Title: CONTINUOUS, NONINVASIVE CARDIAC OUTPUT MONITORING BY ELECTRICAL BIO-IMPEDANCE AND TRANSESOPHAGEAL CONTINUOUS-WAVE DOPPLER ULTRASOUND.

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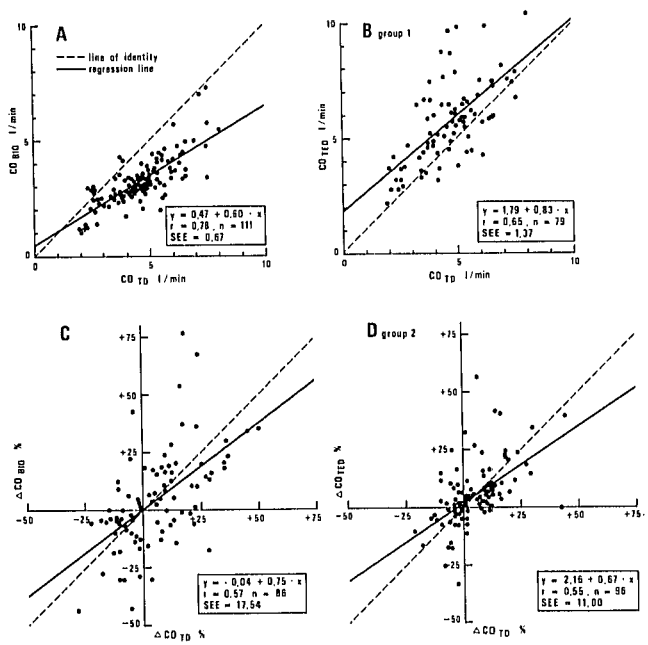
Introduction: Continuous, noninvasive cardiac output (CO) monitoring has been claimed as an alternative to intermittent invasive CO assessment by standard means. The present study was designed to determine the clinical applicability, accuracy and reliability of CO monitoring by electrical bioimpedance (BIO) and transesophageal continuous-wave Doppler ultrasound (TED) in patients after cardiac surgery as compared to the Fick (F) and thermodilution (TD) methods.

Methods: With informed consent of each patient and institutional approval, 111 simultaneous CO measurement sets were carried out early after aorto-coronary bypass surgery (ACBS) in 25 patients (group 1). CO_{BIO} (NCCOM-3, BoMed), CO_{TED} (Accucom, Datascope) and CO_{TD} (Edwards 9520A) were the calculated mean of 5 single CO determinations. Oxygen consumption was measured by indirect calorimetry (MMC, Horizon, Sensor Medics). TED, which measures blood flow velocities in the descending aorta, was calibrated before each measurement period with the aid of its suprasternal continuous-wave Doppler probe (SSD), estimating CO output in the ascending aorta, whereby the value of the built-in nomogram was used as aortic diameter. To test whether TED displayed the CO trend correctly, TED was calibrated by TD in an additional group of 15 patients (group 2) before starting the individual CO measurement series.

Results: CO_F and CO_{TD} showed an excellent agreement ($CO_F = 0.13 + 1.01 \cdot CO_{TD}$, r=0.96, n=99, SEE=0.43). TD was thus chosen as the reference method. CO_{TD} was underestimated by BIO (fig A) and overestimated by TED (fig B) in group 1. Both correlations showed a distinct scatter of data. CO_F and CO_{TD} displayed the relative CO-changes (ΔCO) correspondingly ($\Delta CO_F = 0.56\% + 0.95 \cdot \Delta CO_{TD}$, r=0.87, n=77, SEE=9.00%). The correlation between ΔCO_{TD} and ΔCO_{BIO} as well as ΔCO_{TED} showed a considerable scattering of results (fig C,D).

Discussion: Agreement of CO_F and CO_{TD} as well as of ΔCO_F and ΔCO_{TD}, confirmed the accuracy of these invasive techniques. In contrast, the results obtained with both continuous, noninvasive CO monitoring techniques question their reliability in the patient population investigated. SV_{BIO} is proportional to ET^*L^3/TFI, where SV=stroke volume, ET=ejection time, TFI=thoracic fluid index and L=length of the truncated cone. After ACBS, the thoracic fluid content is likely to be increased. The correspondingly lowered TFI (23.5±2.6; normal 24-45) thus cannot explain the CO_{TD} underestimation by BIO. Comparing only sets of CO measurements where ET_{BIO} was 90-110% of the physiological ET (or less if CI<2.5l/min·m²), the correlation of CO_{BIO} to CO_{TD} slightly improved ($CO_{BIO} = 0.05 + 0.69 \cdot CO_{TD}$, r=0.84, n=80, SEE= 0.66). Finally, slight underestimation of the L by the Bernstein nomogram (1) could explain the observed, considerable CO underestimation, because L enters the CO_{BIO} computation in the third power. TED overestimated CO_{TD} in group 1, mainly because the calibration value ($CO_{CAL\text{-}SSD}$) exeeded CO_{TD} ($CO_{CAL\text{-}SSD} = 1.67 + 0.84 \cdot CO_{TD}$, r=0.65, n=79, SEE =1.40). If only $CO_{CAL\text{-}SSD}$ with physiological ET were considered, the correlations of $CO_{CAL\text{-}SSD}$ and CO_{TED}, respectively, to CO_{TD} improved ($CO_{TED} = 0.99 + 0.96 \cdot CO_{TD}$, r=0.76, n= 49, SEE=1.21). TED failed to display the CO_{TD} trend correctly. Correlation of ΔCO_{TED} to ΔCO_{TD} showed a considerable scatter of data (fig D) and individual correlation coefficients ranged from -0.13 to 0.96. We conclude, that neither BIO nor TED precisely measure CO nor display ΔCO reliably and, thus, repeated CO determination by TD remains the method of choice for accurate hemodynamic assessment in adult patients following cardiac surgery.



References: (1) Bernstein DP: A new stroke volume equation for thoracic electrical bioimpedance: Theory and rationale. Crit Care Med 14:904-909, 1986