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Cardiopulmonary Bypass Produces Non-uniform Pressure Differences between Femoral and Radial Arteries

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Abstract

It is well documented that a pressure difference between central and peripheral arteries may occur following cardiopulmonary bypass (CPB), but how and when it occurs in each patient is still controversial. Accordingly, we evaluated the individual variation of the pressure difference between femoral and radial arteries accompanied by CPB. Sixteen adult patients undergoing coronary artery bypass graft surgery using mild hypothermic CPB were enrolled in this study. Both radial and femoral artery pressures were measured after induction of anesthesia, every 10 min during CPB, and 0, 10, 20, 30, and 60 min after CPB. When the difference for each blood pressure (systolic, mean, and diastolic) exceeded 10 mmHg in any period before, during, or after CPB, the difference was defined as significant. We could assign the patients into three different groups depending on their variation of blood pressures: Groups A, B, and C. In Group A, none of systolic, mean, and diastolic femoral artery pressures exceeded corresponding radial artery pressures significantly at any time before, during, and after CPB. In Group B, femoral artery pressure became higher than radial artery pressure during CPB, and femoral artery pressure was not significantly lower than radial artery pressure after CPB. The patients in Group C showed no significant difference during CPB, but only systolic pressure of femoral artery became higher than that of radial pressure after CPB. In conclusion, our data demonstrated that the pressure difference accompanied by CPB was not uniform among the individual patients. Alteration of the pressure waveforms in each patient may indicate the feature of the difference, and may play a role in prediction of the difference.

Key words : Pressure difference, Cardiopulmonary bypass, Mild hypothermia, Coronary artery bypass graft surgery

Introduction

There exists a physiologic pressure difference between central and peripheral arteries[1]. This is produced by the relationship between the heart and arterial system. Following the use of cardiopulmonary bypass (CPB), both the cardiac function and the tonus of arterial system may be altered and greatly increase the pressure difference. This sometimes makes measuring peripheral blood pressure unreliable and even valueless for diagnosis of low or high blood pressures. Numerous studies documented that considerable pressure differences between central and peripheral arteries could occur after the use of CPB[2~6], but the individual variation of the difference during and after CPB is still obscure. In this study we evaluated the individual variation of the pressure difference accompanied by the use of CPB in each patient undergoing coronary artery bypass graft surgery.

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Methods

After institutional approval and informed consent from each patient were obtained, sixteen adult male patients scheduled for coronary artery bypass graft surgery were enrolled in this study. They were chronic users of nitrates and calcium entry blockers. All patients received intramuscular morphine 0.1 mg/kg and scoplamine 0.3 mg as a premedication. Under monitoring oscillometric blood pressure, multi-leads ECG, SpO_2, $EtCO_2$, and pulmonary artery and central venous pressures, the left or right radial artery was cannulated with a 5.1 cm, 20 gauge Teflon catheter (Becton Dickinson Vascular Access, Sandy, UT, USA). After anesthesia was induced with intravenous fentanyl 1 mg and midazolam 5 mg, vecuronium 0.1 mg/kg was administered to facilitate endotracheal intubation. Anesthesia was maintained with fentanyl 1.5 to 3 mg and less than 1 MAC isoflurane, and vecuronium was used as needed to maintain normocapnic controlled ventilation. A 7.6 cm, 18 gauge Teflon cannula (Becton Dickinson Vascular Access) was inserted in the right femoral artery after induction of anesthesia. Each pressure line was connected to a disposable transducer (Uniflow system, Utah Medical Products, Midvale, UT, USA) to measure blood pressure. The measurement system consisted of the cannula, 120 cm of low-compliance pressure tubing (Baxter, Tokyo, Japan), a continuous flush device, and a disposable transducer. The system was filled with saline, and all visible air bubbles were eliminated. The dynamic response of the system revealed a mean natural frequency of 37.6 Hz with a range of 31.3 - 40.0 Hz and a mean damping coefficient of 0.21 with a range of 0.209 - 0.224. Blood pressures were monitored on a CRT with other variables.

