

CHEST[®]

Official publication of the American College of Chest Physicians



Impedance Cardiography: The Next Vital Sign Technology?

Joseph M. Van De Water, Timothy W. Miller, Robert L. Vogel, Bruce E. Mount and Martin L. Dalton

Chest 2003;123:2028-2033
DOI 10.1378/chest.123.6.2028

The online version of this article, along with updated information and services can be found online on the World Wide Web at:
<http://chestjournal.org/cgi/content/abstract/123/6/2028>

CHEST is the official journal of the American College of Chest Physicians. It has been published monthly since 1935. Copyright 2007 by the American College of Chest Physicians, 3300 Dundee Road, Northbrook IL 60062. All rights reserved. No part of this article or PDF may be reproduced or distributed without the prior written permission of the copyright holder (<http://www.chestjournal.org/misc/reprints.shtml>). ISSN: 0012-3692.

A M E R I C A N C O L L E G E O F



P H Y S I C I A N S[®]



clinical investigations in critical care

Impedance Cardiography*

The Next Vital Sign Technology?

Joseph M. Van De Water, MD, FCCP; Timothy W. Miller, RRT;
Robert L. Vogel, PhD; Bruce E. Mount, BS; and Martin L. Dalton, MD

Objective: To evaluate the following: (1) the intramethod variability of impedance cardiography (ICG) cardiac output (CO) measurements via the latest generation monitor and thermodilution CO measurements (CO-TDs); (2) the intermethod comparison of ICG CO and CO-TD; and (3) comparisons of the intergeneration ICG CO equation to CO-TD, using the latest ICG CO equation, the ZMARC (CO-ICG), and the predecessor equations for measuring the ICG CO of Kubicek (CO-K), Sramek (CO-S), and Sramek-Bernstein (CO-SB).

Design: Prospective study.

Setting: A cardiovascular-thoracic surgery ICU in a community university-affiliated hospital.

Patients: Post-coronary artery bypass graft patients (n = 53) in whom 210 pairs of CO measurements were made.

Interventions: None.

Measurements and main results: The CO-ICG was determined simultaneously while the nurse was performing the CO-TD. Variability within the monitoring method was better for CO-ICG compared to CO-TD (6.3% vs 24.7%, respectively). The correlation, bias, and precision of the CO-ICG was good compared to CO-TD ($r^2 = 0.658$; $r = 0.811$; bias, -0.17 L/min; precision, 1.09 L/min; $\text{CO-ICG} = 1.00 \times \text{CO-TD} - 0.17$; $p < 0.001$). A steady improvement in agreement of the previous ICG methodologies compared to CO-TD was observed as follows: (1) CO-K: $r^2 = 0.309$; $r = 0.556$; bias, -1.71 L/min; precision, 1.81 L/min; $\text{CO-K} = 0.78 \times \text{CO-TD} - 0.45$; $p < 0.001$; (2) CO-S: $r^2 = 0.361$; $r = 0.601$; bias, -1.46 L/min; precision, 1.63 L/min; $\text{CO-S} = 0.80 \times \text{CO-TD} - 0.36$; $p < 0.001$; and (3) CO-SB: $r^2 = 0.469$; $r = 0.685$; bias, -0.77 L/min; precision, 1.69 L/min; $\text{CO-SB} = 1.03 \times \text{CO-TD} - 0.95$; $p < 0.001$. The CO-ICG demonstrated the closest agreement to CO-TD.

Conclusion: The latest ICG technology for determining CO (CO-ICG) is less variable and more reproducible in an inpatient sense than is CO-TD, it is equivalent to the average accepted CO-TD in post-coronary artery bypass graft patients, and showed marked improvement in agreement with CO-TD compared to measurements made using previous generation ICG CO equations. (CHEST 2003; 123:2028–2033)

Key words: bioimpedance; cardiac output; coronary artery bypass graft; impedance cardiography; pulmonary artery catheter; thermodilution

Abbreviations: CABG = coronary artery bypass graft; CO = cardiac output; CO-ICG = impedance cardiography cardiac output measurement via the ZMARC equation; CO-K = impedance cardiography cardiac output measurement via the Kubicek equation; CO-S = impedance cardiography cardiac output measurement via the Sramek equation; CO-SB = impedance cardiography cardiac output measurement via the Sramek-Bernstein equation; CO-TD = thermodilution cardiac output measurement; dZ/dt_{max} = first derivative of the impedance waveform; ICG = impedance cardiography; L = length; LVET = left ventricular ejection time; PAC = pulmonary artery catheterization; SV = stroke volume; SVR = systemic vascular resistance; Z_0 = base impedance

Hemodynamic assessment often does not occur until after an acute cardiac episode. If an accurate, noninvasive measurement of cardiac output (CO) monitoring were available, acutely ill and surgical patients undergoing major operations such as coronary artery bypass graft (CABG) would benefit.

