Underestimation of Cardiac Output by Thermodilution in Patients with Tricuspid Regurgitation

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INTRODUCTION: **This study was done to assess the accuracy and reliability of the thermodilution technique in measuring cardiac output in patients with tricuspid regurgitation.**

PATIENTS AND METHODS: **In 30 subjects (17 men, 13 women, aged 50 ± 14 [mean ± SD] years), cardiac output was measured in close temporal proximity by thermodilution as well as Fick or indocyanine green dye, after which the presence and severity of tricuspid regurgitation were assessed by contrast right ventriculography or pulsed Doppler echocardiography.**

RESULTS: **In the 13 patients without tricuspid regurgitation, there was excellent agreement between the results of thermodilution and Fick or indocyanine green dye cardiac output determinations (4.95 ± 1.19 liters/minute by thermodilution, 4.90 ± 1.11 liters/minute by Fick or indocyanine green dye; NS). In contrast, in the 17 patients with tricuspid regurgitation, the results of thermodilution were consistently lower than those of Fick or indocyanine green dye (4.22 ± 1.45 liters/minute by thermodilution, 4.99 ± 1.67 liters/minute by Fick or indocyanine green dye; p <0.001).**

CONCLUSION: **Thus, the thermodilution technique of measuring cardiac output is inaccurate in patients with tricuspid regurgitation, yielding results that are consistently lower than the actual outputs.**

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Since the balloon-tipped, flow-directed (Swan-Ganz) catheter was introduced in 1971 [1], the measurement of cardiac output by the thermodilution technique has been used extensively in the hemodynamic monitoring of critically ill patients [2]. Numerous studies [1–10] have shown that the thermodilution method is accurate in determining cardiac output, but it is said to be unreliable in patients with significant tricuspid regurgitation [2,11,12]. Such tricuspid regurgitation may occur in subjects with tricuspid valve endocarditis as well as those with right ventricular dilatation of any cause, including dilated cardiomyopathy, pulmonary hypertension (most often due to elevated left-sided filling pressures), and right ventricular infarction. Although the thermodilution technique is said to be inaccurate in these persons, no previously published study in humans (1) has shown this to be true or (2) has determined the magnitude of this inaccuracy. Therefore, the current study was performed to assess the accuracy and reliability of the thermodilution technique in patients with tricuspid regurgitation.

PATIENTS AND METHODS

Patients

From February 1986 to July 1988, 30 patients (17 men, 13 women, aged 21 to 73 years) were studied after informed consent was obtained. In 13 subjects, contrast right ventriculography demonstrated no tricuspid regurgitation, and, therefore, they served as controls (**Table I**). In the other 17 patients, contrast right ventriculography (n = 5) or pulsed Doppler echocardiography (n = 12) demonstrated 2+, 3+, or 4+ tricuspid regurgitation (**Table II**).

Experimental Protocol

In each patient, a balloon-tipped, flow-directed thermodilution catheter (American Edwards model 93A-131-7F, Anasco, Puerto Rico) was advanced to the pulmonary artery under fluoroscopic guidance, and right atrial and pulmonary arterial pressures were measured. At 60-second intervals, a 10-ml bolus of iced sterile saline (0°C) was injected into the right atrium through the catheter's proximal lumen, and the change in temperature at the distal thermistor was recorded. Cardiac output was calculated with a miniature on-line analogue computer system (Electronics for Medicine model DTCCO-06/V2212, Pleasantville, New York) [13–15]. Three measurements of output were performed in each individual and the values were averaged. The variability of thermodilution cardiac outputs in our laboratory is ± 4 percent [10,15].

