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Accurate, Noninvasive Continuous Monitoring of Cardiac Output by Whole-Body Electrical Bioimpedance*

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Study objectives: **Cardiac output (CO) is measured but sparingly due to limitations in its measurement technique (*ie*, right-heart catheterization). Yet, in recent years it has been suggested that CO may be of value in the diagnosis, risk stratification, and treatment titration of cardiac patients, especially those with congestive heart failure (CHF). We examine the use of a new noninvasive, continuous whole-body bioimpedance system (NICaS; NI Medical; Hod-Hasharon, Israel) for measuring CO. The aim of the present study was to test the validity of this noninvasive cardiac output system/monitor (NICO) in a cohort of cardiac patients.**

Design: **Prospective, double-blind comparison of the NICO and thermodilution CO determinations.**

Patients: **We enrolled 122 patients in three different groups: during cardiac catheterization (n = 40); before, during, and after coronary bypass surgery (n = 51); and while being treated for acute congestive heart failure (CHF) exacerbation (n = 31).**

Measurements and intervention: **In all patients, CO measurements were obtained by two independent blinded operators. CO was measured by both techniques three times, and an average was determined for each time point. CO was measured at one time point in patients undergoing coronary catheterization; before, during, and after bypass surgery in patients undergoing coronary bypass surgery; and before and during vasodilator treatment in patients treated for acute heart failure.**

Results: **Overall, 418 paired CO measurements were obtained. The overall correlation between the NICO cardiac index (CI) and the thermodilution CI was $r = 0.886$, with a small bias (0.0009 ± 0.684 L) [mean ± 2 SD], and this finding was consistent within each group of patients. Thermodilution readings were 15% higher than NICO when CI was < 1.5 L/min/m^2, and 5% lower than NICO when CI was > 3 L/min/m^2. The NICO has also accurately detected CI changes during coronary bypass operation and vasodilator administration for acute CHF.**

Conclusion: **The results of the present study indicate that whole-body bioimpedance CO measurements obtained by the NICO are accurate in rapid, noninvasive measurement and the follow-up of CO in a wide range of cardiac clinical situations.** ***(CHEST 2004; 125:1431–1440)***

Key words: cardiac function test; cardiac output; congestive heart failure

Abbreviations: CABG = coronary artery bypass graft; CHF = congestive heart failure; CI = cardiac index; CO = cardiac output; Cpi = cardiac power index; ISDN = isosorbide-dinitrate; MAP = mean arterial BP; NICO = noninvasive cardiac output system/monitor; SV = stroke volume; SVRi = systemic vascular resistance index; TEB = thoracic electrical bioimpedance; WBEB = whole-body electrical bioimpedance

Measurement of cardiac output (CO) and the calculation of cardiac index (CI) has been used selectively over the last 2 decades, mainly due to the fact that CI measurement requires the invasive procedure of right-heart catheterization and placement of a Swan-Ganz catheter (Baxter Healthcare; Irvine, CA). Hence, the experience with its application for monitoring and risk stratification of cardiac patients is limited.

In recent years, however, evidence has accumulated to the effect that CI measurement and the calculation of systemic vascular resistance index (SVRi) and cardiac power index (Cpi, the product of CI

multiplied by mean arterial BP [MAP]) measured simultaneously might be instrumental in the monitoring and risk stratification of cardiac patients, especially those with acute and chronic congestive heart failure (CHF) and patients admitted with cardiogenic shock.[1] In cardiogenic shock, a recent analysis of the SHOCK (SHould We Emergently Revascularize Occluded Coronaries in Cardiogenic ShocK) registry data has shown Cpi to be the strongest independent predictor of in-hospital mortality,[2] while in acute heart failure Cpi was found to be an important tool for diagnosis and risk stratification.[3,4] In patients with chronic CHF, a few studies[5–7] have shown that noninvasive Cpi reserve (the increase in Cpi during exercise or dobutamine stress) is the strongest predictor of outcome (a better oxygen consumption and echocardiographic ejection fraction) in such patients. Furthermore, changes in acute SVRi may be useful for early detection of myocardial ischemia.[8] Moreover, in two separate studies[9–11] examining the efficacy of vasodilators in patients with acute CHF, medication was found to be effective mainly in patients who were submitted to hemodynamic monitoring, implying that perhaps in order to be efficacious, vasodilator treatment should be monitored attentively to prevent overtreatment and undertreatment. In different studies,[12,13] we have also demonstrated that careful titration of vasodilator treatment administered for acute heart failure and acute coronary syndromes is important to optimize its efficacy. In the present study, we evaluated the accuracy of a novel method of CI measurement (whole-body electrical bioimpedance [WBEB]) in different cardiac clinical settings (during cardiac catheterization and coronary artery bypass graft [CABG] surgery, and for monitoring patients with acute CHF) and over a wide range of CI values and severity of left ventricular dysfunction.