Our CPB circuit creating steady, non-pulsatile flow consisted of an ordinary kit: a pump, a membrane oxygenator and heat exchanger, a venous drainage line through the right atrium, and an arterial inflow line to the aorta. Arterial flow from CPB was cooled to produce mild hypothermia between 31 and 34 ℃ by core temperature. After the aorta was unclamped, the arterial flow was gradually rewarmed to achieve core temperatures above 35℃ (bladder temperature).

Values of femoral and radial artery pressures and their traces of pressure waveforms were recorded by a monitor (HOR-2200, Mnnen Medical, Israel) after induction of anesthesia, every 10 min during CPB, and 0, 10, 20, 30, and 60 min after CPB. At any period before, during, and after CPB, a pressure difference more than or equal to 10 mmHg was deemed significant difference. We used one way ANOVA to find any difference among variances of the three groups after performing Bartlett test to examine the homogeneity of them. A value of p less than 0.05 was deemed significant in each test.

Results

Depending on the individual features of the pressure difference between femoral and radial arteries, we could assign the sixteen patients into three different groups; Groups A, B, and C (Table 1). In Group A (n = 5), no values for systolic, mean, and diastolic femoral artery pressures exceeded those for radial artery pressures significantly at any time before, during, and after CPB. In Group B (n = 5), mean femoral artery pressure became higher than radial artery pressure in some periods during CPB, and no values for femoral artery pressure became significantly lower than those for radial artery pressure after CPB. The patients in Group C (n = 6) showed no significant difference regarding the mean arterial pressures during CPB, but only the values for systolic pressure of femoral artery became higher than those of radial artery after CPB. Mean age, total pump time, and aortic cross clamp time were 62.6 ± 10.8 years old (mean ± SD), 117.4 ± 16.2 min, and 80.8 ± 10.0 min for Group A. They were 65.4 ± 7.9 years old, 126.0 ± 33.2 min, and 84.8 ± 31.0 min for Group B, and 64.0 ± 11.0 years old, 130.8 ± 15.4 min, and 84.7 ± 18.8 min for Group C. No statistically significant differences were obtained in their variances.

Comparing pressure waveforms of femoral and radial arteries after CPB with those before CPB, we could find some features in each group. In Group A, a steep peak in systole and diastolic augmentation seen

Table 1. Characteristics of the pressure difference between femoral and radial arteries before, during, and after CPB in each patient

Group A	Blood Pressure	Before CPB	During CPB	After CPB
A-1	systolic	R>F	R>F	NS
	mean	R>F		R>F
	diastolic	R>F		R>F
A-2	systolic	R>F	NS	NS
	mean	NS		NS
	diastolic	NS		NS
A-3	systolic	R>F	NS	R>F
	mean	NS		NS
	diastolic	NS		NS
A-4	systolic	NS	NS	R>F
	mean	NS		NS
	diastolic	NS		NS
A-5	systolic	NS	NS	R>F
	mean	NS		NS
	diastolic	NS		NS
Group B	**Blood Pressure**	**Before CPB**	**During CPB**	**After CPB**
B-1	systolic	NS	F>R	F>R
	mean	NS		F>R
	diastolic	NS		NS
B-2	systolic	R>F	F>R	F>R
	mean	NS		F>R
	diastolic	NS		NS
B-3	systolic	NS	F>R	F>R
	mean	NS		F>R
	diastolic	NS		NS
B-4	systolic	R>F	F>R	NS
	mean	NS		NS
	diastolic	NS		NS
B-5	systolic	NS	F>R	NS
	mean	NS		F>R
	diastolic	NS		NS
Group C	**Blood Pressure**	**Before CPB**	**During CPB**	**After CPB**
C-1	systolic	NS	NS	F>R
	mean	NS		NS
	diastolic	NS		NS
C-2	systolic	R>F	NS	F>R
	mean	NS		NS
	diastolic	NS		NS
C-3	systolic	R>F	NS	F>R
	mean	NS		NS
	diastolic	NS		NS
C-4	systolic	NS	NS	F>R
	mean	NS		NS
	diastolic	NS		NS
C-5	systolic	NS	NS	F>R
	mean	NS		NS
	diastolic	NS		NS
C-6	systolic	F>R	NS	F>R
	mean	NS		NS
	diastolic	NS		NS

NS, not significant difference (the difference was less than 10 mmHg) ; R>F or F>R, the difference was equal to or more than 10 mmHg at least some periods before, during and after CPB ; R, radial artery pressure ; F, femoral artery pressure.