Immediately thereafter, cardiac output was measured by the Fick (n = 14) or indicator dilution technique using indocyanine green dye (n = 16). Indocyanine green dye was injected into the pulmonary artery

TABLE I

Hemodynamic Data for the 13 Patients without Tricuspid Regurgitation

Patient Number	Age	Sex	Fick or Green Dye Cardiac Output (liters/minute)	Thermodilution Cardiac Output (liters/minute)	Right Atrial Mean Pressure (mm Hg)	Pulmonary Artery Mean Pressure (mm Hg)	Diagnosis
1	45	M	4.85	4.76	2	39	Dilated cardiomyopathy
2	64	M	4.78	4.61	2	13	Coronary artery disease
3	56	M	5.36	5.76	2	13	Coronary artery disease
4	47	M	5.78	5.93	2	19	Coronary artery disease
5	51	M	5.06	4.84	4	13	Coronary artery disease
6	58	M	3.63	4.17	8	18	Coronary artery disease
7	44	M	3.77	3.66	1	13	Coronary artery disease
8	34	M	6.61	6.98	2	16	Coronary artery disease
9	59	M	3.47	3.35	5	13	Coronary artery disease
10	69	F	6.08	6.18	8	23	No demonstrable disease
11	58	F	5.00	4.68	0	12	Aortic regurgitation
12	60	M	3.16	3.20	2	17	Coronary artery disease
13	35	M	6.14	6.18	10	33	Coronary artery disease
Mean	52		4.90	4.95	4	19	
SD	11		1.11	1.19	3	8	

TABLE II

Hemodynamic Data for the 17 Patients with Tricuspid Regurgitation

Patient Number	Age	Sex	Fick or Green Dye Cardiac Output (liters/minute)	Thermodilution Cardiac Output (liters/minute)	Right Atrial Mean Pressure (mm Hg)	Pulmonary Artery Mean Pressure (mm Hg)	Grade of Regurgitation	Diagnosis
1	21	M	5.40	4.70	12	36	2+	Dilated cardiomyopathy
2	47	F	4.58	4.11	26	78	2+	Mitral stenosis
3	69	F	3.67	2.94	13	26	2+	Coronary artery disease
4	35	M	5.44	4.08	14	42	2+	Mitral regurgitation
5	53	M	7.81	4.80	11	31	3+	High output failure
6	73	F	7.33	6.85	NA	NA	2+	Aortic stenosis
7	23	F	4.53	3.23	3	24	3+	Mitral stenosis
8	27	F	1.80	1.52	22	25	3+	Endomyocardial fibrosis
9	43	F	2.46	2.99	14	32	2+	Aortic stenosis
10	51	M	5.70	5.05	6	15	2+	Coronary artery disease
11	60	F	4.22	3.30	7	48	2+	Mitral stenosis
12	35	F	6.81	6.74	14	22	2+	S/P cardiac transplant
13	69	F	4.18	3.10	16	32	3+	Mitral regurgitation
14	42	F	6.43	5.05	3	18	2+	Dilated cardiomyopathy
15	45	M	6.16	5.52	9	24	2+	Tricuspid endocarditis
16	64	F	3.06	2.63	19	65	2+	Mitral regurgitation
17	68	M	5.27	5.07	21	37	4+	Dilated cardiomyopathy
Mean	49		4.99	4.22*	13	35		
SD	17		1.67	1.45	7	17		

S/P = status post; NA = data not available.
* $p < 0.001$ in comparison to Fick or indocyanine green dye.

during the simultaneous withdrawal of blood from the descending aorta through a densitometer cuvette, according to methods described previously [10,15–17]. Measurement of cardiac output was performed with a miniature on-line analogue computer system [13,14]. In each patient, measurements of output were performed in triplicate and the results were averaged. The variability of indocyanine green dye measurements of cardiac output in our laboratory is ± 4 percent [10,15].

Contrast right ventriculography or pulsed Doppler echocardiography was performed to assess the presence and severity of tricuspid regurgitation. With ventriculography, tricuspid regurgitation was graded from 1+ to 4+ (mild to severe), in accordance with previously described angiographic criteria [18]. Pulsed Doppler echocardiography of the right atrium was performed with a Hewlett-Packard phased-array two-dimensional echocardiogram (model 77020 AC, Mountain View, California) and a 2.5 mHz transducer using the four-chamber apical view. The severity of tricuspid regurgitation was assessed according to the distance that the regurgitant jet extended from the plane of the tricuspid valve into the right atrium on the two-dimensional image, with 2+ = 15 to 30 mm, 3+ = 30 to 45 mm, and 4+ = greater than 45 mm [19].