Materials and Methods

Patient Populations

Group 1: Group 1 consisted of 40 patients with coronary artery disease referred during March to July 1993 for left and right cardiac catheterization based on conventional clinical indications. During the right-heart study, a pulmonary artery catheter was introduced under fluoroscopy; at a single time point, a paired measurement of CI by a noninvasive cardiac output system/monitor (NICO) [NICaS; NI Medical; Hod-Hasharon, Israel] and by thermodilution was performed.

Group 2: Group 2 included 51 patients undergoing CABG operations. The first 15 patients were studied at Wolfson Medical Center (Israel) during October to November 1994. The next 16 patients were studied at Johns Hopkins Medical Center during April to May 1995. The remaining 20 patients were studied again at Wolfson Medical Center during August to October 1995. A balloon-guided, Swan-Ganz catheter was introduced after the induction of anesthesia, and five paired NICO CI and thermodilution CI measurements were obtained at specific operative and postoperative stages: immediately prior to the skin incision; after sternotomy; after pericardiotomy; 10 min after weaning from the pump; and immediately after arrival to the ICU. The results obtained from the first 31 cases of this series have already been published.[14]

Group 3: Group 3 consisted of 31 patients admitted during September to December 2001 to the ICU of Assaf–Harofeh Medical Center (Israel) because of an acute exacerbation of CHF. Prior to admittance, they underwent a right-heart study in the catheterization laboratory for the assessment of their cardiac condition, and a Swan-Ganz catheter was inserted under fluoroscopy. CO measurement was begun on arrival to the ICU, where three baseline measurements were obtained, 15 min apart. In 17 patients who required vasodilator therapy, four measurements were obtained during the initiation and up-titration of IV isosorbide-dinitrate (ISDN) treatment. In the 14 patients who did not require ISDN treatment, an additional (fourth) baseline measurement was obtained. All the studies were approved by the review boards and the Helsinki committees of the various hospitals. Consents for the studies were obtained from each patient.

Measuring CI

Thermodilution: In all three study groups, a No. 7F Swan-Ganz balloon flotation catheter was placed in the pulmonary artery. In groups 1 and 2, the Swan-Ganz catheter was introduced in the catheterization room, and in group 2 on the operating table, following anesthesia. In the 16 patients of group 2 who were studied at Johns Hopkins Medical Center, CO measures were obtained by the 7010 Series Marquette (Marquette; Madison, WI). In the remaining 35 patients of group 2 studied at Wolfson Medical Center, and also in group 1 patients at the Tel Aviv Medical Center (Israel), the Horizon 2000 (Mennen Medical; Rohovot, Israel) was used. In group 3, the CO was measured by Marquette 8000 Clinical Information Center 419897-015 (Marquette).

A volume of 10 mL of 5% dextrose at room temperature was injected in all patients via the proximal port. Temperature changes were measured via the distal port located in the pulmonary artery, ascertained by fluoroscopy, oxygen saturation, and wedge pressure measurements. In all patients, three CI measurements were obtained; when a $> 15\%$ disparity occurred between the two extreme measurements, two further injections, or more, were administered until an average of three measurements within the 15% range was obtained.

NICO WBEB Technology

When transmitting a small electrical current through the body, an impedance to its transmission (restivity, R) is being measured.

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This resistivity is called *bioimpedance*. According to Kirchov's law, electric current passes through conduits of higher conductance (lowest resistivity). The resistivity of blood and plasma is the lowest in the body (resistivity of blood is 150; plasma, 63; cardiac muscle, 750; lungs, 1,275; and fat, 2,500 ohm/cm).[15] Thus, when an alternating current of 20 to 100 kHz is applied to the body, it is primarily distributed via the extracellular fluid and the blood. The changes in the body resistivity (ΔR) over time (milliseconds) are therefore related to the dynamic changes of the blood and plasma volume. This pertains particularly to the passage of the stroke volume (SV) from the left ventricle into the aorta and its branches. However, in the capillaries and in the venous system the blood volume is relatively constant, because the flow in these vessels is not pulsatile. Consequently, each systolic increase in the aortic blood volume is associated with a proportional increase in the measurable conductance of the whole body (Fig 1).[16] Thus, for measuring the aortic SV by means of its impedance change, Frinerman and Tsoglin developed the following algorithm[14]:

$$SV = \frac{Hctcorr}{Ksex,\ age} \times K_{el} \times K_{weight} \times IB \times \frac{H^2corr\ \Delta R}{R} \times \frac{\alpha + \beta}{\beta}$$

in which the $\Delta R/R$ is corrected for hematocrit (Hctcorr), electrolytes (K_{el}), body composition (K sex, age), weight (K_{weight}), time characteristics (α = systolic time, β = diastolic time), and index balance (IB), which measures the body water composition.