In addition, many patients with chronic and comorbid diseases that ultimately lead to the need for major operations and other costly interventions might benefit from more routine monitoring of CO and its dependent parameters such as systemic vascular resistance (SVR). Studies have shown that clini-

cian estimation of CO and SVR show poor correlation to measured CO and SVR values,¹ thus patients are subject to potential misdiagnosis and mistreatment when CO and SVR are part of the therapeutic goal.

The most commonly used method of measuring CO in the ICU is with the indicator-dilution technique of thermodilution (CO-TD), which utilizes a pulmonary artery catheter (PAC) to estimate CO.^{2,3} However, the risks of estimating CO-TDs via PAC are well-documented to include infection, sepsis, and arrhythmias, as well as increased morbidity and mortality.⁴⁻⁶ As such, hospitals have reserved the technique for only the most critically ill patients or have discontinued using the PAC altogether. Furthermore, CO-TD estimations can be inaccurate and variable due to the assumptions used by the technology, operator technique, and/or patient factors.⁷⁻¹¹ Clearly, there is a need for a low-cost, accurate, noninvasive alternative.

A noninvasive alternative method for determining CO and SVR is that of impedance cardiography (ICG). ICG measures the beat-to-beat changes of thoracic bioimpedance via four dual sensors applied on the neck and thorax in order to calculate stroke volume (SV). ICG was first advanced in 1940 by Nyboer et al,¹² who, using the resistivity (ρ) of blood and the length (L) of the chest, established the relationship of impedance change (ΔZ) and base impedance (Z_0) to the volume change (ΔV) of the tissue under measurement as follows:

$$\Delta V = \rho \frac{L^2}{Z_0^2} \Delta Z$$

In the 1960s, Kubicek et al¹³ were commissioned by the National Aeronautics and Space Administration to develop a noninvasive method of determining CO. The result of that work was the development of the Minnesota Impedance Cardiograph and a new equation for SV that incorporated the maximum value of the first derivative of the impedance waveform (dZ/dt_{\max}) and the left ventricular ejection time (LVET), as follows:

$$SV = \rho \frac{L^2}{Z_0^2} \left(\frac{dZ}{dt} \right)_{\max} LVET$$

In the 1980s, Sramek et al¹⁴ developed a less cumbersome ICG device with a new SV equation that substituted the cylindrical model of the chest used by

Kubicek et al¹³ with that of a truncated cone. At the same time, L was approximated as 17% of the patient's height (H). This yielded the following equation:

$$SV = \left(\frac{(0.17 H)^3}{4.2} \right) \frac{\left(\frac{dZ}{dt} \right)_{\max}}{Z_0} LVET$$

In 1986, Bernstein¹⁵ modified the equation of Sramek et al¹⁴ by introducing the term δ (the actual weight divided by the ideal weight), which accounted for deviations from ideal body weight as established by Metropolitan Life insurance tables. The purpose was to determine more accurately the volume of the thorax, as follows:

$$SV = \delta \times \left(\frac{(0.17 H)^3}{4.2} \right) \frac{\left(\frac{dZ}{dt} \right)_{\max}}{Z_0} LVET$$

Advancements in hardware and software with the latest generation ICG monitor (BioZ; CardioDynamics; San Diego, CA), including digital signal processing (DISQ digital impedance signal quantifier; CardioDynamics)¹⁶ and the creation of a proprietary modification to the Sramek-Bernstein equation (ZMARC impedance-modulating aortic compliance) have yielded significantly better results.¹⁷⁻²⁰ These advancements and the experience of this investigator led to a desire to reevaluate ICG CO measurements using the ZMARC equation (CO-ICGs) in post-CABG patients comparing them to CO-TDs, as well as to those derived from predecessor ICG CO equations in the same patient population.