Statistical Analyses

All data are reported as mean ± 1 SD. Within each group (control subjects and those with tricuspid regurgitation), the cardiac outputs by Fick or indocyanine green dye were compared with those measured by thermodilution with a paired t test. The two groups were compared with Student's t test. For each individual, the value for thermodilution cardiac output was subtracted from that obtained by Fick or indocyanine green dye, yielding the absolute difference; in turn, this absolute difference was divided by the Fick or

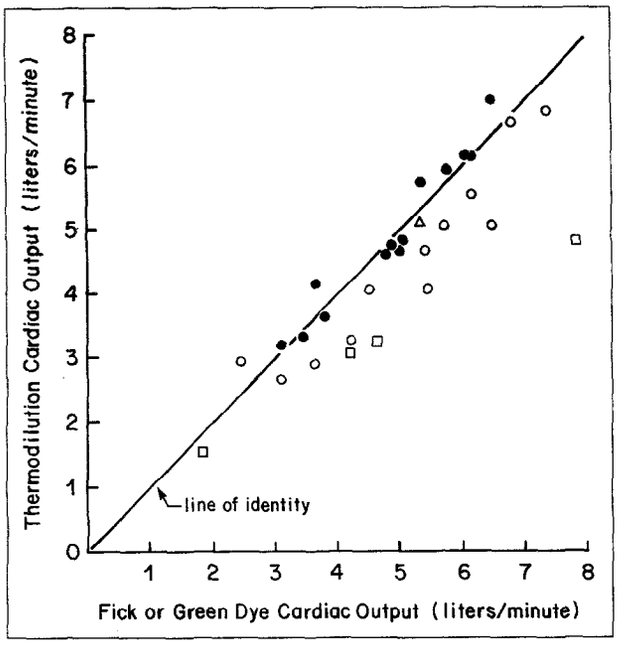

Figure 1. Comparison of the results of Fick or indocyanine green dye (**horizontal axis**) and thermodilution (**vertical axis**) for the 13 patients without (**closed circles**) and the 17 subjects with (**open symbols**) tricuspid regurgitation. Data from those with 2+ regurgitation are depicted as **open circles** (n = 12), 3+ as **open squares** (n = 4), and 4+ as **open triangles** (n = 1). The thermodilution technique yielded results that were consistently lower than those obtained by Fick or indocyanine green dye for subjects with tricuspid regurgitation.

indocyanine green dye output to yield the percent difference between the techniques. For all analyses, a p value <0.05 was considered significant [20].

RESULTS

For the 13 control subjects, cardiac output by thermodilution was similar to that measured by Fick or indocyanine green dye (Table I, **Figure 1**). In contrast, for the 17 patients with tricuspid regurgitation, cardiac output by thermodilution was less ($p < 0.001$) than that measured by Fick or indocyanine green dye (Table II, Figure 1). The absolute difference between the results of Fick or indocyanine green dye and thermodilution was 0.04 ± 0.26 liters/minute for the control subjects and 0.77 ± 0.76 liters/minute for those with tricuspid regurgitation ($p < 0.001$); similarly, the percent difference between the results of Fick or indocyanine green dye and thermodilution was −1 ± 6 percent for the control subjects and +15 ± 14 percent for those with tricuspid regurgitation ($p < 0.001$) (**Figure 2**).

The 17 patients with tricuspid regurgitation had an average right atrial mean pressure of 13 ± 7 mm Hg and an average pulmonary arterial mean pressure of 35 ± 17 mm Hg (Table II), both of which were significantly higher ($p < 0.001$) than those of the 13 control subjects (4 ± 3 mm Hg and 19 ± 8 mm Hg, respectively) (Table I).

Of the 17 patients with tricuspid regurgitation, 12 had 2+, four had 3+, and one had 4+ regurgitation (Table II, Figure 1). The discrepancy between the results of thermodilution and Fick or indocyanine green dye was similar for all grades of regurgitation, but the small number of subjects with 3+ or 4+ regurgitation did not allow a meaningful analysis.

