Title: MEASUREMENT ERROR IN THERMODILUTION CARDIAC OUTPUT WITH VENTRICULAR INJECTION

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Introduction The estimation of End-diastolic volume (EDV) of the right ventricle (RV) by thermodilution (TD) with RV injection has been reported and utilized high fidelity TD curves from which cardiac output (Q) and ejection fraction (EF) were measured. EDV is often reported as a percentage of the baseline cardiac output (Q) and ejection fraction (EF) are calculated. The integral (area) of the temperature-time curve and the step change (plateaus) of decreasing indicator concentration must be measured accurately for Q and EF, respectively. Most TD cardiac output computers do not integrate the area of the TD curve directly but estimate the area with algorithms intended for damped TD curves and right atrial (RA) injection. In a pulsatile flow RV model (RVM), we investigated the accuracy of two clinically useful algorithms (comparing them to direct integration) when presented high fidelity TD curves at precisely known Q, EF, and injecting the indicator upstream from (RA injection) or directly into RVM (RV injection).

Methods A RVM was used that permitted independent setting of Q and EF. Rate of the piston pump (basal/min) and stroke volume (ml) were set to 60 for all measurements, timed volume collections (30 sec) in duplicate were performed before and after each measurement set, measured flow (Qm) varied <2%. Injection of 0.2C water (5ml) proximal to the inflow valve and directly into RVM were performed with two identical catheters and a pressure injector. Onset of injection was not synchronized and varied throughout systole and diastole; duration of injection was 800 msec. A fast response thermistor (FRT), 100 msec. and slow response thermistor (SRT), 1200 msec. were centered in the RVM outflow tract. Each component was used to make TD measurements. The analog outputs were 1) determined to be linear from 37 to 330C; 2) A/D converted (60 times/sec); and 3) stored and processed by an HP-9845B computer. A large 370C water bath (40L) prevented any recirculation of indicator. Three integration methods (IM) were performed on each curve. The computer integrated 1) the total area from beginning end of curve directly (DI); 2) the area until 30% (A3) of peak height (PH), IM-A=1.22 x A3; and 3) the area until 80% of PH (A8), separately integrated the area from 80 to 40% of PH (A4), IM-B=A8 + 2 x A4. With Q, SV, injectate temp, volume and catheters and bath temp held constant, 12 pairs of TD curves (FRT and SRT) were measured alternating between the RA and RV injection sites (6RA and 6RV) at EF of 25, 33, 50 and 50% of baseline output (Q). IM-A and IM-B were applied to each curve and each resultant area divided into the same constant to calculate a TDO value. Results The mean TDO + standard deviation (SD) for both RA & RV injection, EF, and IM was calculated. The difference in per cent (A%) between Q and IM were calculated and presented in table A = TDQ-QM/0M. EF 0.25 0.33 0.50 0.66 DI 2.8 ± 4.3 1.6 ± 3.8 2.2 ± 3.2 2.4 ± 2.5 RA A 6.4 ± 3.7 3.2 ± 4.1 6.5 ± 6.3 5.6 ± 5.1 B 2.0 ± 7.4 7.4 ± 2.0 13.7 ± 14.4 25.3 ± 15.5 RV A 15.1 ± 3.9 8.7 ± 7.3 52.4 ± 25.4 15.1 ± 16.4 B -0.6 ± 5.9 7.7 ± 12.0 46.6 ± 25.6 1.9 ± 23.0 DI 6.1 ± 5.5 3.7 ± 5.6 0.0 ± 4.8 5.0 ± 3.2 RA A 3.6 ± 4.6 1.1 ± 4.2 -1.1 ± 3.3 -2.4 ± 3.6 B 1.4 ± 6.1 -1.6 ± 5.1 0.8 ± 6.4 -2.7 ± 5.5 RV A 11.5 ± 3.0 3.7 ± 3.6 14.2 ± 4.9 9.1 ± 3.4 B 1.6 ± 5.5 2.1 ± 3.4 8.3 ± 5.2 5.6 ± 6.1 RA, RV=Injection Site; DI, A, B=Integration Method

Discussion The overestimation of Qm and wide SD with RV injection and FRT by IM appears to result from at least three distinct factors, which can operate singly or together. First, at EF > 50% with IM-C and both RA & RV injections, there were curves on which the 80 & 40% points of PH fell during single step change and true area was underestimated. Second, some RV injections at high EF caused an artifactual spike on many TD curves because indicator was ejected during injection without much ventricular mixing; this caused area values from IM-A and IM-B to vary considerably since both depend on an accurate PH detection. Finally, DI at times overestimated Qm with both the FRT and SRT after RV injection; it appears that streaming of the indicator occurred and some area was not detected. None of the above overestimations of Qm were seen for DI or IM-A with RA injection and either the FRT or SRT when performed under identical conditions as the RV injections. The data from the RVM indicate that an unsynchronized RV injection and detection with FRT or SRT may present serious errors in measuring TDO with clinical algorithms and instrumentation.