MATERIALS AND METHODS

Study approval was obtained from the institutional review board. Patients who already had PACs and were having their CO-TDs determined were identified and approached for participation in the study. Informed written consent was obtained from each patient, or from their spouse or guardian. Fifty-three postoperative ICU patients (37 men and 16 women) consented to be included in the study. No patient was excluded. All but three patients had undergone a CABG procedure. The three exceptions included a patient who had undergone an isolated valve replacement, a patient who had undergone an abdominal aortic aneurysm repair, and a patient who had undergone a pneumonectomy following a gunshot wound to the chest. All comparison CO measurements were performed within 24 h after surgery, after each patient had recovered from anesthesia and was alert. Patient acuity was variable, with four patients being assisted by an intra-aortic balloon pump. Ages ranged from 18 years for the gunshot wound patient to 87 years for a CABG patient (mean age, 64 years; SD, 12.2 years), and all patients survived. All ICG CO measurements in this study were performed with one monitor (BioZ ICG monitor; CardioDynamics; San Diego, CA).

CO-ICGs were performed according to the manufacturer's guidelines at times coinciding with the routine CO-TD obtained

*From the Departments of Surgery (Drs. Van De Water and Dalton, and Mr. Miller and Mr. Mount) and Family Practice (Dr. Vogel), Mercer University School of Medicine, Macon, GA. Manuscript received June 11, 2002; revision accepted October 31, 2002.

Reproduction of this article is prohibited without written permission from the American College of Chest Physicians (e-mail: permissions@chestnet.org).

Correspondence to: Joseph M. Van De Water, MD, FCCP, Department of Surgery, Mercer University School of Medicine, Macon, GA 31201; e-mail: Vandewater.joseph@mccc.org.

by the nursing staff during each thermodilution fluid bolus injection. As the nurse injected each fluid bolus (*ie*, a room temperature saline solution), attempting to obtain a minimum of three CO-TD values with a < 10% variation, we recorded the CO-ICG values. Unlike the CO-TD values, which are obtained with individual injections of saline solution, usually at various times during the respiratory cycle, the CO-ICG values were continually displayed and updated on the ICG monitor every 10 beats. In this manner, at least three pairs of CO measurements were obtained for each patient. The nurse-determined acceptable CO-TDs were averaged to obtain the final CO-TD for each patient. The CO-ICGs corresponding to the accepted CO-TDs also were averaged for each patient to obtain the final CO-ICG for each patient. All CO-TDs, including discarded measurements, were recorded for further analysis of variability associated with the thermodilution technique. All CO-ICGs also were recorded for variability analysis without any being either objectively or subjectively rejected.

In addition to displaying the CO-ICG values continuously, this ICG monitor also electronically recorded and stored other values (*ie*, heart rate, LVET, dZ/dt_{max} , and Z_0) that allowed us to retrospectively calculate the ICG CO measurements via the previous-generation SV equations (*ie*, those by Kubicek [CO-K], Sramek [CO-S], and Sramek-Bernstein [CO-SB]). The CO-S ($L = 0.17 \times H$) was used to calculate the thoracic length for the CO-K. Fifty-two of the 53 patients (36 men and 16 women) had data stored for further analysis due to the inadvertent deletion of one patient file from the ICG monitor.

The following statistical analyses for comparing the average CO-ICGs to CO-TDs were performed: Pearson correlation; regression analysis; and Bland-Altman analysis for bias and precision.²¹ In addition to comparing the paired averages for the two CO methods, intramethod variability also was analyzed by restricted maximum likelihood estimation and intramethod linear regression analysis.

RESULTS

Two hundred ten CO-ICGs were obtained in tandem with the nurses' CO-TDs in 53 separate patients. These raw CO-TD measurements were the basis of the intramethod variability shown in Table 1. Of 210 CO-TDs, 160 (76.2%) were accepted. The accepted CO-TD average was used to compare to the ICG average for intermethod comparison.

Intramethod Comparison

The variability of measurements within a patient monitoring session was assessed via the differences

between the first three measurements of the given technique compared to each other in a pairwise fashion. Results for the Pearson correlation coefficient, p values, bias, SD, and linear regression analysis with slope and intercept are listed in Table 1. Using the restricted maximum likelihood estimation, the variability of the 210 individual CO-ICGs was 6.3%, and that for CO-TDs was 24.4%.

