Transcutaneous Monitoring of pCO_2 in Infants and Children After Cardiac Surgery

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Infants and children after cardiac surgery in most cases need mechanical ventilation for at least 24 h. Continuous monitoring of arterial pCO_2 would be of great importance for adequate adjustment of the ventilator. Recently cutaneous pCO_2-monitoring has been introduced into intensive care monitoring. To find out the validity of the correlation between cutaneous and arterial pCO_2 we made 50 simultaneous measurements of arterial and cutaneous pCO_2. In 38 instances the blood samples were taken from a radial artery catheter, in two from an umbilical artery catheter and in 10 arterialized capillary blood was used. The blood samples were analyzed in an "AVL-Gascheck" and for transcutaneous measurements the cutaneous pCO_2 electrode of "Roche" was used. The electrode was heated to 43 °C. The clinical data of the patients are listed in Table 1. The age of the patients ranged between one day and 8 years. Except in cases 1, 2 and 9 all measurements were performed within 24 h after operation. Patients 1 and 2 were in deep cardiac shock, therefore their data were analyzed separately. All other patients showed a good cardiac performance with normal blood pressure and normal skin temperature.

Results

Analysis of our data showed a highly significant correlation ($r = 0.9$) between cutaneous and arterial pCO_2 (Fig. 1). At least in the range 27 – 51 mmHg arterial pCO_2 the regression line is linear. In the hypercapnic region more data are necessary to confirm the linear regression. The data of the two babies in shock are also shown in Fig. 1. Their data show a

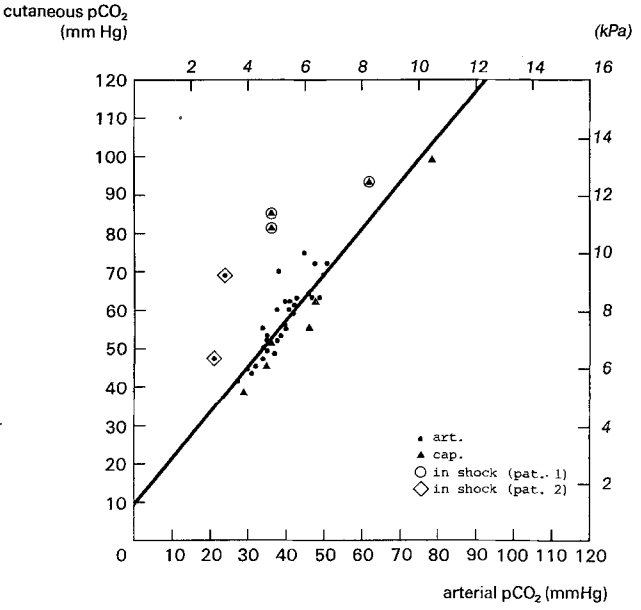

Fig. 1. Relationship between cutaneous and both arterial and hyperemized capillary pCO_2. Two patients in shock are not included in the regression equation.

Sensor core temperature:	43 °C
Number of patients:	16
Number of measurements:	50
Regression line:	$cpCO_2 = 1.21\ p_aCO_2 + 9.4$ mmHg
Standard error of estimate:	$s_{y/x} = 4.8$ mmHg
Correlation coefficient:	$r = 0.90$

Table 1. Clinical data of patients

Patient no.	Age	Sex	Diagnosis	Operation	Electrode location	Blood sample	No. meas.
1	1 day	m	aortic stenosis	–	chest	cap.	3
2	4 days	m	coarctation, VSD	–	abd.	umb.	2
3	6 months	m	VSD	closure of VSD	chest	rad.	3
4	6 months	f	patent ductus	ligation	chest	rad. + cap.	6
5	9 months	m	AV-canal	corrective surgery	abd.	rad.	3
6	10 months	f	VSD	closure of VSD	abd.	rad.	1
7	11 months	f	VSD	closure of VSD	chest	rad.	2
8	$1\frac{3}{12}$ years	m	Ondine's curse	phrenic pacer implantation	chest	cap.	7
9	$1\frac{3}{12}$ years	m	pulmonary stenosis	commissurotomy	chest	rad.	2
10	$1\frac{6}{12}$ years	m	pulmonary stenosis	commissurotomy	chest	rad.	3
11	$1\frac{7}{12}$ years	f	AV-canal	corrective surgery	abd.	rad.	5
12	3 years	m	Fallot	corrective surgery	chest	rad.	1
13	5 years	f	obstructive cardiomyopathy	resection of left ventricular outflow tract	chest	rad.	5
14	6 years	m	VSD	closure of VSD	chest	rad.	2
15	6 years	m	Fallot	corrective surgery	chest	rad.	2
16	8 years	f	Bland-White-Garland-syndrome	corrective surgery	chest	rad.	3

abd. = abdomen, cap. = capillary, umb. = umbilical artery, rad. = radial artery, meas. = measurements, VSD = ventricular septal defect

high difference between arterial and cutaneous pCO_2. The difference is variable.