Table 2. Alteration of pressure waveforms for femoral and radial arteries before and after CPB in Group A

Group A	Arterial Pressure	CPB	Systole early phase	Systole late phase	Diastole augmentation
A-1	radial	before	peak	hump	×
		after	one peak		×
	femoral	before	shoulder	round peak	×
		after	peak	shoulder	×
A-2	radial	before	one peak		×
		after	one peak		○
	femoral	before	shoulder	round peak	×
		after	peak	hump	×
A-3	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		×
		after	peak	shoulder	×
A-4	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		○
		after	round peak		×
A-5	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		×
		after	shoulder	peak	×

○, presence ; ×, absence.

in radial artery pressure were almost preserved even after CPB (Table 2, Figure 1-A). In Group B, diastolic augmentation in radial artery pressure was still observed in most cases (Table 3, Figure 1-B). But round systolic waveforms of femoral artery pressure before CPB changed after CPB to an early peak and a late systolic shoulder in 4 of the 5 patients. And in Group C, the diastolic augmentation in radial artery pressure was hardly recognized after CPB (Table 4, Figure 1-C). Further, systolic waveforms of femoral artery pressure also changed from typical round peak to an early peak and a late systolic shoulder or hump after CPB as seen in Group B.

Discussion

Our results showed that the individual variations exist in the pressure difference between femoral and radial arteries both during and after CPB. In this study, patients were clearly assigned into three different groups (Groups A, B, and C) depending on the features of the pressure difference in each patient. In addition, each group also had some features in the pressure waveforms of femoral and radial arteries. Patients in Group A, whose values for femoral artery pressure never exceeded those for radial artery pressure, had a typical physiologic waveform in radial artery pressure before CPB. That is a steep peak in early systole, a late systolic shoulder or hump, and a diastolic augmentation. The late systolic wave and the diastolic wave are greatly affected by the reflex pressure wave from lower extremities[1]. Accordingly, in this group, the reflex from the lower extremities still existed even after CPB. This may result from the individual characteristics of the arterial system, because the ways of cooling and rewarming during CPB and the use of cathecholamines (dopamine, dobutamine and norepinephrine) and vasodilators (nitroglycerin and prostaglandin E_1) at termination of and after CPB were similar among all three groups. In Group B, this reflex was also preserved in most cases, whereas in Group C, reflex waves in late systole or diastole nearly disappeared.

