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Original contribution

Cardiac index measurements during rapid preload changes: a comparison of pulmonary artery thermodilution with arterial pulse contour analysis[☆]

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Abstract
Study Objective: To compare cardiac index (CI) values obtained by pulmonary artery thermodilution (CI_{PA}), arterial thermodilution (CI_{TD}), and arterial pulse contour analysis (CI_{PC}) during rapid fluid administration, as accurate and rapid detection of CI changes is critical during acute preload changes for guiding volume and vasopressor therapy in critically ill patients, and the accuracy of CI_{PC} during acute changes in loading condition is currently unknown.
Design: Prospective clinical study.
Setting: Cardiac surgical intensive care unit of a university hospital.
Patients: Seventeen American Society of Anesthesiologists (ASA) physical status II and III patients, aged 32 to 76 years, with normal left ventricular function during the early postoperative period after elective coronary artery bypass graft surgery.
Measurements: After baseline determinations of CI_{PA}, CI_{PC}, and CI_{TD} were made, fluid loading was performed using 10 mL times body mass index of hydroxyethyl starch 6%. CI_{PA}, CI_{PC}, and CI_{TD} were determined, and changes in CI (ΔCI) were calculated. Fluid load was repeated until no increase in stroke volume index (ΔSVI <10%) was achieved.
Main Results: Regression analysis between CI_{PA}/CI_{PC}, CI_{PA}/CI_{TD}, and CI_{PC}/CI_{TD} revealed $r^2 = 0.92$, $r^2 = 0.92$, and $r^2 = 0.98$. Regression analysis between $\Delta CI_{PA}/\Delta CI_{PC}$, $\Delta CI_{PA}/\Delta CI_{TD}$, and $\Delta CI_{PC}/\Delta CI_{TD}$ revealed $r^2 = 0.57$, $r^2 = 0.67$, and $r^2 = 0.74$, respectively. Bland-Altman analysis was used to determine accuracy and precision of the 3 methods compared. The mean differences (m) and SD between $\Delta CI_{PA}/\Delta CI_{PC}$, $\Delta CI_{PA}/\Delta CI_{TD}$, and $\Delta CI_{PC}/\Delta CI_{TD}$ resulted in $m = -1.01\%$, SD = 6.51%; $m = -0.83\%$, SD = 5.80%; and $m = -0.33\%$, SD = 4.65%, respectively.

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Conclusion: Compared with pulmonary artery thermodilution, arterial pulse contour analysis reflects relative changes in CI during rapid changes of preload with clinically acceptable accuracy.

1. Introduction

Patients undergoing cardiac surgery frequently experience hemodynamic instability and require rapid administration of intravenous fluids. Therefore, invasive monitoring of cardiac performance may be critical in these patients to optimize fluid administration and guide vasopressor therapy or inotropic support. In fact, there is some evidence that postoperative monitoring of cardiac performance may contribute to improving outcome in high-risk patients [1]. The determination of cardiac index (CI) as a parameter of cardiac performance reflects the measurement of end-organ blood flow much better than blood pressure (BP) monitoring, which is not only a function of arterial blood flow but is also influenced by systemic vascular resistance (SVR). Over the past 2 decades, measurement of CI has evolved as a useful parameter of cardiac performance in these patients. Cardiac index values are frequently derived from a pulmonary artery catheter (PAC; CI_{PA}) as introduced by Swan et al [2] approximately 30 years ago and are considered the clinical "gold standard" [3,4]. However, the unfavorable results of recent randomized trials of PAC monitoring and patient outcome have evoked a very controversial discussion on using PAC measurement as a guideline for fluid and vasopressor therapy [5-8].

A major improvement of hemodynamic monitoring in high-risk patients was the development of continuous arterial BP measurements using an arterial catheter and a pressure transducer, compared with the conventional, discontinuous, noninvasive BP measurements. Similarly, a continuous cardiac output (CO) device would be an improvement, as a continuous monitoring device would allow recognition of small hemodynamic changes much earlier. Consequently, therapeutic interventions could be performed earlier and more precisely.

Conventional pulmonary thermodilution does not provide continuous monitoring of CI. Cardiac index estimation by arterial pulse contour analysis (CI_{PC}), based on the algorithm of Wesseling et al [9], may therefore provide a reliable alternative approach to estimate CI while avoiding the risks associated with a PAC. Furthermore, CI_{PC} continuously estimates CI, which may improve patient care by facilitating early recognition of circulatory dysfunction [10,11]. Meanwhile, pulse contour analysis has demonstrated a good agreement with pulmonary artery (PA) thermodilution in different intraoperative and postoperative settings in cardiac surgical or critically ill patients [12-18]. The principle of CI_{PC} is based on the physiological relationship between stroke volume (SV) and the area under the systolic portion of the aortic pressure waveform

Table 1 Hemodynamic parameters before and after fluid loading

					CI_{PA} (L/m^2)			SVI_{PA} (mL/m^2)			CVP (mm Hg)		PAOP (mm Hg)	
Patient	Age	BMI (m/kg^2)	FL (mL)	FLS	Baseline	After FL	ΔCI (%)	Baseline	After FL	ΔSVI (%)	Baseline	After FL	Baseline	After FL
1	48	24.4	244	3	3.4	3.8	11.8	43	47	9.3	8	12	5	10
2	54	34.3	343	3	3.7	4.1	10.8	38	45	18.4	5	6	4	11
3	69	31.2	312	3	3	3.4	13.3	35	41	17.1	7	9	3	8
4	32	25.7	257	4	5.8	5.9	1.7	61	63	3.3	10	12	4	9
5	49	30	300	3	3.6	3.81	5.8	34	36	5.9	11	13	11	13
6	57	26.8	268	5	2.4	3.2	33.3	24	31	29.2	10	9	6	9
7	80	27.7	277	3	3.1	3.6	16.1	34	38	11.8	8	12	3	6
8	55	30.1	301	3	3.2	3.5	9.4	33	38	15.2	14	13	7	8
9	67	26.4	264	3	3.1	3.1	0.0	33	33	0.0	12	7	7	7
10	73	26.7	267	4	2.1	2.9	38.1	21	30	42.9	6	10	2	6
11	75	26.6	266	2	2.9	2.5	−13.8	31	31	0.0	7	7	6	6
12	74	27	270	2	2.7	3	11.1	29	32	10.3	10	10	10	12
13	65	25.2	252	2	2.7	3	11.1	29	32	10.3	6	4	8	9
14	51	26.2	262	4	3.1	3.8	22.6	33	41	24.2	11	11	5	8
15	76	28.7	287	4	1.8	2.3	27.8	27	34	25.9	9	13	10	14
16	70	38.4	384	3	2.5	2.9	16.0	26	31	19.2	17	18	14	17
17	58	30.6	306	2	2.9	2.5	−13.8	31	26	−16.1	10	11	6	7

BMI indicates body mass index (height [in meters] divided by body weight [in squared kilograms]); VL, volume loading (10 mL times BMI volume infused over 5 minutes); FLS, number of fluid loading steps performed; After FL, after the last fluid load performed.