Intermethod Comparison

The results of the average CO-ICGs corresponding to the average of the accepted CO-TDs are listed in Table 2. The results for Pearson correlation coefficient, p values, bias, SD, and linear regression analysis with slope and intercept are listed in Table 2 and are graphically represented in a scattergram in Figure 1. When the 53 paired average CO-ICGs vs CO-TDs were tested with the Bland-Altman analysis,²¹ the bias and precision were -0.18 and 1.09 L/min, respectively, with a 95% level of agreement between -2.36 and 1.99 L/min (Fig 2). All differences fell within the 95% upper and lower levels of agreement.

Retrospective Intermethod Comparison

The results of the retrospectively calculated average ICG CO measurements made via the CO-K, CO-S, and CO-SB compared to the corresponding average of the accepted CO-TDs are listed in Table 2. Pearson correlation coefficient, p values, bias, SD, and linear regression analysis with slope and intercept also are listed.

DISCUSSION

For many biological and clinical measurements, a true standard for accuracy does not exist. The reason for this is that, like most clinical measurements, the desired quantity of measurement is not directly accessible and/or quantifiable. Therefore, technologies are developed that measure an indirectly related quantity to that which clinicians are interested. Often times, these various technologies are measur-

Table 1—Intramethod, Intrasession Comparison of CO Measurement by Thermodilution and ICG

Comparison	Correlation, r/R^2	Bias, L/min	SD, L/min	Slope	Intercept	p Value
CO-TD 2 vs CO-TD 1 (n = 53)	0.828/0.686	-0.13	1.02	0.76	1.23	< 0.001
CO-TD 3 vs CO-TD 2 (n = 53)	0.840/0.706	0.16	1.01	0.95	0.47	< 0.001
CO-TD 3 vs CO-TD 1 (n = 53)	0.829/0.687	0.03	1.07	0.86	0.84	< 0.001
CO-ICG 2 vs CO-ICG 1 (n = 53)	0.972/0.945	0.08	0.44	0.98	0.17	< 0.001
CO-ICG 3 vs CO-ICG 2 (n = 53)	0.979/0.958	-0.06	0.39	0.96	0.14	< 0.001
CO-ICG 3 vs CO-ICG 1 (n = 53)	0.973/0.947	0.02	0.43	0.97	0.18	< 0.001

Table 2—Summary of ICG CO Method Comparisons to CO-TD

Method of CO-ICG Comparison	Correlation, r/R^2	Bias, L/min	SD, L/min	Slope	Intercept	p Value
CO-K vs CO-TD (n = 52)	0.556/0.309	-1.71	1.81	0.78	-0.45	< 0.001
CO-S vs CO-TD (n = 52)	0.601/0.361	-1.46	1.63	0.80	-0.36	< 0.001
CO-SB vs CO-TD (n = 52)	0.685/0.469	-0.77	1.69	1.03	-0.95	< 0.001
CO-ICG vs CO-TD (n = 53)	0.811/0.658	-0.18	1.09	1.00	-0.17	< 0.001

ing two or more separate quantities for the purpose of inferring yet a separate third quantity. As such, each technology is subject to different sources of error in determining the same desired clinical measurement. And since a true reference standard does not exist, the existing accepted technology often is substituted and is defined as the reference for determining the accuracy of new technologies.

CO is a prime example of such a clinical measurement. For example, CO may be calculated via any of the following independent physical measurements: the Fick method measures O₂ concentration and consumption; the thermodilution technique measures temperature; and ICG measures bioimpedance. In this study, we wanted to determine whether CO-ICG was accurate enough to be used clinically in postoperative CABG patients. In other words, how well does CO-ICG agree with the reference method? To answer this question, we had to define the term *accurate enough*. Therefore, we evaluated the reference technology (in this case, CO-TD via PAC) to see how well inpatient CO-TDs compared.