In our clinical routine cutaneous pCO_2-monitoring has proven to be very useful for proper adjustment of the ventilator, for weaning the patient from the ventilator and for the time after extubation. In shock patients no estimation of the arterial pCO_2 from cutaneous measurements was possible. Perhaps the difference between arterial and cutaneous pCO_2 can be used as shock parameter.

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Transcutaneous pCO_2 Monitoring in Cardiopulmonary Bypass Patients

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Recently, there has been increasing interest in the development of noninvasive techniques for continuous arterial blood gas and acid-base measurement. Various studies have now been published on the monitoring of arterial pO_2 and pH via skin electrodes [1, 2]. The more recent development of transcutaneous pCO_2($tcPCO_2$) electrodes has created the possibility of continuous arterial blood pCO_2 (p_aCO_2) monitoring [3]. This study was carried out to assess the validity of $tcPCO_2$ as an index of p_aCO_2 in adult patients during normothermic continuous flow cardiopulmonary bypass (CPB) and during their recovery in the Intensive Therapy Unit (ITU).

Materials and Methods

The sensor (Roche Bio-electronics) was prepared, according to the manufacturer's instructions, and was calibrated daily using humidified CO_2 (5% and 10%) at room temperature (23° – 26°C). The temperature of the sensor was set at 44°C during calibration and for all measurements. The shoulder was used as the monitoring site, to prevent disturbance of the electrode during surgery.

Twelve adults, admitted for elective cardiac surgical procedures, were studied, their ages ranged from 24 to 72 years (mean, 52.3 ± 12.5). Operations were performed using a Bentley BOS-10 bubble oxygenator and 5% dextrose prime, with nitrous oxide oxygen and relaxant anaesthesia. Patients were not actively cooled during the operation but the mean lowest nasopharyngeal and skin temperatures were 33.2 ± 1.2°C and 30.1 ± 1.8°C respectively. The mean operating room temperature was 20.3 ± 1.4°C. Patients were warmed to above 37°C before discontinuing bypass. Post-operatively patients were nursed in the ITU, flat in bed, with the trunk and lower limbs covered with blankets. Controlled ventilation was continued for at least eight hours. Arterial and central venous pressures, rectal and skin temperatures were measured continuously and hourly urine output was recorded.

Blood samples were taken from the cannulated radial artery as clinically indicated and analysed immediately in duplicate using an automatic blood-gas analyser (Radiometer-ABL2). The measurements of p_aCO_2 were compared with the simultaneous $tcPCO_2$ values.

Results

A total of 85 paired arterial and transcutaneous pCO_2 observations were made, in the operating theatre, on 12 patients, and the correlation coefficient (r) for all measurements was 0.76 ($p < 0.01$). The values varied greatly during the operation viz. 0.84 before, 0.54 during and 0.62 after CPB, on 23, 34 and 28 samples respectively. Nor was the difference between values constant (Fig. 1).

The skin and core temperature were generally low when the patients arrived in the ITU. During the time of $tcPCO_2$ measurement (up to six hours) skin temperatures ranged from 25.4 to 36.1°C (mean 30.1 ± 4.2). Ambient temperature varied little (22.8 to 25.6°C) but the core temperature of 33.7 to 39.4°C indicated the poor cutaneous perfusion. Seventy intermittent (arterial) and continuous (transcutaneous) observations were made on 12 patients. Overall correlation was poor ($r = 0.59$) but the value of correlation coefficient between p_aCO_2 and $tcPCO_2$ varied from patient to patient ($0.5 < r < 0.9$). In all cases a change in ventilatory status was rapidly indicated by the $tcPCO_2$

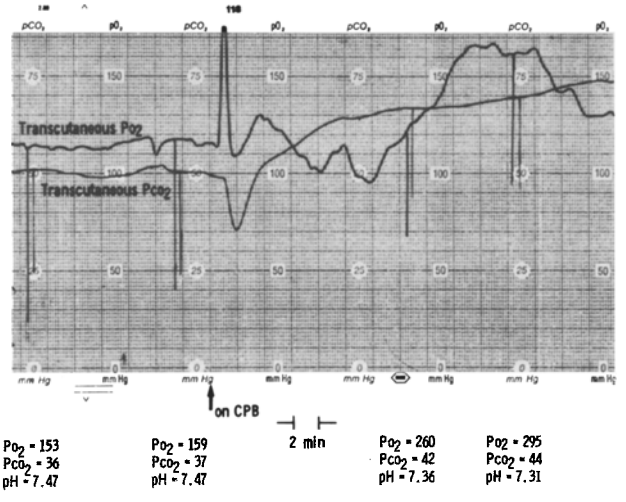

Fig. 1. Simultaneous recordings of $tcPO_2$ and $tcPCO_2$ in a patient during cardiopulmonary bypass. Arterial blood gas values measured in vitro are shown below the tracings