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☐ Original Article ☐

Pulse Oximetry during Shunt Surgery in Pediatric Patients with Tetralogy of Fallot

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Pulse oximetry is a noninvasive technique for measuring O_2 saturation (SpO_2) continuously. We applied pulse oximetry to 9 pediatric patients with tetralogy of Fallot during shunt surgery. Arterial oxygen tensions (PaO_2) and saturations (SaO_2) were also measured at the time of postinduction, just before the shunt, after the shunt and at the end of the operation. The SpO_2 and SaO_2 levels were identically changed in all 4 periods. The PaO_2 was increased a little without statistical significance after the shunt procedure and at the end of the operation compared with the values before the shunt. However, SaO_2 values increased with statistical significance after the shunt procedure and SpO_2 values also showed similar increases with significance. In conclusion, continuous monitoring of SpO_2 by pulse oximetry, instead of PaO_2, is a very useful and reliable method to assess the improvement of perfusion after shunt, particularly in cyanotic cases.

Key Words: Measurement techniques: pulse oximetry, blood, hemoglobin: saturation.

Tetralogy of Fallot is one of the serious congenital cardiac malformations commonly accompanied by cyanosis. Total correction has been successfully achieved in most cases by surgical treatment, but in some forms of tetralogy of Fallot a shunt operation is required because the anatomy and physiology require maturation before total correction is possible. The physiologic goal of the shunt is to obtain sufficient blood flow to maintain an acceptable arterial oxygen content when oxygenated pulmonary venous blood returns to the heart and mixes with systemic venous blood. Optimally, the surgical shunt should provide a restrictive shunt allowing an adequate, but not excessive pulmonary blood flow. Immediately after the shunt the improved oxygenation status of the systemic circulation can be assessed through arterial blood gas tensions. The arterial blood gas analysis is accurate, but invasive, and time is required to get the result, and it can not monitor the oxygenation status continuously.

Pulse oximetry has recently been developed to measure oxygen saturation noninvasively and continuously. It has been reported that oxygen saturation as determined by pulse oximetry correlates closely with direct SaO_2 measurements (Yelderman and New Jr 1983).

Oxygen saturation in infants and children with cyanotic congenital heart disease lies on the steep portion of the oxyhemoglobin dissociation curve (Deckart and Stewart 1984), thus it can be expected that changes in SaO_2 at this portion are much greater than those in PaO_2.

On the basis of this assumption, we applied pulse oximetry to evaluate the significance of changes of oxygen saturation during shunt surgery in pediatric patients with tetralogy of Fallot.

PATIENTS AND METHODS

Nine pediatric patients with tetralogy of Fallot were studied and the demographic data are shown in Table 1.

As a premedication, diazepam 0.2 mg/kg was administered orally 90 minutes before operation. Thirty minutes later atropine 0.01 mg/kg, meperidine 0.5 mg/kg and hydroxyzine 0.5 mg/kg were administered intramuscularly.

Anesthesia was induced with ketamine 1 mg/kg and vecuronium 0.1 mg/kg was given intravenously to facilitate endotracheal intubation. Bain circuit was used and ventilation was mechanically controlled with pure oxygen. A cannula was inserted into a radial artery for blood sampling and continuous monitor-

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Table 1. Demographic data

	No. of cases
Age (months)	18.22±24.94*
Weight (kg)	9.38±3.63*
Height (cm)	74.86±14.87*
Sex (m/f)	4/5
Diagnosis	
TOF	6
TOF with PDA	3
Operation (shunt)	
modified Blalock-Taussig	6
modified Waterston-Cooley	3
Shunted sites of pulmonary artery	
left pulmonary artery	6
right pulmonary artery	3

TOF: tetralogy of Fallot, PDA: patent ductus arteriosus
* Mean±SD, n=9

ing of arterial blood pressure. The finger probe for pediatric use of the Biox 3700 pulse oximeter (Ohmeda, Boulder, Co, USA) was placed on the thumb or great toe. The site of radial artery cannulation and placement of the probe was chosen on the contralateral side of the operating site.

Ketamine 0.2% was infused at a rate of 2 mg/kg/hr under the control of an IVAC infusion pump (model No. 530, San Diego, CA, USA). CVP catheterization was done via the external or internal jugular vein.