Intramethod Comparison

The difficulties in obtaining a reproducible and accurate CO-TD via PAC have been well-documented.⁷⁻¹¹ This study experienced similar results. Comparisons of the first three serially measured CO-TDs resulted in a mean absolute difference between CO-TDs of 12% (SD, 13%). While the variation of the same paired CO-ICGs resulted in a lower mean absolute difference of 5.9% (SD, 6.5%). Linear regression analysis of the intramethod CO comparisons clearly reveals a wider variability and less agreement in the CO-TDs, compared to the case with the CO-ICGs (Table 1). While restricted maximum likelihood estimation produced a substantially larger variability (24.7%) for intramethod CO-TD compared to that for the intramethod CO-ICG (6.3%), it cannot be concluded that CO-TD is less accurate than CO-ICG. It does, however, indicate that the inpatient precision of CO-ICG is better than that of CO-TD. Nevertheless, with so much inpatient variation between the CO-TDs within a given patient, it is fair to ask how

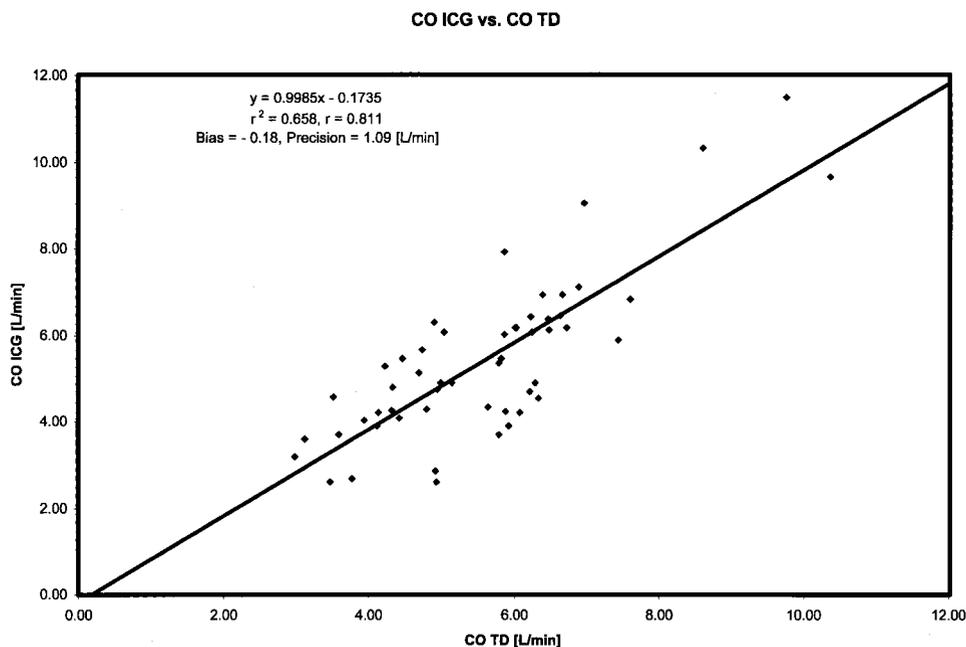


FIGURE 1. CO-ICGs vs CO-TDs.

Bland Altman Analysis

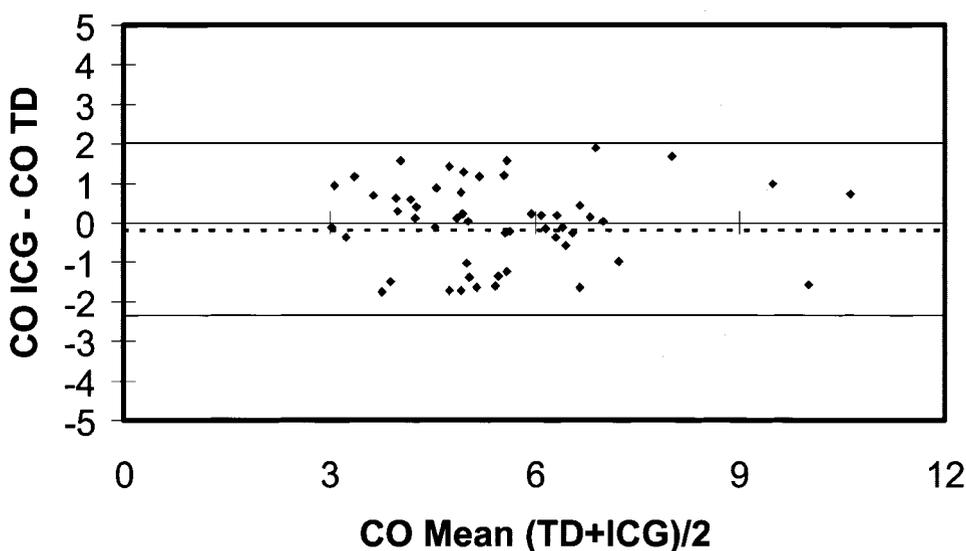


FIGURE 2. Bland-Altman plot of the differences of CO-ICG and CO-TD vs the mean with bias, and upper and lower 95% levels of agreement. Values given as liters per minute.

well any new method for measuring CO can compare to the CO-TD method, given its inherent intramethod variability.

