses	Sepsis, ARDS, renal failure	73/0.8	5.73 ± 0.57	2.54	Sur-vived
N.R.	29/M	UGI hemorrhage, esophageal varices, cirrhosis, ascites	Porta-caval shunt	ARDS, hepatic failure, aspiration pneumonia, sepsis	70/1.0	7.95 ± 0.35	3.25	Died

Table 1. (Continued).

Patient initials	Age/ sex	Diagnosis	Operation	Complications	PaO_2/FiO_2	Cardiac index (Mean ± SD)[53a]	Blood volume index[b]	Out-come
E.H.	64/F	Hodgkins lymphoma	Exploratory laparotomy, excision of retroperitoneal mass; control of intraabdominal hemorrhage	ARDS, sepsis, intraabdominal hemorrhage, esophageal tear, mediastinitis	69/0.4	2.98 ± 0.14	3.22	Died
J.M.	59/M	Peptic ulcer disease	Vagotomy and antrectomy; drainage of multiple intraabdominal abcesses	Multiple enterocutaneous fistulae, pneumonia, ARDS, sepsis, DIC	56/0.9	1.75 ± 0.22	2.77	Died

[a] Normal = 3.0–3.4 L/min m^2

[b] Normal = 2.37 L/M^2 in females and 2.74 L/m^2 in males

Instruments; Costa Mesa, Calif.) consists of a miniaturized Clark-type electrode with a silver-silver chloride anode and platinum cathode; the instrument also contains a precision thermistor which serves to correct for the Clark electrode temperature-dependant variations and to provide a measurement of local tissue temperature (Fig. 1). All components are embedded in a polymethylmethacrylate conformer designed to fit into the superior and inferior conjunctival fornices. The sensor characteristics include a 90% response time of less than 40 seconds, a sensitivity drift of less than 1% per h and an absolute temperature accuracy of ± 0.1° C. Sensor preparation has been described elsewhere (4).

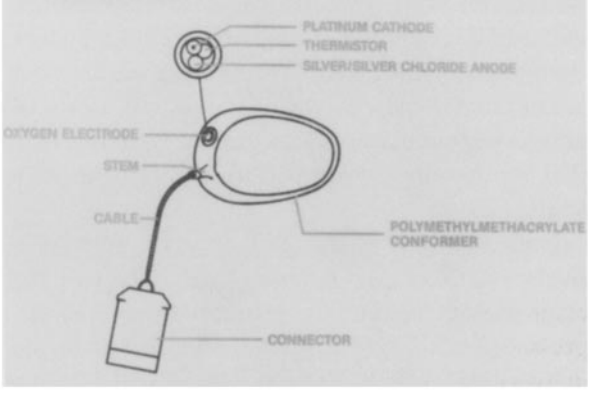

Fig. 1. Diagram of the conjunctival oxygen sensor.

Physiologic measurements

Systemic and pulmonary arterial pressures, central venous pressure (CVP), pulmonary artery wedge pressure (WP) and cardiac output were measured by previously described methods (1). Cardiac output was determined, in duplicate or triplicate, by the thermal dilution technique (Edwards Laboratories; Santa Ana, Calif.); simultaneous arterial and mixed venous blood gas samples were obtained and analyzed using a Corning Model 165 pH/blood gas analyzer. Oxygen delivery, defined as the product of cardiac index and arterial O_2 content, and oxygen consumption were calculated from these measurements by standard formulas and indexed by dividing the values by body surface area.

Prior to each study, the patient's blood volume was measured with iodinated I-125 serum albumin because of previous observations that neither CVP nor WP accurately reflected the actual blood volume measurements in critically ill postoperative patients (5, 6). If the indexed volume was less than normal (2.37 L/m^2 in females and 2.74 L/m^2 in males), the patient was given a volume load consis-

ting of 500 ml plasma protein fraction or 100 ml 25% albumin, if the hematocrit was 32% or greater, or packed red blood cells if the hematocrit was less than 32% (7, 8).

Protocol

Following two-point calibration, the $PcjO_2$ sensor was placed in the patient's right eye by gently retracting the upper eyelid and inserting the upper rib of the conformer into the superior conjunctival fornix, followed by retraction of the lower eyelid and insertion of the lower rib of the conformer into the inferior conjunctival fornix. One or two drops of an ophthalmic anesthetic agent was used prior to sensor placement. Usually the eyelid was taped closed. Because the $PcjO_2$ sensor does not require heating in order to measure tissue oxygen tension, stabilization of the electrode usually occurred within five minutes after placement.

