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 $tcPCO_2$

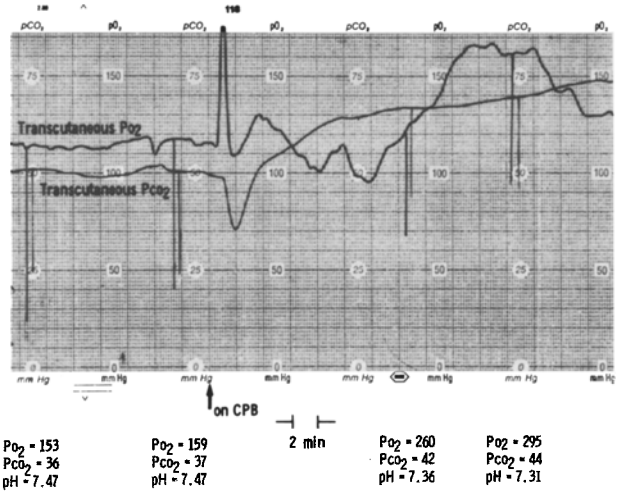

Fig. 1. Simultaneous recordings of $tcPO_2$ and $tcPCO_2$ in a patient during cardiopulmonary bypass. Arterial blood gas values measured in vitro are shown below the tracings

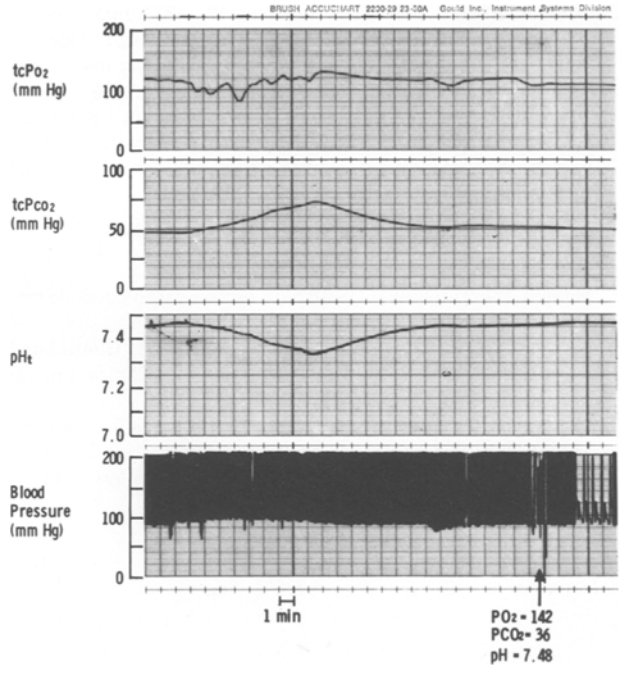

Fig. 2. Simultaneous recordings of transcutaneous pO_2 and pCO_2, tissue pH and arterial blood pressure in a mechanically ventilated patient who was recovering in the ITU after open-heart surgery

reading (Fig. 2). The measurements of transcutaneous pCO_2 were significantly higher than arterial values.

Discussion

Several factors, including elevated skin metabolism and an increase in pCO_2 from warming the blood beneath the heated electrode, contribute to higher $tcPCO_2$ levels [4]. However, a disproportionate rise in $tcPCO_2$ may be associated with the metabolic consequence of inadequate perfusion and hypoxia of the skin tissue under the electrode [5]. The arterial and transcutaneous pCO_2 measurements, therefore bear no relationship in haemodynamically unstable patients and reflect only the changes in peripheral tissue perfusion [6].

The results of this study indicate that $tcPCO_2$ is not a reliable substitute for p_aCO_2 in the patients studied. The potential usefulness of the $tcPCO_2$ electrode as a clinical monitoring device, however, lies in the ease with which it can be applied to the patient and used continuously thus alerting the clinician of rapid changes in the respiratory and metabolic status.

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Transcutaneous pO_2 and pCO_2 Monitoring of Adult Surgical Patients With and Without Low Flow Shock

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Since the introduction of skin surface pO_2 measurements ($p_{tc}O_2$) with heated polarographic electrodes by Eberhard and Huch, the technique has become a standard tool for respiratory management of neonates [1, 2]. $p_{tc}O_2$ has also been demonstrated to be of clinical value in tracking arterial pO_2 (p_aO_2) values of adult patients during adequate cardiac output and to track cardiac output (CO) during severe low flow shock and resuscitation [3, 4]. In recent years, skin surface pCO_2 ($p_{tc}CO_2$) has been demonstrated to follow arterial pCO_2 (p_aCO_2) values in neonates and adult neurosurgical patients [5, 6]. Animal studies have also shown $p_{tc}CO_2$ to be inversely related to CO during hypovolemic shock and resuscitation [7]. The following work was undertaken to determine the clinical usefulness of $p_{tc}O_2$ and $p_{tc}CO_2$ monitoring on adult surgical intensive care and intraoperative patients.

Thirty studies were performed on 26 patients who were continuously monitored with $p_{tc}O_2$ and $p_{tc}CO_2$ sensors[1]. The patients were intermittently monitored with arterial and mixed venous blood gases and full hemodynamic and oxy-

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