Six patients were operated in the lateral decubitus position following anesthetic induction. The changes of the SpO_2 levels were recorded throughout the operation (Fig. 1). Pancuronium was administered intermittently. Fresh frozen plasma was used for hemodilution and volume replacement when transfusion was needed. Dopamine and Ephedrine were given when circulatory instability occured and sodium

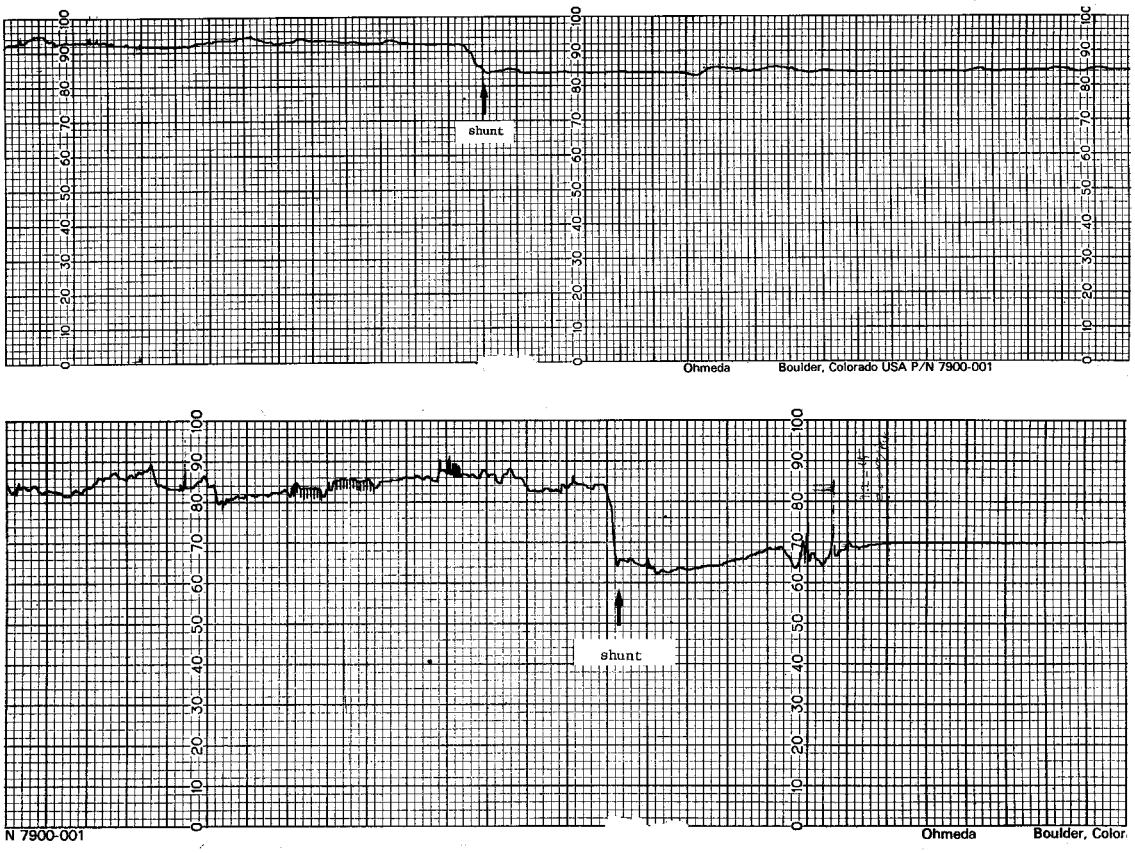

Fig. 1. *Changes of SpO_2 following the shunt. SpO_2 increased from 84% to 93% following the shunt in case above and from 64% to 85% in case below.*

bicarbonate was administered when metabolic acidosis was present. Arterial blood samples were analyzed by a NOVA blood gas analyzer (NOVA Biomedical, Waltham, MA, USA) at the time of postinduction, before the shunt, immediately after the shunt and at the end of the operation. The SaO_2 values were compared with the SpO_2 reading on the digital display of the pulse oximeter at the times when the arterial samples were obtained.

The two-sample Student's t-test was used to compare the SaO_2 values of the arterial blood gas study with the SpO_2 values of pulse oximetry. One-way ANOVA with the Scheffe procedure was used to test the significance of differences among the 4 arterial blood gas values and 4 pulse oximetry readings.

A p-value of less than 0.05 was considered statistically significant.

RESULTS

In the blood gas analysis the mean PaO_2 values in the periods of postinduction, before the shunt, after the shunt and at the end of operation were 52.61±9.25, 40.76±19.46, 57.37±13.15 and 58.49±22.32 mmHg, respectively (Table 2) but there were no statistical differences between the 4 periods.

The SaO_2 levels obtained from blood gas analysis in the 4 periods during the operation were 83.91±9.67, 68.30±20.29, 88.19±7.08 and 87.10±12.42, respectively.

These showed a more statistically significant increase in SaO_2 after the shunt and at the end of operation than before the shunt (Table 3).

The SpO_2 levels obtained by pulse oximetry in the 4 periods were 80.50±8.93, 72.11±14.63, 89.22±7.87 and 91.63±6.32%, respectively. There were no differences between the findings of O_2 saturation by blood gas analysis and pulse oximetry in each periods.