In the control period, two sets of baseline data were taken. Repeated data sets were then obtained immediately before and 10–20 min following major therapeutic interventions. The data acquisition was accelerated in patients who were unstable or showed signs of circulatory compromise. Calibration of the $PcjO_2$ sensor was rechecked following each study.

Data for each of the patients were retrospectively evaluated for periods of respiratory or circulatory compromise, as evidenced by severely depressed PaO_2, PvO_2 cardiac index (CI), oxygen delivery or oxygen consumption. The $PcjO_2$ and conjunctival index (CjI), defined as the $PcjO_2$ divided by the PaO_2, was compared between those patients who were ventilatory or hemodynamically unstable and those that were stable.

Results

The $PcjO_2$ values in patients who were hypoxic ($PaO_2 \leq 70$ torr) were appreciably lower than those in patients with normal PaO_2 tensions (Table 2). Patients with severe hypoxemia ($PaO_2 < 60$ torr) consistently had $PcjO_2$, values less than 40 torr (Fig. 2). Mixed venous oxygen tensions (PvO_2) less than 32 torr were associated with even greater

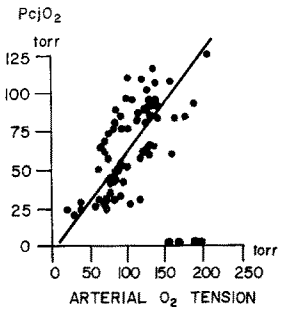

Fig. 2. Relationship of conjunctival and arterial oxygen tension in 11 patients with postoperative respiratory failure with and without circulatory shock (n = 89).

decreases in $PcjO_2$ tension (Table 2). This is illustrated in a representative patient in whom positive end-expiratory pressure was progressively increased from 0 to 20 cm H_2O with the FiO_2 kept constant at 0.70 (Fig. 3).

The CjI varied directly with the circulatory status of the patient (Table 3); CjI values were decreased in association with decreased CI, oxygen delivery or oxygen consumption values. Patients in severe circulatory shock (CI <2.0 L/min m^2 or oxygen delivery <250 ml/min m^2) consistently had CjI values less than 0.4. Decreased CjI values were also seen in association with depressed oxygen consumption.

The overall mortality of the study group was 10/11 (91%). There were no complications associated with use of the $PcjO_2$ sensor during or after the monitoring protocol. Continuous $PcjO_2$ monitoring was performed for a duration ranging from 2–10 hours in each patient. Data regarding $PcjO_2$

Table 2. Relationship of conjunctival oxygen ($PcjO_2$) tension with arterial and mixed venous oxygen tensions.

	$PcjO_2$ values	
	N	$PcjO_2$ (torr)
PaO_2 <70 torr	13	36 ± 14
PaO_2 70–100 torr	29	50 ± 19
PaO_2 >100 torr	47	76 ± 30
$PvO_2 \leq 32$ torr	15	22 ± 12
PvO_2 >32 torr	74	70 ± 25

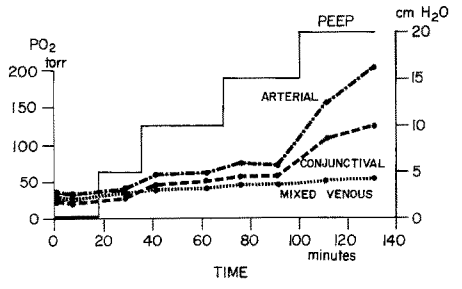

Fig. 3. Sequential arterial, conjunctival and mixed venous oxygen tensions during optimization of PEEP therapy in representative patient with severe respiratory failure (ARDS). The FiO_2 was kept constant at 0.70.

monitoring for longer periods of time is not presently available.

Discussion

Intermittently measured hemodynamic and oxygen transport variables are frequently used to assess the overall circulatory status in critically ill patients; the calculated oxygen delivery and consumption variables reflect systemic hemodynamics and oxygen transport. Measured $PcjO_2$ tension, on the other hand, reflects local oxygen transport at the tissue level. Disturbances of tissue perfusion not only accompany, but often precede, major deteriorations in conventionally monitored variables (9–11).

Measurement of conjunctival O_2 tension serves as a noninvasive method for assessing tissue perfusion. Furthermore, $PcjO_2$ monitoring allows on-line, real-time assessment of oxygen transport during periods of hemodynamic instability and may serve as an early indicator of changes in cardiorespiratory function. For example, one patient in the present series with respiratory failure and hemorrhagic shock had a $PcjO_2$ tension less than 5 torr for a duration of 40 min prior to cardiac arrest and death; the PaO_2 was well above 150 torr throughout this same period. Severely low $PcjO_2$ tensions immediately prior to cardiovascular collapse and death have been previously reported (10, 11).