To collect patient signals, the NICO uses proprietary electrodes arranged in a wrist-to-ankle configuration (Fig 2); in certain conditions when this particular form is not applicable (as with severe peripheral edema or severe peripheral vascular disease), a wrist-to-wrist configuration is used. The precise positioning of the NICO electrodes is not critical; an untrained operator can make the attachments. An alternating current of 30 kHz, 1.4 mA is delivered through the two electrodes, and the bioimpedance and its fluctuations over time are measured. In addition, a standard three-lead ECG connection is made for measuring the pulse rate. The other variables required for SV and CI calculation (age, gender, weight, height, hematocrit, electrolytes) are introduced into the machine only at the start of monitoring. For measuring the CO, the SV is multiplied by the heart rate.

Although the idea of the WBEB was conceived and tested in the Soviet Union in 1941,[17] it remained dormant until recently. Meanwhile another bioimpedance approach for measuring the CO was initially introduced by Kubicek et al[18] in the United States in 1966, and further refined in 1974.[19] His method is called *thoracic electrical bioimpedance* (TEB), and the tools of this approach are commercially available. Noted here are dissimilarities in the operation of the two technologies. In the NICO, one electrode is applied to the wrist and the other to the ankle; in TEB, a number of electrodes are placed at the root of the neck and another set around the lower part of the chest cage. In WBEB, the SV is measured by the impedance variation (ΔZ or ΔR) induced by the systolic volume ejected into the aorta. In the original TEB formula of 1966,[18] the SV measurement was based on a similar principle. However, since when the electrodes are placed on the chest, the ΔZ wave could be hardly detected, Kubicek et al[19] adopted another principle, whereby the SV measurement is based on the depiction of the aortic systolic dp/dt (instantaneous pressure change over time) for calculation of the systolic blood flow into the great arteries.

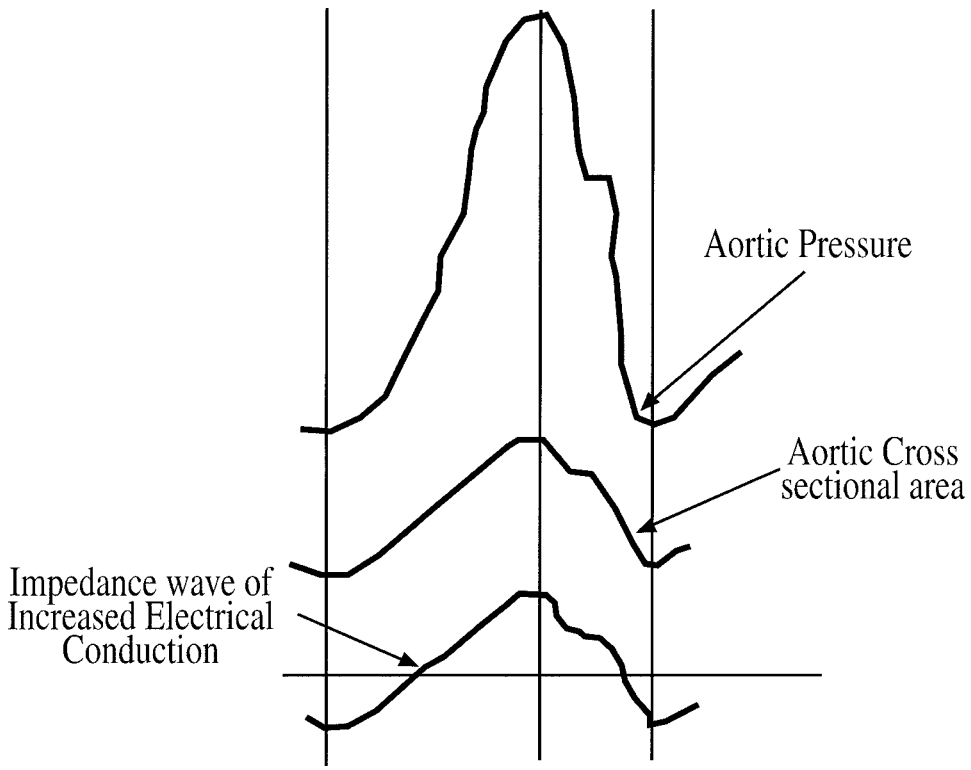

FIGURE 1. Recordings of the interrelation between impedance variations and hemodynamic parameters, according to Djordjevich and Sadove.[16]