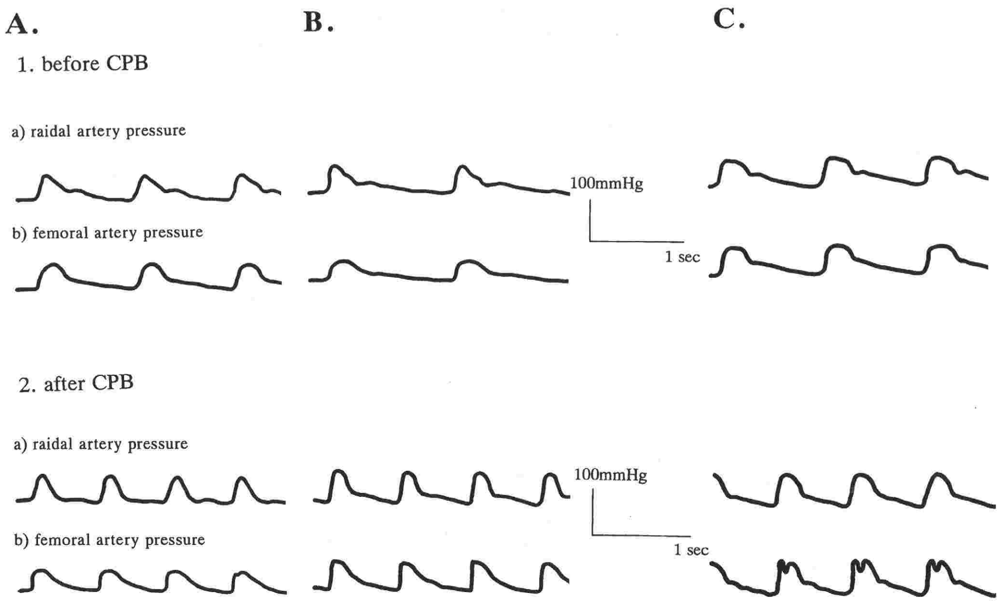

Fig. 1 Representative traces of arterial pressures in each group.
A for Group A (A-5), B for Group B (B-4), and C for Group C (C-4)

1 : pressure waveforms for radial (a) and femoral (b) arteries before cardiopulmonary bypass (CPB)
2 : pressure waveforms for radial (a) and femoral (b) arteries 10 min after CPB
A : A steep systolic peak and diastolic augmentation in radial artery pressure are relatively preserved after CPB.
B : A steep systolic peak and diastolic augmentation in radial artery pressure are still preserved after CPB. But the pressure waveforms of femoral artery fail to show the roundness of systolic wave.
C : An early steep peak and a late systolic hump are prominent in the pressure waveforms of femoral artery after CPB.

Table 3. Alteration of pressure waveforms for femoral and radial arteries before and after CPB in Group B

Group B	Arterial Pressure	CPB	Systole early phase	Systole late phase	Diastole augmentation
B-1	radial	before	round peak		○
		after	one peak		×
	femoral	before	round peak		×
		after	peak	shoulder	×
B-2	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		×
		after	peak	shoulder	×
B-3	radial	before	one peak		○
		after	one peak		○
	femoral	before	one peak		○
		after	peak	shoulder	×
B-4	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		×
		after	peak	shoulder	×
B-5	radial	before	peak	shoulder	○
		after	one peak		○
	femoral	before	round peak		×
		after	round peak		×

○, presence ; ×, absence.

Table 4. Alteration of pressure waveforms for femoral and radial arteries before and after CPB in Group C

Group C	Arterial Pressure	CPB	Systole early phase	Systole late phase	Diastole augmentation
C-1	radial	before	peak	shoulder	○
		after	peak	hump	×
	femoral	before	round peak		×
		after	peak	shoulder	×
C-2	radial	before	peak	shoulder	○
		after	one peak		×
	femoral	before	shoulder	round peak	×
		after	peak	shoulder	×
C-3	radial	before	peak	shoulder	○
		after	one peak		×
	femoral	before	shoulder	round peak	×
		after	peak	shoulder	×
C-4	radial	before	peak	hump	×
		after	one peak		×
	femoral	before	round peak		×
		after	peak	hump	×
C-5	radial	before	peak	hump	×
		after	one peak		×
	femoral	before	round peak		×
		after	peak	shoulder	×
C-6	radial	before	one peak		○
		after	one peak		○
	femoral	before	one peak		×
		after	peak	shoulder	×

○, presence ; ×, absence.