Therapy for acute respiratory failure should be titrated in an ongoing basis to achieve optimal physiologic goals; a major function of the ICU is to obtain physiologic measurements at the bedside and to apply them to the titration of therapy to achieve these goals (7, 12). In the present study, we used $PcjO_2$ monitoring to aid in the titration of respiratory, cardiovascular and volume therapy in patients with acute postoperative respiratory failure with and without circulatory shock and multiple vital organ failure. Conjunctival O_2 monitoring was especially useful during titration of ventilatory therapy (Fig. 3), giving immediate information regarding the adequacy of ventilator adjustments to improve tissue oxygenation. $PcjO_2$ monitoring should not replace the judicious use of arterial blood gas measurements, but since $PcjO_2$ values are dependant on both the arterial oxygen tension and cardiac output (3), they may signal circulatory compromise that might not be detected by arterial blood gas measurement alone.

Measured $PcjO_2$ values were consistently depressed during episodes of severe respiratory or hemodynamic instability, as manifested by low PaO_2 or CI (Tables 2 and 3). From a practical standpoint, when the $PcjO_2$ is depressed, an arterial blood gas measurement should be obtained. If the PaO_2 is normal, but the CjI is depressed, a cardiac output determination should be performed. Normal PaO_2 associated with decreased $PcjO_2$ is reflected by a reduced CjI value indicating poor flow, while decreases in both PaO_2 and $PcjO_2$ indicate inadequate ventilation (3).

We conclude that noninvasive $PcjO_2$ monitoring is a valuable adjunctive method to assess tissue

Table 3. Relationship of conjunctival index (CjI) with cardiac index (CI), oxygen delivery (DO_2) and oxygen consumption (VO_2).

	CjI values	
	N	CjI
CI ≤2.5 L/M/m²	15	0.32 ± 0.17
CI >2.5 L/M/m²	74	0.64 ± 0.20
DO_2 ≤300 ml/M/m²	15	0.30 ± 0.19
DO_2 >300 ml/M/m²	74	0.65 ± 0.19
VO_2 ≤100 ml/M/m²	23	0.48 ± 0.21
VO_2 >100 ml/M/m²	66	0.63 ± 0.22

perfusion and oxygenation, and to titrate therapy in critically ill surgical patients.

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References

1. Shoemaker WC, Montgomery ES, Kaplan E: Physiologic patterns in surviving and nonsurviving shock patients. Arch Surg 106: 630, 1973.
2. Lewis FS, Quinn ML: Continuous electrocardiogram monitoring in a surgical ICU. Crit Care Med 5: 73, 1977.
3. Shoemaker WC, Fink S, Ray CW: Effect of hemorrhagic shock on conjunctival and transcutaneous oxygen tensions in relation to hemodynamic and oxygen transport changes. Surgery Crit Care Med (in press).
4. Kram HB, Bratanow N, White RA: Conjunctival and transcutaneous oxygen monitoring during carotid arterial surgery. Crit Care Med (submitted).
5. Baek SM, Makbali GG, Bryan-Brown CW: Plasma expansion in surgical patients with high central venous pressure (CVP); the relationship of blood volume to hematocrit, CVP, pulmonary wedge pressure, and cardiorespiratory changes. Surgery 78: 304, 1975.
6. Shippy CR, Appel PL, Shoemaker WC: Reliability of clinical monitoring to assess blood volume in critically ill patients. Crit Care Med 12: 107, 1984.
7. Walkinshaw M, Shoemaker WC: Use of volume loading to obtain preferred levels of PEEP. A preliminary study. Crit Care Med 8: 81, 1980.
8. Shoemaker WC: Fluid management. Sem Anesthesiol 2: 251, 1983.
9. Tremper KK, Waxman K, Bowman R: Continuous transcutaneous oxygen monitoring during respiratory failure, cardiac decompensation, cardiac arrest, and CPR. Crit Care Med 8: 377, 1980.
10. Abraham E, Smith M, Silver L: Conjunctival and transcutaneous oxygen monitoring during cardiac arrest and cardiopulmonary resuscitation. Crit Care Med 12: 419, 1984.
11. Isenberg SJ, Shoemaker WC: The transconjunctival oxygen monitor. Am J Opthamology 95: 803, 1983.
12. Waxman K, Shoemaker WC: Management of postoperative and posttraumatic respiratory failure in the intensive care unit. Surg Clin North Am 60: 1413, 1980.

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