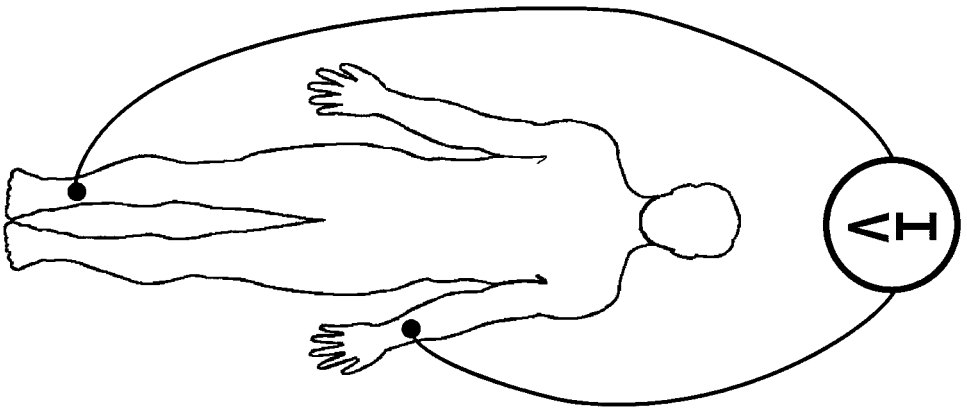

FIGURE 2. Wrist-to-ankle configuration of the electrodes in WBEB. I = electric current; V = electric voltage.

Measuring CI by the NICO

For each CI determination, three NICO measurements were obtained. Since the CO results that are displayed on the scope are updated every 20 s, for the determination of the CI an average CO is derived from a 60-s monitoring.

Statistical Methods

Agreement between the CI values of the NICO and thermodilution was evaluated in three ways: the mean CI values of the NICO and thermodilution were compared by a paired Student *t* test; correlation between these values was evaluated by calculating the Pearson correlation coefficient and by applying a linear regression model of the NICO on thermodilution; the differences between the paired CI values of the NICO and thermodilution were plotted against the average CI values of both methods, instead of against thermodilution alone. This statistical method was recommended by Bland and Altman[20] for evaluating a new device (NICaS) against an established method (thermodilution), which has its own inaccuracies. Bias was defined as the mean difference between the NICO CI and thermodilution CI values. Limits of agreement (precision) were calculated as bias ± 2 SD of the differences between the NICO CI and thermodilution CI values. All three analyses were carried for the whole sample and for each specific clinical group: cardiac catheterization patients (group 1), CABG patients (group 2), and CHF patients (group 3).

We have examined the differences between the CI determination by the NICO and thermodilution at different CI readings by classifying the readings into four subgroups according to the mean CI levels: CI < 1.5, CI ≥ 1.5 and < 2, and CI ≥ 2 and < 3, and CI ≥ 3. CI readings by the NICO and thermodilution in each group were compared using the paired Student *t* test and presented as mean and SDs.

The sensitivity of the two methods (NICO and thermodilution) to a change in a specific medical condition was compared in the CABG group at five operative and postoperative stages. A variance analysis with repeated measures (type of method and stage) was performed, followed by contrast analysis that compared successive stages. This analysis could be performed only for patients with complete data at all the five stages. A similar analysis was performed at seven time points in CHF patients who had been treated with an IV vasodilatory drug. All statistical analyses were performed using the SAS System for Windows (version 8.01; SAS Institute; Cary, NC).

RESULTS

No significant differences between the means of NICO CI and thermodilution CI in the three clinical groups, as well as the whole cohort, were observed (Table 1). A significant, high correlation was found between the NICO CI and the thermodilution CI measurements: 0.886 in the whole cohort, and 0.881, 0.902, and 0.851 in the catheterization, bypass surgery, and CHF groups, respectively. All correlation coefficients were statistically significant ($p < 0.0001$).

The results of applying linear regression models to the data (Table 2, Fig 3) demonstrate similar models in the three clinical groups, as the intercepts and slopes of the regression lines are not significantly different (intercepts, $p = 0.2398$; slopes, $p = 0.2310$). Figure 4 shows differences between CI values plotted against the average value of the two methods with limits of agreement: two SDs from the mean difference.

Significant differences between the NICO CI and thermodilution CI were observed when comparing the average CI of the four CI ranges (Table 3). When CI is < 2 L/min/m^2, the thermodilution CI readouts

Table 1—*Comparison Between the Mean CI Values of the NICO and Thermodilution in the Three Clinical Groups and in the Whole Cohort**

Group	No.	Thermodilution CI, L/min/m^2		NICO CI, L/min/m^2		p Value
		Mean	SD	Mean	SD	
Whole sample	418	2.39	0.70	2.38	0.73	NS
Catheterization	40	2.81	0.72	2.81	0.68	NS
CABG	208	2.33	0.72	2.31	0.77	NS
CHF	170	2.35	0.63	2.38	0.66	NS

*NS = not significant.