Intermethod Comparison

When comparing CO-ICG to the clinically accepted value for CO-TD, we found that the bias, precision, correlation, slope, and intercept were equivalent to the intramethod CO-TD values when compared to themselves (Tables 1 and 2).

Retrospective Intermethod Comparison

Retrospective analysis and comparison of the previous and current ICG CO equations (*ie*, CO-K, CO-S, CO-SB, and CO-ICG) all displayed a progression of improved agreement with CO-TD for the patients in this study (Table 2). Each subsequent generation of method for ICG CO measurement resulted in a higher correlation, a slope more closely approaching unity, an intercept more closely approaching zero, less bias, and lower SD values than its predecessor.

CONCLUSION

Our evaluation of this ICG monitor (BioZ ICG monitor) has demonstrated clinically acceptable accuracy and superior inpatient reproducibility compared to CO-TD via PAC. These findings, cou-

pled with the drastically lower cost per patient and continuous monitoring capability of this ICG monitor led us to conclude that in those circumstances in which intracardiac pressures and mixed venous blood samples are not necessary, ICG is preferable to CO-TD via PAC in determining CO. Furthermore, the ICG monitor enables us to quickly and easily monitor CO and SVR in clinical areas where the PAC is not typically utilized, such as the emergency department, subacute care, and outpatient hypertension and heart failure clinics. More successful treatment of chronic outpatient diseases could reduce the development of even more costly short-term interventions, such as CABG surgery. Recent results²² have demonstrated up to 70% improvement in the treatment success of patients with hypertension when using ICG hemodynamic measurements to guide treatment compared to clinician-only-directed treatment without the availability of hemodynamic measurements.

Our retrospective intermethod comparison also confirmed the findings of other investigators that CO-K, CO-S, and CO-SB were not accurate enough to be used in assessing seriously ill patients. They also confirmed that clear advancements have been made with the ICG monitor used in this study, providing a level of agreement that is equivalent to CO-TD.

Currently, noninvasive pulse oximetry is considered to be a *de facto* vital sign by clinicians. While

the accuracy of pulse oximetry has been established, it is not without its limitations. In addition, to date no conclusive outcome studies on prospective assessments, diagnoses, and treatments based on pulse oximetry values have been completed. Contrasted to oxygen saturation via pulse oximetry, CO and SVR are affected by a wide range of pharmacologic agents that are routinely prescribed for managing both acute and chronic diseases. In most cases, these agents are prescribed and the patients are treated without any direct, objective evaluation of the complete hemodynamic condition by the treating clinician. Based on our findings of the equivalent and clinically acceptable accuracy and reproducibility of the ICG monitor use in this study, we believe that there is substantial merit in declaring noninvasive CO to be a useful vital sign in the assessment, diagnosis, and treatment of postoperative CABG patients.

