Carbon dioxide partial pressure and oxygen saturation in venous blood from the upper body compared with mixed venous blood

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Editor—Carbon dioxide partial pressure (P_{CO_2}) and oxygen saturation (S_{O_2}) in venous blood are informative measures of tissue perfusion and oxygenation.[1,2] Mixed venous blood collected from the pulmonary artery (PA) is representative of whole-body perfusion, but is usually unavailable. Blood samples from central venous catheters (CVCs) are often used as a surrogate, but may differ from PA-derived values significantly in P_{CO_2} and S_{O_2}.[3] Differences likely reflect the composition of CVC blood, which may derive disproportionately from the two venae cavae, coronary sinus, and azygos vein.[4,5] This suggests that the superior and inferior venae cavae, which provide most PA blood, may differ substantially in P_{CO_2} and S_{O_2} values. We hypothesised that differences between blood from the superior vena cava (SVC) and the PA are not random, but reflect the values in the SVC territory (i.e. the portion of venous flow from above the diaphragm except for the heart). If this hypothesis were correct, P_{CO_2} and S_{O_2} should be assessed in blood drawn from the right atrium and not from the SVC. This study (ClinicalTrials.gov identifier: NCT03591029) compared P_{CO_2} and S_{O_2} values in the left brachiocephalic vein (LBV) and the PA.

After approval by the local ethics committee, we enrolled and obtained written informed consent from 50 adult patients scheduled for either myocardial revascularisation or valve replacement/repair with cardiopulmonary bypass. All patients had arterial, central venous, and PA catheters, the last two into the left internal jugular vein. Central venous catheters were advanced until proximal ports were about 3 cm below the origin of the LBV (usually 6 cm long); the position was verified with ultrasound by visualising agitated saline microbubbles. We collected blood samples from the radial artery, PA, and proximal CVC port (LBV): (i) after positioning the catheters, (ii) 10 min after sternotomy, (iii) 10 min after weaning from cardiopulmonary bypass, (iv) 30 min after arrival in the ICU, (v) postoperative Day 1 (POD 1), and (vi) POD 2. We measured P_{CO_2} and S_{O_2} values with a Stat Profile® pHOx® Ultra Analyzer (Nova Biomedical, city, USA). Sequential Organ Failure Assessment difference (ΔSOFA) between POD 2 and baseline was considered high if it is ≥2.

We reported values as mean (standard deviation [SD]), and analysed P_{CO_2} and S_{O_2} values with two-way analysis of variance (ANOVA) and arterial–venous differences with mixed factorial ANOVA. Sampling site and blood collection time were within-subjects variables, and high or low ΔSOFA was a between-subjects variable. Based on a previous study, 44 patients were needed to measure a P_{CO_2} difference >0.35 kPa (effect size: 0.50; α=0.05; β=0.10) using a paired Student's *t*-test, as a conservative estimate, given the uncertainty of the variance–covariance matrix structure.

We enrolled 50 patients, mean 65.7 (40–81) yr old, 64% male; 24 underwent myocardial revascularisation and 26 underwent valve replacement/repair. The SOFA score was 1(0, 1) before surgery and 2(2, 4) on POD 2, with 22 patients presenting with a high ΔSOFA.

The P_{CO_2}(LBV) was significantly higher than P_{CO_2}(PA) at all times of the study (ANOVA: P<0.0001; Student–Newman–Keuls test: P<0.0001); the mean difference was 0.36 (0.35) kPa (95% limits of agreement: −1.10 and 1.15 kPa). Arterial–venous difference analysis included ΔSOFA, which was significant (interaction ΔSOFA-SITE: P=0.039) (Fig. 1a and b). Indeed, P_{CO_2}(LBV-ART) did not differ between patients with low or high ΔSOFA, whilst P_{CO_2}(PA-ART) was higher in patients with high ΔSOFA.

The S_{O_2}(LBV) did not differ from S_{O_2}(PA), P=0.31, but was poorly informative of it (mean difference: 0.5%; 95% limits of agreement: −11.8% and 12.8%). Arterial–venous differences were affected by ΔSOFA (interaction ΔSOFA-SITE: P<0.0001 (Fig. 1c and d). As for P_{CO_2}, S_{O_2}(ART-LBV) did not differ between patients with low or high ΔSOFA, whilst S_{O_2}(ART-PA) was larger in patients with high ΔSOFA.

Our results confirmed that P_{CO_2} and S_{O_2} differences between LBV and PA blood were not random but systematic. Other authors have stated that CVC blood was not an acceptable substitute for PA blood[1,3]; our study adds that differences might reflect dissimilarities in tissue perfusion when CVC blood derives exclusively from the SVC.

From a clinical perspective, an average P_{CO_2} gradient of >0.36 kPa between LBV and PA blood is significant, as venous-arterial differences >0.8 kPa have been associated with tissue hypoperfusion and increased mortality. High P_{CO_2} levels in LBV blood probably mirror those in the cerebral vasculature. In a study of healthy subjects, the P_{CO_2} value in blood from the jugular venous sinus was ~6.7 kPa, and the venous-arterial difference is ~1.3 kPa.[6]

We also found that P_{CO_2} and S_{O_2} arterial–venous differences increased in high ΔSOFA patients, but only in PA