Table 2—*Linear Regression Analysis, Bias, and Precision in the Three Clinical Groups and in the Whole Cohort*

Sample	Intercept	Slope	R^2	Bias (Mean Between-Method Difference), L/min	Precision (Mean ± SD), L/min
Whole	0.18	0.92	0.79	− 0.0009	− 0.6849 ± 0.6831
Catheterization	0.45	0.84	0.77	0.0040	− 0.7134 ± 0.6393
CABG	0.08	0.96	0.81	− 0.0247	− 0.6789 ± 0.7331
CHF	0.29	0.89	0.72	0.0271	− 0.684 ± 0.692

are significantly higher than the NICO CI; when CI is > 3 L/min/ m^2, the thermodilution CI is lower than the NICO CI (Table 3). When CI was between 2 L/min/m^2 and 3 L/min/m^2, there was a slight difference of only 3.28% between the two methods, with a borderline significance (Table 3).

Twenty-five patients with CABG (subgroup A) had complete information of the NICO CI and thermodilution CI results at five operative and postoperative stages (Table 4, Fig 5, *top*). A further 26 CABG patients (subgroup B) had incomplete data (< 5 paired measurements for each patient), yielding additional 80 paired measurements (Table 4). There were time-related changes in the CI, and the NICO and the thermodilution followed these changes by producing similar results at each time point ($p = 0.0035$ and $p = 0.0058$, respectively; Fig 5, *top*). A contrast analysis, performed to compare the CO in successive stages of the measurements, found that the difference between stage 3 and stage 4 was statistically significant according to the two measurements in subgroup A (NICO CI, $p = 0.0135$; thermodilution CI, $p = 0.002$; Fig 5, *top*). In 17 of the CHF patients in group 3 who were treated with an IV vasodilator agent, and in whom the CI was measured simultaneously at seven time points during the treatment, the total time trend was significant in the NICO ($p = 0.0056$) but not significant in thermodilution (Fig 5, *bottom*).

Discussion

In recent years it has been suggested that CO and MAP measurement and the calculation of CI, Cpi, and SVRi might be instrumental in the diagnosis, treatment titration, and risk stratification of cardiac patients, especially those with CHF.[7–10] However,

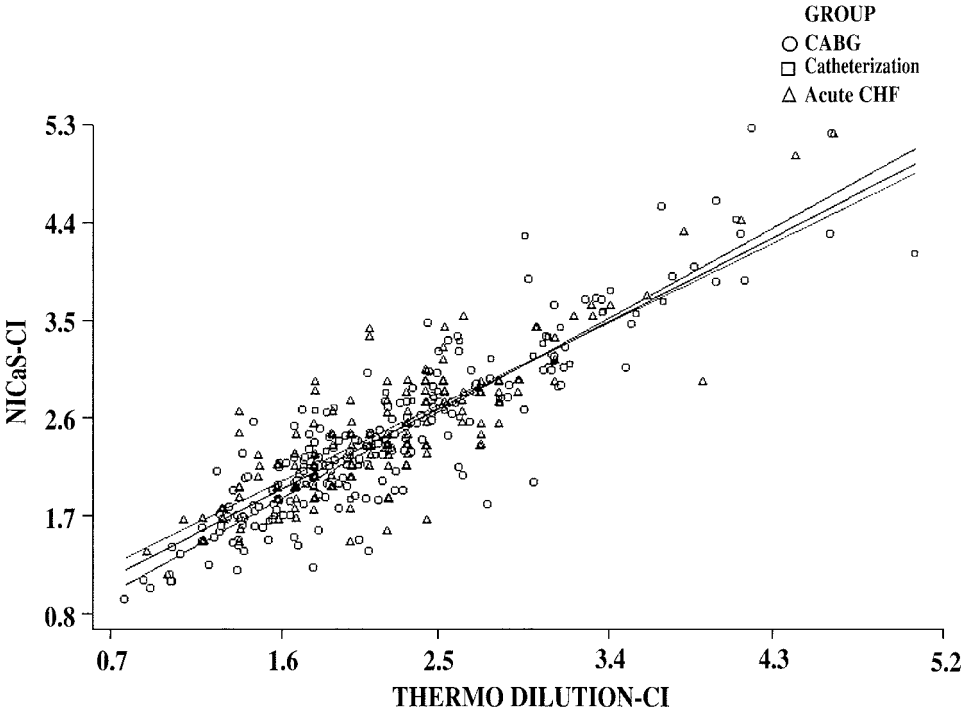

Figure 3. Plot of CI values measured by the NICO and thermodilution.