COMMENTS

Although the thermodilution technique has been shown to be accurate in measuring cardiac output [1–10], it is believed to be unreliable in subjects with tricuspid regurgitation [2,11,12]. However, no previously published study has assessed the influence of tricuspid regurgitation on the results of the thermodilution technique in humans. Our data demonstrate that the results of the thermodilution method correlate well with those of the Fick or indocyanine green dye techniques in patients without tricuspid regurgitation (Table I, Figures 1 and 2). In contrast, the thermodilution technique is inaccurate in patients with tricuspid regurgitation, and the results of the thermodilution method are consistently lower than those of the Fick or indocyanine green dye techniques in these persons (Table II, Figures 1 and 2).

The equation by which cardiac output is calculated with the thermodilution technique is as follows:

$$\text{Cardiac Output} = \frac{(T_B - T_I)\,(10)\,(60)\,(1.10)\,(0.825)}{\int_0^\infty \Delta T_B\,(t)\,dt},$$

in which T_B = body temperature, T_I = temperature of injectate, 10 = volume of injectate (in ml), 60 = number of seconds in one minute, and 1.10 = ratio of the products of specific heat and gravity of normal saline and blood; 0.825 is an empiric factor that accounts for warming of injectate within the catheter. The denominator of the equation is the integral of the change in blood temperature during the injection of cold and is reflected by the area of the inscribed curve. If the transit time of indicator from the site of injection (right atrium) to the thermistor (pulmonary artery) is prolonged (due, for example, to bidirectional flow across the tricuspid valve), the upslope and downslope

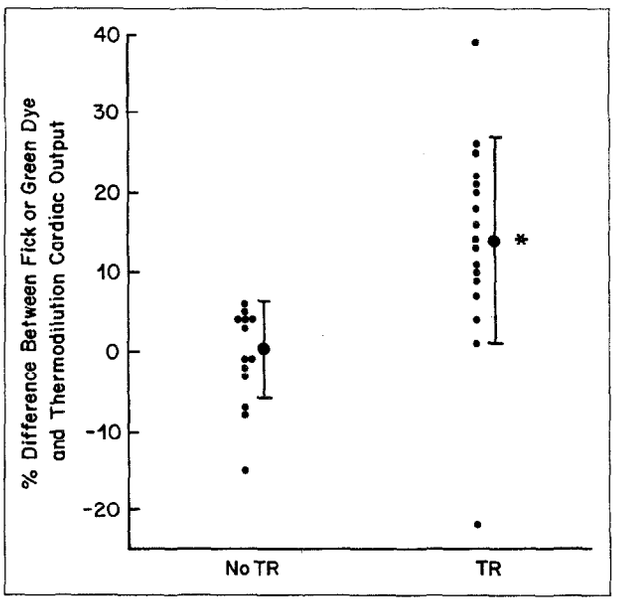

Figure 2. The percent difference between the results of Fick or indocyanine green dye and thermodilution cardiac outputs for those without (**left**) and those with (**right**) tricuspid regurgitation (TR). Each **dot** represents the data from one patient, and the mean ± 1 SD are displayed for each group. In comparison to the control subjects, those with tricuspid regurgitation demonstrated a larger percent difference (* $p < 0.001$).

of the inscribed curve are splayed and prolonged. As a result, the area of the thermodilution curve is increased and the cardiac output proportionately decreased. Thus, an artifactually low value for cardiac output is obtained. In support of this, the results of the thermodilution technique were lower than those of the Fick or indocyanine green dye methods in 16 of our 17 patients with tricuspid regurgitation (Table II, Figures 1 and 2).

In the coronary care unit, medical and surgical intensive care units, and operating room, the thermodilution technique is frequently used to measure cardiac output. Some of the patients in whom this method is employed have substantial tricuspid regurgitation, due most often to tricuspid valve endocarditis, right ventricular infarction, or right ventricular dilatation of any cause, including dilated cardiomyopathy and left ventricular failure and dilatation. In such persons, the results of the thermodilution technique are inaccurate and are consistently lower than actual outputs.

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