As far as femoral artery pressure was concerned, all groups had same features. Pressure waveforms of femoral artery physiologically consist of a round-shaped systolic wave shifting to a downward diastolic pressure[1]. Contours of the pressure waves of femoral artery is greatly changed after CPB, particularly in systole. The systolic waveforms after CPB were usually composed of an early steep peak and a late systolic shoulder or hump in most cases, as if they had been pressure waveforms of upper extremities. It is not clear by this study why these changes occur after CPB. One speculation is that the function of arterial system is greatly changed because of CPB in which a nonpulsatile, steady arterial flow and some degree of hypothermia are induced. In fact, it was reported that hand vascular resistance or arterial vasodilation in the upper extremity was reduced after CPB[4~6]. The use of vasodilators made the pressure difference between central (femoral) and peripheral (radial) arteries increase after CPB[7]. Rich et al. reported that the aortic-to-radial artery pressure differene is associated with events occcurring during initiation of CPB rather than with rewarming or termination of CPB[8]. Their results are in accordance with the results obtained in Group B, and somewhat different from our results showing no pressure difference during CPB obtained in most patients of Group A and all patients in Group C. Accordingly, it is hard to conclude that initiation of CPB is mainly responsible for the pressure difference. They also stated that it is unclear whether hemodilution associated with the onset of CPB contributes to the pressure difference. Recently, Goda et al demonstrated that the femoral-to-radial artery pressure difference after CPB was correlated well with hemodilution, and they concluded that hemodilution was responsible for the pressure difference[9]. These studies indicate that the great change in arterial system and hemodilution induced by CPB play important roles in the pressure difference between central and peripheral arteries. The thermoregulatory mechanism in the human body may also affect the tonus of the arterial tree in cooling and rewarming periods[10]. Radial systolic pressure exceeded femoral systolic pressure during vasoconstriction, and the difference was reversed during vasodilation. The fact that femoral systolic pressure exceeded radial systolic pressure after CPB in Groups B and C may be related to vasodilation. However, it is not clear whether vasoconstriction may be responsible for the pressure difference after CPB in Group A because intropes and vasodilators used in Group A were similar to those used in Groups B and C. There are many factors including cooling and rewarming, catecholamine release, anesthetics during surgery, the use of inotropes and vasodilators at termination and after CPB, and hemodilution which are responsible to the pressure differences between central and peripheral arteries. It is difficult to conclude which factor plays the most important role in the pressure difference during and after CPB.

In conclusion, CPB produces pressure differences between femoral and radial arteries both during and after CPB, and the difference is not uniform because the individual variations exist. Alteration of the pressure waveforms in each patient may indicate the feature of the difference, and may play a role in prediction of the difference.

References

1) O'Rourke MF, Kelly RP, Avolio AP : The arterial pulse. Lea & Febiger, Philadelphia, 1992, pp. 47–71
2) Stern DH, Gerson JI, Allen FB, et al : Can we trust the direct radial artery pressure immediately following cardiopulmonary bypass ? Anesthesiology 62 : 557–561, 1985
3) Rulf ENR, Mitchell MM, Prakash O, et al : Measurement of arterial pressure after cardiopulmonary bypass with long radial artery catheters. J Cardiothorac Vasc Anesth 4 : 19–24, 1990
4) Gravlee GP, Wong AB, Adkins TG, et al : A comparison of radial, brachial, and aortic pressures after cardiopulmonary bypass. J Cardiothorac Vasc Anesth 3 : 20–26, 1989
5) Pauca AL, Hudspeth AS, Wallenhaupt SL, et al : Radial artery-to-aorta pressure difference after discontinuation of cardiopulmonary bypass. Anesthesiology 70 : 935–941, 1989
6) Pauca AL, Wallenhaupt SL, Kon ND : Reliability of the radial arterial pressure during anesthesia. Is wrist compression a possible diagnostic test? Chest 105 : 69–75, 1994
7) Maruyama K, Horiguchi R, Hashimoto H, et al : Effect of combined infusion of nitroglycerin and nicardipine on femoral-to-radial arterial pressure gradient after cardiopulmonary bypass. Anesth Analg 70 : 428–432, 1990
8) Rich GF, Lubanski RE, McLoughlin TM : Difference between aortic and radial artery pressure associated with cardiopulmonary bypass. Anesthesiology 77 : 63–66, 1992
9) Goda Y, Takita K, Gando S, et al : Hemodilution has an important role in femoral-to-radial artery pressure graddient after cardiopulmonary bypass. Circ Cont 16 : 223–228, 1995
10) Urzua J, Sessler DI, Meneses G, et al : Thermoregulatory vasoconstriction increases the difference between femoral and radial arterial pressures. J Clin Monit 10 : 229–236, 1994

(Circ Cont 18 : 235～241, 1997)