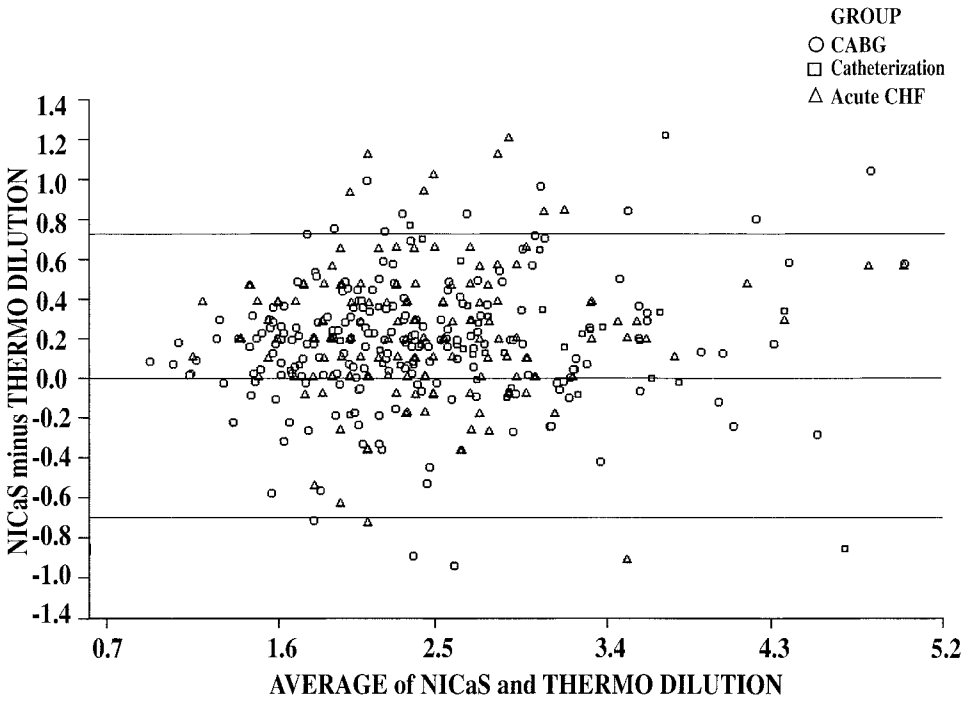

FIGURE 4. Differences between CI values (NICO vs thermodilution) plotted against the average values of the two methods.

CI has been measured only during invasive right-heart catheterization, which requires intensive care admission and may be associated with complications.[21–23] Hence, CI was measured only rarely, and in the sickest patients. Therefore, a simple, reliable, noninvasive, and continuous method for CI measurement has become necessary in order to enable its application to cardiac patients with different degrees of medical severity and in diverse settings.

Currently there are four accepted methods for noninvasive CO measurement. The Doppler echocardiogram obtained from the left ventricular outflow track and CO_2 rebreathing techniques have been shown to be accurate in measuring CI. But these methods are limited by the requirement for expensive equipment and specialized personnel for their application and therefore are not simple to use, and moreover do not enable continuous measurements. Thoracic bioimpedance has been used in the last decade for continuous CO measurement. Judging by the literature,[24–26] as long as the heart function is intact, TEB can be useful for monitoring the hemodynamic state in various clinical conditions such as trauma, massive surgery, sepsis, etc.[24] But when it comes to monitoring and managing pathologic cardiac conditions TEB requires further improvement.[24–26]

Thus far, eight groups of patients who submitted to CO measurements by WBEB have been reported in six published articles. Kedrov,[17] who was the first, compared the average CI measured by the WBEB in 57 subjects with normal hearts in published results of the Fick method, revealing 3.3 ± 28% vs 3.31 L/min/m^2 (range, 2.4 to 4.2 L/min/m^2), respectively. Tischenko[27] compared the CI results measured by WBEB in three groups of subjects with normal hearts vs three standard methods. There were 31 cases vs acetylen (r = 0.84), 28 cases vs thermodilution (r = 0.95), and 28 cases vs Fick (r = 0.99). Using a modified Tischenko algorithm vs thermodi-

Table 3—*Differences Between the NICO CI and Thermodilution CI Within the CI Ranges*

CI Ranges by NICO CI	Results, No.	NICO CI, Mean	Thermodilution CI, Mean	Relative Difference, %	Significance
< 1.5	30	1.278 ± 0.16	1.515 ± 0.35	− 12.99	0.0002
1.5 < CI < 2	98	1.749 ± 0.14	1.876 ± 0.33	− 4.65	< 0.0001
2 < CI < 3	220	2.433 ± 0.28	2.392 ± 0.40	3.28	0.0484
CI > 3	70	3.594 ± 0.57	3.449 ± 0.64	5.44	0.0045

Table 4—*Trend Follow-up of the NICO CI and Thermodilution CI During the Five Operative and Postoperative Stages*