DISCUSSION

The pulse oximeter functions by placing a pulsating arterial vascular bed between a light source and a detector. The pulsating vascular bed, by expanding and contracting, creates a change in the light path that modifies the amount of light detected. Nonpulsatile substances such as skin, bone and venous blood are not detected. In order to determine the percentage of arterial hemoglobin saturated with oxygen, the oximeter measures the ratio of the pulse amplitude of a pulse in red light (660 nm) and compares it with the pulse amplitude of the same pulse in infrared light (940 nm). The ratio varies depending upon the sensitive fraction of saturated to unsaturated hemoglobin in the arterial blood. The ratio is used to calculate the SaO_2 (Brodsky et al. 1985).

The pulse oximeter has a few limitations, the most

Table 2. Changes in arterial blood gas analysis during operation

Mean±SD, n=9

	Postinduction	Before shunt	After shunt	End of op.
PaO_2 (mmHg)	52.61±9.25	40.76±19.46	57.37±13.15	58.49±22.32
SaO_2 (%)	83.91±9.57	68.30±20.29	88.19± 7.08*	87.10±12.42*
pH	7.34±0.93	7.35± 0.07	7.38± 0.07	7.44± 0.05*
$PaCO_2$ (mmHg)	38.12±8.25	42.72±11.42	40.70±13.92	35.00± 6.45
HCO_3^- (mEq/L)	20.63±2.39	23.38± 3.13	23.48± 4.89	23.82± 2.32
B.E. (mEq/L)	−3.17±4.35	−2.07± 1.64	−0.93± 3.36	0.59± 1.43

* $p<0.05$ vs before shunt
+ $p<0.05$ vs postinduction

Table 3. Changes of O_2 Saturation values by pulse oximetry and blood gas analysis

Mean±SD, n=9

	Postinduction	Before shunt	After shunt	End of op.
P.Oximetry (%)	80.50±8.93	72.11±14.63	89.22±7.87	91.63± 6.32
BGA (%)	83.91±9.57	68.30±20.29	88.19±7.08	87.10±12.42

significant being signal failure as a result of poor digital infusion. The oximeter may be unable to detect arterial saturations in patients who are hypothermic. Hypotension (mean blood pressure less than 50 mmHg), infusion of vasoconstrictive drugs, and peripheral vascular disease may also result in pulse oximeter signal failure. We attached the finger probe at the site of the arterial cannulation and found that signal failure was not noted.

The presence of dyshemoglobinemia (carboxyhemoglobinemia, methemoglobinemia, sulfhemoglobinemia) may also affect the oximeter accuracy (Mihm and Halperin 1985).

During the surgical procedure, as the subclavian artery is partially clamped to anastomose the biological tube graft, the direct radial arterial pressure on the anastomosis site will be affected. If the flow is insufficient, pulse oximetry will be able to show signal failure, and then the SpO_2 reading will be inaccurate. The Ohmeda 3700 pulse oximeter is highly accurate when used with an ear probe, and responds quickly enough to be used for hypoxic drive determinations during acute desaturation. When used with a finger probe, the version J software tends to underestimate the arterial oxygenation when the SaO_2 level is below 90%. The prediction limits indicate that, when the SaO_2 level is below 90%. The prediction limits indicate that, when the SaO_2 level is 60%, the Ohmeda 3700 version J finger probe could conceivably give readings as low as 47%. The 24-s delay in finger as compared to ear probe readings is certainly within acceptable limits for most clinical situations (Kagle *et al.* 1987).

Although an increase in PaO_2 levels after the shunt in comparison with before the shunt was noted, the values were not different statistically. The $PaCO_2$ level was not changed through the operation. During the operation, as the nondependent lung was compressed to better ensure the surgical field, the chances of CO_2 retention were increased. We solved this problem by increasing the usual tidal volume. The actual bicarbonate and base excess were not changed. However, immediately after induction we frequently found metabolic acidosis, and sodium bicarbonate was administered for correction of the acid-base imbalance. Dopamine was administered in most cases for maintaining adequate systemic blood pressure.

As the pediatric patient is anesthetized in the lateral decubitus position, relaxed by a neuromuscular blocker and the thorax is opened, ventilation perfusion mismatch can occur. Surgical compression of the upper lung for easy visualization of the surgical field can also cause more hypoxia and hypercarbia (Miller 1986).

Positive pressure ventilation by a mechanical ventilator can decrease the pulmonary blood flow (Cournad *et al.* 1948). As the cardiac output in pediatric patients is dependent upon the heart rate, control of the pulse rate is very important.

Friesen (1985) and Casthely (1986) reported that pulse oximetry was valuable to detect the desaturation due to decreased pulmonary blood flow in pulmonary artery bending and shunt surgery. They could also prevent the occurrence of bradycardia and cyanosis immediately with the information provided by the pulse oximetry.

In conclusion, continuous monitoring of SpO_2 through pulse oximetry is a very useful and reliable method for assessing the improvement of pulmonary perfusion after the shunt instead of intermittent PaO_2 measurement.

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