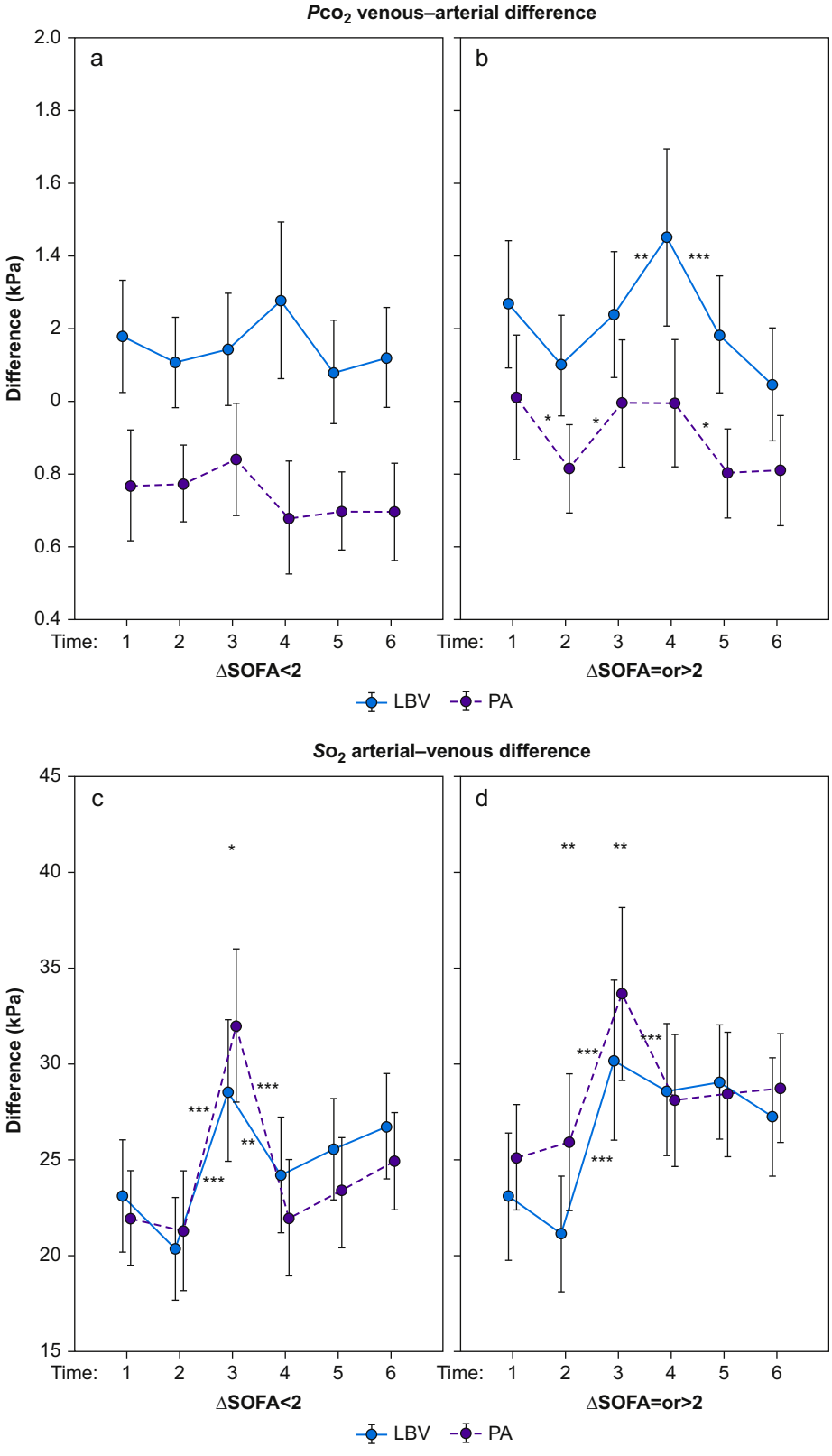

Fig 1. Carbon dioxide partial pressure (P_{CO_2}) and oxygen saturation (S_{O_2}) arterial–venous differences. Timeline of the study: 1, after positioning the catheter in the pulmonary artery; 2, 10 min after the sternotomy; 3, 10 min after the end of the extracorporeal circulation; 4, 30 min after arrival in intensive care; 5, postoperative Day 1 (POD 1); and 6, POD 2. Data are reported as means; vertical bars denote 0.95% confidence intervals. Comparisons between LBV and PA blood (upper part of the figures) and between consecutive values: *P<0.05; **P<0.01; ***P<0.001. LBV, left brachiocephalic vein; PA, pulmonary artery.

blood and not in LBV blood. These patients likely experienced tissue hypoperfusion because ΔSOFA effectively reflects the degree of organ dysfunction over time.[7] Hypothetically, differences between PA and LBV blood might reveal renal and splanchnic hypoperfusion. Ho and colleagues[8] reported a negative correlation between the cardiac output and S_{O_2} difference between central and mixed venous blood in patients affected by circulatory failure. However, P_{CO_2} and S_{O_2} of the LBV mainly reflect cerebral blood flow, with the brain receiving 20% of the cardiac output while the entire compartment drained by the SVC receives 35%. P_{CO_2} and S_{O_2} values of LBV blood were less affected by moderate low cardiac output states, which do not seriously impair cerebral perfusion.[9,10]

The main limitations of this study were the inability to measure P_{CO_2} and S_{O_2} in the inferior vena cava and coronary sinus, and the assumption that P_{CO_2} and S_{O_2} values were equal in left and right brachiocephalic veins.

In conclusion, CVC blood should be collected from the right atrium to provide information on the whole-body perfusion, including renal and splanchnic areas. Further studies are needed to investigate whether any useful information can be obtained by analysing LBV blood and, in general, SVC blood, which may be mainly representative of cerebral perfusion.

Declarations of interest

The authors declare that they have no conflicts of interest.

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Mechanistic insights into spinal neurones involved in neuraxial opioid-induced pruritus

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Editor—Neuraxial administration of opioids consistently evokes clinical pruritus, which is reported in nearly half of obstetric patients who receive neuraxial opioids for labour or Caesarean delivery anaesthesia and analgesia.[1] Historically, pruritus has been assumed to result from a direct effect of opioids within the neuraxis; in particular, it has been