	NICO CI				Thermodilution CI			
	Subgroup A (n = 25)		Subgroups A + B (n = 51)		Subgroup B, (n = 26)		Subgroups A + B, (n = 51)	
Method	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	2.28	0.87	2.25	0.83	2.22	0.69	2.22	0.67
2	2.09	0.58	2.09	0.57	2.14	0.57	2.14	0.52
3	2.17	0.62	2.26	0.69	2.15	0.68	2.22	0.70
4	2.72	0.79	2.54	0.81	2.80	0.74	2.61	0.77
5	2.56	0.74	2.46	0.85	2.61	0.83	2.53	0.87

lution, Koobi et al[28] obtained simultaneous measurements in 74 patients with coronary disease, reaching a bias between the two methods of 0.25 ± 0.8 L/min (SD), where the limits of agreement (2 SD) were – 1.37 L/min and 1.897 L/min, respectively. Using the NICaS apparatus, Cohen et al[14] compared its performance against thermodilution by measuring the CO in patients undergoing CABG operations, with a correlation of $r = 0.91$. Thus, this six-clinical series, which included 274 subjects, revealed similar correlation coefficients between the compared methods, just as in the present series. Moreover, in none of these publications did the authors express reservations about the performance of the WBEB.

There were, nonetheless, two publications in which no correlation was found between WBEB and thermodilution; in both instances, the underlying clinical conditions are listed in the exclusion criteria of the NICO. Lamberts et al[29] compared the original Tischenko equation with dye dilution CO in 10 patients, 4 of whom had significant aortic regurgitation and 1 had coarctation of the aorta. The NICO apparatus cannot measure the CO in such conditions.

Imhoff et al[30] compared the NICO apparatus against thermodilution in 22 postpancreatectomy or esophagectomy patients. They were all managed postoperatively by Swan-Ganz catheters for boosting the oxygen delivery to 600 mL/min/m^2 and the CI to 4.5 L/min/m^2. Hence, in these patients the radical surgical procedures were followed by massive intercompartmental volume shifts due to IV administration of up to 6 L per 24 h of crystalloids and plasma, often accompanied by massive peripheral edema. In such hemodynamic situations, the baseline impedance should properly become distorted, preventing an accurate measurement of the systolic impedance variation.

In the present study, the agreement between NICO CI and thermodilution CI as tested by comparisons of the means is highly significant. The similarity between the means in the entire cohort as well as in each diagnostic group, together with the relatively large sample size, further endorses the significance of the results.

The mean difference between the NICO and thermodilution in the entire sample range was 0.0009 L/min (Table 2, Fig 4), ranging from 0.0040 to 0.0271 L/min in the three diagnostic groups. This disparity is smaller than the level of accuracy of thermodilution, which is defined to a 15% range.[31] Linear regression applied to the data revealed that the line slope was close to 1.00 in the entire sample range and in each specific diagnostic group. There were no significant differences between the slopes and the intercepts of the three diagnostic groups. This indicates that the relation between the NICO and thermodilution is similar in all diagnostic groups. Following the recommendations of Bland and Altman,[20] the differences between the two measurements were plotted against their means. This plot demonstrates that the range of differences is similar along the different values of the average.

Although the main purpose of this work was to compare the performance of the NICO vs thermodilution, following the suggestion in previous studies[31–35] that thermodilution tends to overestimate CI when low and underestimate it when high, we have compared the NICO CI and thermodilution CI in the different CI ranges. The results of this analysis have shown that when the CI was < 2 L/min/m^2, the thermodilution results were higher than the NICO results; when the CI was > 3 L/min/m^2, the thermodilution results were slightly lower than the NICO results (Table 3). As a consequence, the differences of the hemodynamic responses to vasodilation therapy may be better depicted by the NICO when compared with thermodilution (Fig 5, *bottom*).

The link between a low CI and a higher thermodilution readout, and between a higher CI with a low thermodilution readout, is also expressed in the stability of the range of differences along the different values of the average (Fig 4). Furthermore, the