REFERENCES

- 1 Eisenberg PR, Jaffee AS, Schuster DP. Clinical evaluation compared to pulmonary artery catheterization in the hemodynamic assessment of critically ill patients. *Crit Care Med* 1984; 12:549–553
- 2 Fegler G. Measurement of cardiac output in anesthetized animals by a thermo-dilution method. *Q J Exp Physiol* 1954; 39:153–164
- 3 Swan HJC, Ganz W, Forrester J, et al. Catheterization of the heart in man with the use of a flow-directed balloon-tipped catheter. *N Engl J Med* 1970; 283:447–451
- 4 Connors AF Jr, Speroff T, Dawson NV, et al. The effectiveness of right heart catheterization in the initial care of critically ill patients. *JAMA* 1996; 276:889–897
- 5 Mermel LA, McCormick RD, Springman SR, et al. The pathogenesis and epidemiology of catheter-related infection with pulmonary artery Swan-Ganz catheters: a prospective study utilizing molecular subtyping. *Am J Med* 1991; 91:197S–205S
- 6 Guyatt G. A randomized controlled trial of right heart catheterization in critically ill patients: Ontario Intensive Care Study Group. *J Intensive Care Med* 1991; 6:91–95
- 7 Levett JM, Replogle RL. Thermodilution cardiac output: a critical analysis and review of the literature. *J Surg Res* 1979; 27:392–404
- 8 MacKenzie JD, Haites NE, Rawles JM. Method of assessing the reproducibility of blood flow measurement: factors influencing the performance of thermodilution cardiac output computers. *Br Heart J* 1986; 55:14–24
- 9 Sommers MS, Woods SL, Courtade MA. Issues in methods and measurement of thermodilution cardiac output. *Nurs Res* 1993; 42:228–233
- 10 Renner LE, Morton M, Sakuma GY. Indicator amount, temperature, and intrinsic cardiac output affect thermodilution cardiac output accuracy and reproducibility. *Crit Care Med* 1993; 21:586–597
- 11 Stetz CW, Miller RG, Kelly GE, et al. Reliability of thermodilution method in the determination of cardiac output in clinical practice. *Am Rev Respir Dis* 1982; 126:1001–1004
- 12 Nyboer J, Bagno S, Barnett A, et al. Radiocardiograms: electrical impedance changes of the heart in relation to electrocardiograms and heart sounds. *J Clin Invest* 1940; 19:963
- 13 Kubicek WG, Karnegis JN, Patterson RP, et al. Development and evaluation of an impedance cardiac output system. *Aerosp Med* 1966; 37:1208–1212
- 14 Sramek BB, Rose DM, Miyamoto A. Stroke volume equation with a linear base impedance model and its accuracy, as compared to thermodilution and magnetic flowmeter techniques in humans and animals. Paper presented at: the 6th International Conference on Electrical Bioimpedance, Zadar, Yugoslavia, 1983; 38
- 15 Bernstein DP. A new stroke volume equation for thoracic electrical bioimpedance: theory and rationale. *Crit Care Med* 1986; 14:904–909
- 16 Osypka MJ, Schafer EE. Impedance cardiography: advancement in system design. Paper presented at: 10th International Conference on Electrical Bioimpedance, Barcelona, Spain, April 5 to 9, 1998; 437–440
- 17 Sageman WS, Riffenburgh RH, Spiess BD. Equivalence of bioimpedance and thermodilution in measuring cardiac index after cardiac surgery. *J Cardiothorac Vasc Anesth* 2002; 16:8–14
- 18 Yung GL, Fletcher CC, Fedullo PF, et al. Noninvasive cardiac index using bioimpedance in comparison to direct Fick and thermodilution methods in patients with pulmonary hypertension [abstract]. *Chest* 1999; 116:281S
- 19 DeMaria AN, Raisinghani A. Comparative overview of cardiac output measurement methods: has impedance cardiography come of age? *Congest Heart Fail* 2000; 6:7–18
- 20 Drazner M, Thompson B, Rosenberg P, et al. Comparison of impedance cardiography with invasive hemodynamic measurements in patients with heart failure secondary to ischemic or nonischemic cardiomyopathy. *Am J Cardiol* 2002; 89:993–995
- 21 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1:307–310
- 22 Taler SJ, Textor SC, Augustine JE. Resistant hypertension: comparing hemodynamic management to specialist care. *Hypertension* 2002; 39:982–988

Impedance Cardiography: The Next Vital Sign Technology?
Joseph M. Van De Water, Timothy W. Miller, Robert L. Vogel, Bruce E.
Mount and Martin L. Dalton
Chest 2003;123;2028-2033
DOI 10.1378/chest.123.6.2028

This information is current as of July 11, 2008

Updated Information & Services	Updated information and services, including high-resolution figures, can be found at: http://chestjournal.org/cgi/content/full/123/6/2028
References	This article cites 19 articles, 3 of which you can access for free at: http://chestjournal.org/cgi/content/full/123/6/2028#BIBL
Citations	This article has been cited by 7 HighWire-hosted articles: http://chestjournal.org/cgi/content/full/123/6/2028
Permissions & Licensing	Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at: http://chestjournal.org/misc/reprints.shtml
Reprints	Information about ordering reprints can be found online: http://chestjournal.org/misc/reprints.shtml
Email alerting service	Receive free email alerts when new articles cite this article sign up in the box at the top right corner of the online article.
Images in PowerPoint format	Figures that appear in CHEST articles can be downloaded for teaching purposes in PowerPoint slide format. See any online article figure for directions.

A M E R I C A N C O L L E G E O F



P H Y S I C I A N S[®]