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Title: A Comparison between Three Cardiac Outputs: Pulse Contour, Doppler, and Thermal Dilution

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INTRODUCTION. It is generally agreed that a beat-to beat method for measuring cardiac output (CO) is preferable to an intermittent one. However, it is difficult to evaluate any CO technique since the "gold standard," thermal dilution, can be inaccurate, especially during nonsteady-state conditions. This study compares two beat-to-beat methods — Doppler (DCO) and pulse contour (PCCO) — with each other and with thermal dilution (TDCO).

METHODS. After securing approval from our two IRBs, we obtained written informed consent from 5 males scheduled for open heart cardiac surgery. DCO was obtained with a carefully positioned, special Swan-Ganz catheter containing Doppler and echo crystals, (FLOWCATH and DopCom, Cardiometrics, Inc.) (1) while PCCO was obtained from a radial artery catheter via a modification of the Wesseling technique.(2) TDCO was obtained at the discretion of the anesthesiologist, as well as at predefined intervals. DCO and PCCO values were obtained at the same time. For PCCO comparisons, four individual TDCO determinations with stable injectate temperature and corresponding PCCO values were averaged. PCCO values were then recalibrated with a new arterial compliance (Zao). For DCO measurements, DCO values were paired with acceptable TDCO measurements. The DCO catheter was repositioned as instructed by the self-diagnostic alerts, which did not necessarily occur at the time of the TDCO determinations. Of the 52 total attempted TDCO sets, 21 of the values were accepted for the PCCO study, whereas 41 met the criteria for DCO inclusion. All data were recorded on a 286 IBM compatible computer. Regression, correlation, and descriptive statistics were performed, with $p < 0.05$ being set as the level of significance.

RESULTS. CO values ranged from 3.26 to 7.07 for TDCO,and 3.34 to 6.94 for the PCCO study. CO values ranged from 3.58 to 7.23 for TDCO and 1.84 to 6.48 for DCO for the DCO portion of the study. To compare the two-beat to-beat methods, only those values that met the criteria for inclusion in both protocols were included. The only comparison between the three techniques that showed a significant correlation was PCCO vs. TDCO. The table shows the results of the comparisons. When DCO changed, it did so in occasionally large steps, probably due to a change in position of the catheter. When PCCO changed in relation to TDCO, it tended to drift gradually.

DISCUSSION. The very reason for using beat-to-beat methods — the variability in CO — makes it difficult to obtain accurate TDCOs and therefore meaningful comparisons with other methods for measuring CO. There are very few times during cardiac surgery when there is a steady state **and** it is convenient to perform a TDCO. Nevertheless, for the foreseeable future, both beat-to-beat methods that we have tested will probably require frequent recalibration by TDCO. The position of the catheter is very important with the DCO, and the catheter may require frequent readjustment. PCCO, on the other hand, depends on a good radial arterial trace, which may become unreliable, especially immediately post bypass. It should be emphasized that the DCO transducer test failed a majority of times, indicating possible difficulties with the transducer. These failures may have been related to the large amount of extraneous equipment present in the room.

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TABLE

	Bias	Precision	Intercept	slope	correl.
TD vs. PC	1.81	12.01	0.77±0.66	0.86±0.66	0.84
TD vs. D	-6.02	37.37	2.32±1.03	0.45±0.20	0.33
PC vs. D	-15.38	35.22	1.27±1.58	0.57±0.31	0.40

The first variable is considered the "gold standard" for the bias and precision comparison.

1. J. of American College of Cardiologist 16: 1398-1407, 1990
2. Proc. San Diego Biomed. Symp. 13: 113-119, 1974

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TITLE A VERSATILE COMPUTER-CONTROLLED CLOSED-LOOP SYSTEM FOR CONTINUOUS INFUSION OF MUSCLE RELAXANTS

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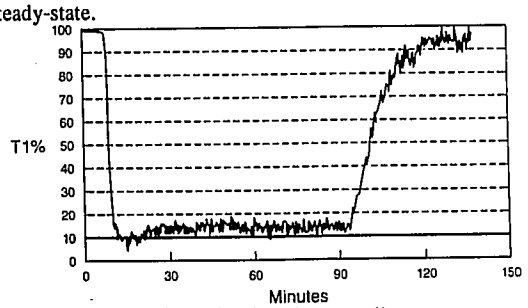
INTRODUCTION Computer-controlled, closed-loop systems have been demonstrated to out-perform experienced anesthesia personnel in the regulation of a variety of endpoints such as depth of anesthesia or arterial blood pressure.[1] Previously described computer-controlled, closed-loop systems for continuous infusion of muscle relaxants are limited with respect to choice of muscle relaxant, target level of neuromuscular blockade (NMB), and the monitor used for feedback control input.[2] In this study, we tested the clinical performance of a versatile computer-controlled, closed-loop system for continuous infusion of muscle relaxants which allows the operator to choose either atracurium or vecuronium to provide any desired level of NMB.

METHODS **System Design:** A proportional algorithm was developed to control the infusion rate of atracurium or vecuronium based on the feedback control input from either a integrated electromyograph (EMG, Puritan Bennett 221 NMT Monitor) or an accelerometer (Biometer). This algorithm allows the operator to set the target level of NMB to any value ranging from 0% to 100% of the baseline twitch height (T1%). The system is equiped with a multitude of safety features including a cyclic redundancy check algorithm to protect the intergrity of communication between components.

System Evaluation: After Institutional Review Board approval and informed consent, the system was evaluated in 20 ASA I and II patients. Patients were randomized with respect to the muscle relaxant infused (atracurium or vecuronium), the monitor used for the feedback control input (EMG or accelerometer), and the target level of NMB (T1% of 10 or 50).

RESULTS The figure is an actual tracing from a patient who received atracurium to produce NMB to a target T1% of 10. In all patients, the target level of NMB was achieved within 15 minutes of initiating the infusion and was maintained throughout the surgical procedure. There was a transient overshoot at the onset of NMB and minimal oscillation at steady-state.



CONCLUSION We have developed a versatile computer-controlled, closed-loop system for continuous infusion of atracurium or vecuronium which can provide any desired level of NMB. Furthermore, we have tested the clinical performance of the system and demonstrated it's capability to rapidly induce the target level of NMB and to maintain this level with minimal oscillation. This system is likely to find its greatest clinical utility in those selected surgical procedures where there is a need to provide precisely controlled, but partial NMB such as operations that require monitoring of motor-evoked potentials or facial nerve EMG.

References
1.Smith N.T., et al: Anesth Analg 63: 715-722, 1984
2.O'Hara DA, et al: Anesthesiology 74: 258-263, 1991