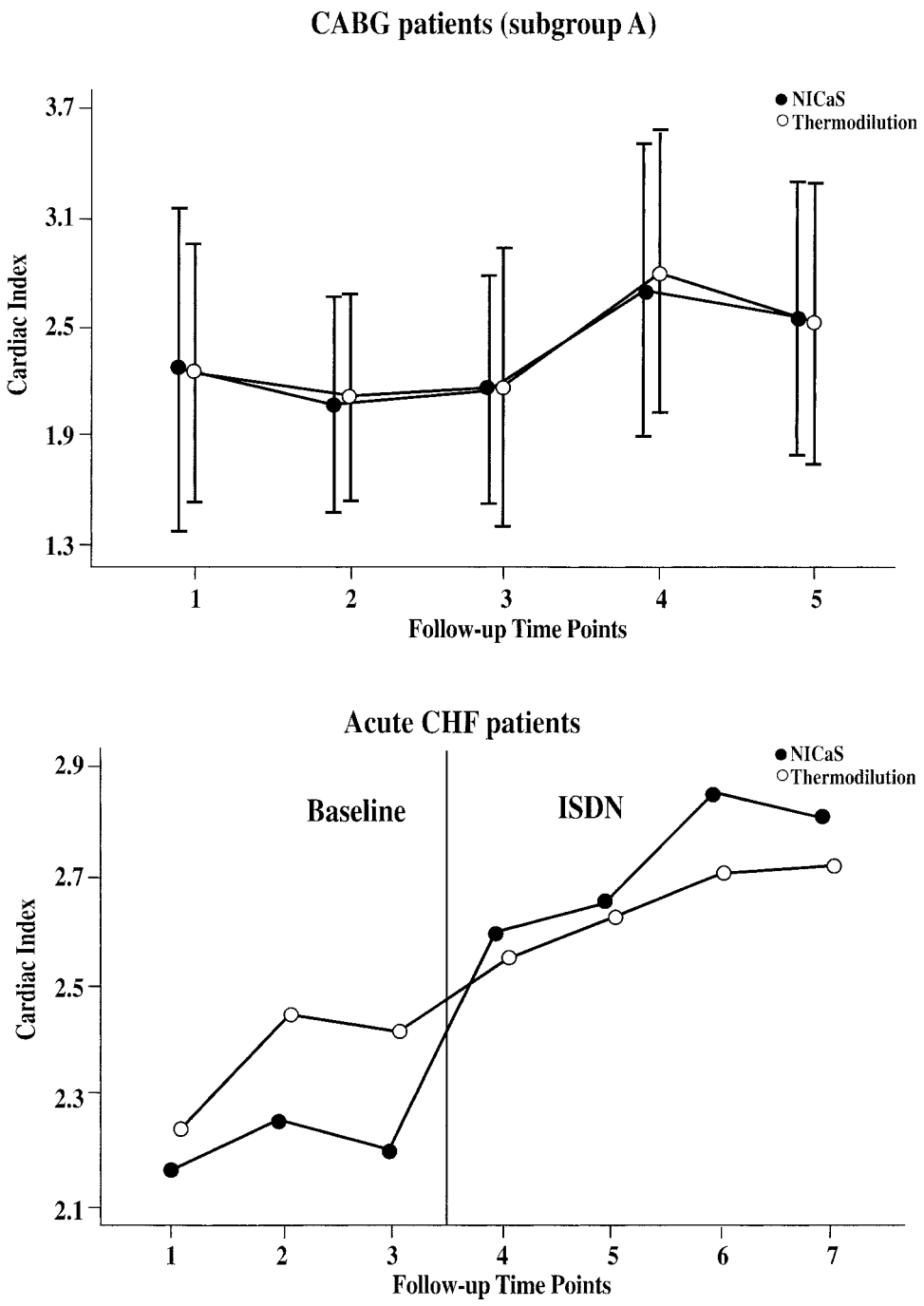

FIGURE 5. *Top*: Comparisons between the NICO CI and thermodilution CI at five operative and postoperative stages. *Bottom*: NICO CI and thermodilution CI responses to vasodilating titration therapy in patients with acute CHF.

almost identical results of thermodilution and the NICO observed in the CI < 2 to < 3 range (Table 3) yield a mutual endorsement of the technical operations of the measuring devices by the two methods. It should also be noted that the two methods switch their interrelations at CI of approximately < 2.5 L/min/m^2 (Fig 5, *bottom*), which is close to the lower border.

Limitations of the NICO

Diseases of the Aorta and Aortic Valve: The NICO measures the SV of the aorta and its derivatives (including the peripheral arteries). For determining the CO, SV is multiplied by the heart rate. Any aberration in the hemodynamics of the aorta and its derivatives may interfere with the proper function of

the NICO. In aortic insufficiency, the SV is pathologically increased. Coarctation and significant aneurysms of the aorta and also severe peripheral arterial disease may produce inaccurate readouts of the SV.

Significant (+3/+4) Peripheral Edema: In significant edema, the baseline impedance of the body is occasionally very low, currently interfering with the accuracy of the results.

Shunts: Our experience with congenital heart disease is limited, but we assume that since there is no complete separation between the two circulations the impedance technique may not be appropriate.

Restlessness: The impedance test requires a motionless condition; in addition, restlessness is associated with fluctuating activation of the sympathetic system, resulting in an unstable hemodynamic state.

Arrhythmias: In most cases, there is no interference with the CO measurement, although when associated with a heart rate > 150 beats/min or when there is a severe disarray of the complexes (ECG and SV), the results may become inaccurate, as may be for any technique measuring CO.

Resections: Major abdominal and thoracic surgical resections, especially those that include major rapid shifts in fluid distribution between the intravascular and extravascular space.

Conclusions

In spite of these limitations, the NICO apparatus offers a simple, noninvasive, reliable, and continuous measurement of CI in cardiac patients with particular emphasis on CHF. This measurement combined with MAP measurement and the calculation of Cpi and SVRi is destined to become a safe, simple, rapid, noninvasive method for evaluating and treating primarily coronary patients sustaining chronic and acute exacerbations of CHF.

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